Development of Woody Biomass High Ratio Co-Firing Technology for Pulverized Coal Boiler Plants

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Co-firing technology that achieves a very high woody biomass-to-coal ratio has been developed. This paper presents the results of experiments on newly developed biomass pulverizers and burners. When used for woody biomass, conventional coal pulverizers can achieve only one-tenth of their coal grinding capacity. Modifications to increase the interior up-flow velocity of pulverizers and to optimize the primary air channel have been carried out. As a result, the grinding capacity for woody biomass has exceeded the coal grinding capacity. A load changing ratio of 1.5-3.0%/min. has also been achieved. This modification to the pulverizer structure can be easily reversed, returning the pulverizer to its original configuration to allow coal grinding if required. The newly developed burners can burn both coal and woody biomass separately.

1. Introduction

Coal continues to be an indispensable fuel for power plants as it is so cheap and plentiful, but because of coal's high environmental impact, implementing and expanding measures to reduce CO_2 is an urgent task. Methods of reducing CO_2 from pulverized coal-fired power plants can be roughly categorized into ① reducing fuel consumption through increased efficiency, ② carbon capture and storage, and ③ reducing coal consumption by substituting it with a renewable fuel. Increased efficiency means improving plant efficiency by raising the vapor temperature. The net thermal efficiency of the 600°C class (currently the highest class) is 42%, but this can be improved to 46% when the 700°C class is developed.(1) In Japan, development has been conducted since 2008 as a national project, but as it is a long-term project extending over nine years, it will take time for the project to be practically realized.(2) With regard to CO_2 capture and storage (CCS: Carbon Capture and Storage), technologies for chemical absorption of CO_2 from combustion exhaust gas(3) and oxy-firing are being developed. For example, the aim of the Callide Oxyfuel Project being carried out in Australia is to raise the CO_2 concentration in exhaust gas by combusting pulverized coal using air-separated oxygen and recycled CO_2, thereby making it easy to capture carbon.(4), (5) This technology has been proven, but there is still a need for legal provisions and societal acceptance with regard to CO_2 storage. Meanwhile, among renewable fuel sources, woody biomass is easy to implement in pulverized coal-fired power plants that can use solid matter other than coal as fuel as well, and woody biomass technology is expected to be immediately effective for CO_2 reduction. Accordingly, we have been developing technology for co-firing large quantities of woody biomass in pulverized coal-fired power plants for the last several years.(6), (7) This article reports the recently obtained forecast of 50% (thermal percentage) co-firing for woody pellets.

2. The concept of co-firing

Woody biomass is already being used in many pulverized coal-fired power plants.(8), (9) In most cases, pulverized coal and wood powder are ejected from the same burner in a mixed state, and combusted inside a furnace. The methods of grinding woody biomass used by Japanese power companies all involve mixed grinding, in which coal and woody biomass are fed into a pulverizer simultaneously and ground together. In the case of this mixed grinding method, the pulverizer capacity and woody biomass grindability restrict the woody biomass mixture to a ratio of 1-5% (thermal percentage) in terms of calorific value. On the other hand, there are examples of successfully raising the co-firing ratio to a maximum of 17% (thermal percentage) by grinding the woody biomass in a pulverizer specially made for the task, and then mixing it with pulverized coal in the pulverized coal pipe.(10)

This technology aims to achieve a high woody biomass co-firing ratio of 30-50% (thermal percentage) in the near future, and is being developed in conjunction with firing technology, as well as investigation of a compatible boiler system configuration and biomass fuel supply system. This article reports on the development of a pulverizer able to grind large quantities of woody biomass, and a woody biomass burner. We took into account not only new installations but also modification of existing systems with the aim of enabling a modified coal pulverizer to grind large quantities of woody biomass, as well as provide a burner that can burn both pulverized coal and woody biomass separately through the same port.

3. Test facilities

A small-scale combustion test facility capable of burning 150 kg/h of bituminous coal and a large-scale combustion test facility capable of 1.6 t/h were used. In the large-scale combustion test facility, a pulverizer with a standard coal grinding capacity of 3 t/h was installed, and was subjected to woody biomass grinding tests.

3.1 Small-scale combustion test facility

The small-scale combustion test facility illustrated in **Fig. 1** was used to evaluate burnout performance in the case of co-firing pulverized coal and woody biomass inside the furnace. **Figure 2** is a schematic diagram of the small-scale combustion test facility.

The vertical cylindrical furnace has a maximum heat capacity of 1.2 MW, an inner diameter of 1.3 m, and a furnace length of 7.5 m. The furnace has a water-cooled jacket, with fireproof material cast on the inner surface. Pulverized coal is portioned out by a gravimetric feeder, and fed to a burner installed at the top of the furnace via a primary air fan. Flue gas passes through a gas cooler and undergoes heat exchange in an air preheater. Fly ash is then removed from the flue gas, and the flue gas is exhausted from a chimney by an induced draft fan. Visual inspection or sampling probe insertion was conducted as necessary through any of the multiple observation windows along both the circumferential and lengthwise directions of the furnace.

Wood powder from a sawmill was used as the pulverized woody biomass in the combustion tests, and the combustion efficiency was evaluated for each case of mixing wood powder with pulverized coal in the pulverized coal pipe, furnace blow-in of wood powder, and separate combustion.

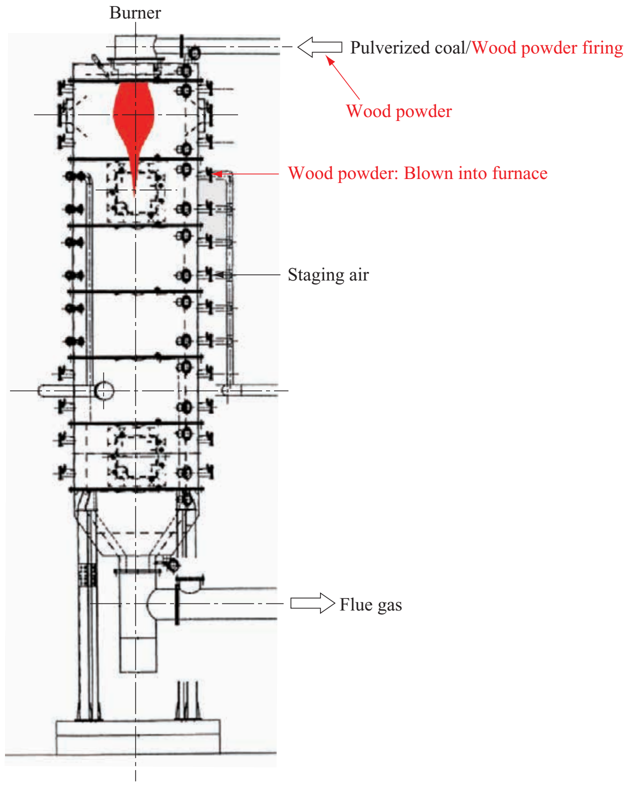

Fig. 1 Small-scale combustion test facility

3.2 Large-scale combustion test facility

The large-scale combustion test facility illustrated in **Fig. 3** has a pulverizer and a combustion furnace, and has two modes to select from: an indirect combustion method in which pre-made pulverized coal is first stored in pulverized coal bins, and a direct combustion method in which pulverized coal is sent directly to the burner from the pulverizer. The direct combustion mode was selected for the woody biomass grinding/combustion tests. However, in some combustion tests for the purpose of burner development, wood powder from the sawmill was directly supplied to the burner.

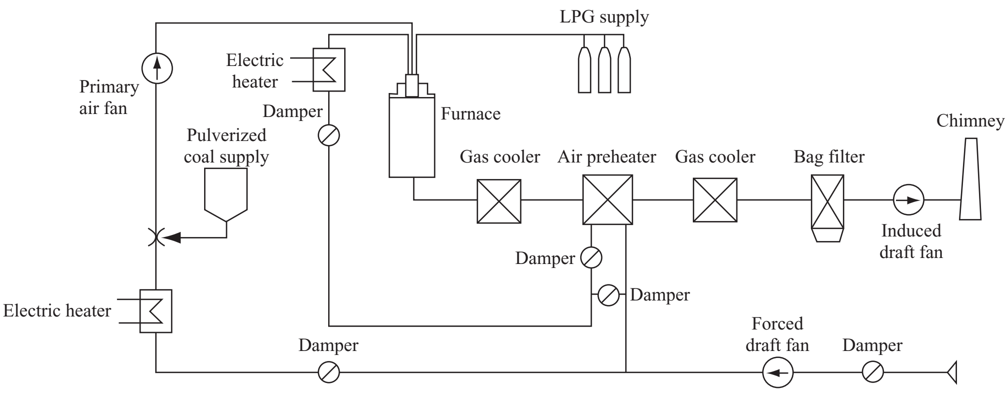

Fig. 2 Schematic diagram of combustion test facility

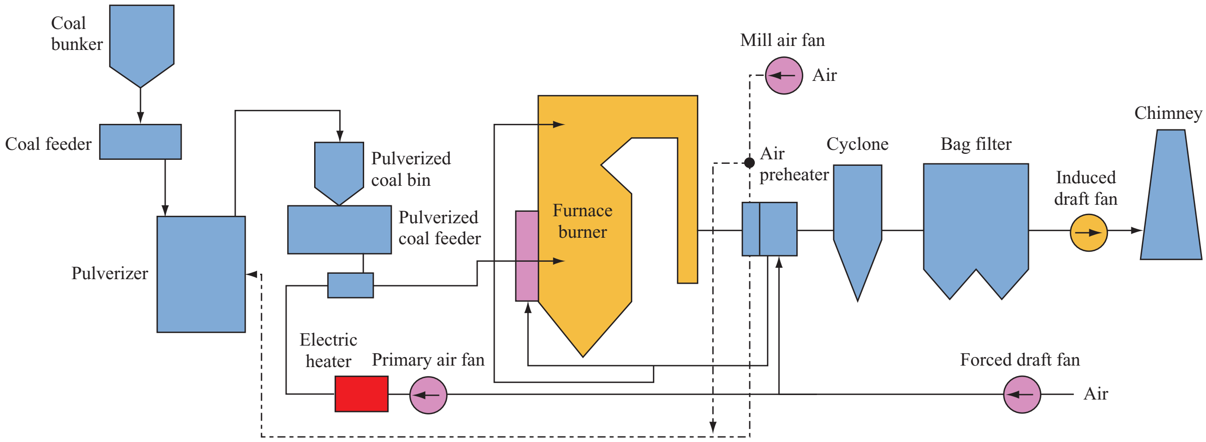

Fig. 3 Large-scale combustion test facility

4. Pulverizer development

Previously, the use of woody biomass in existing pulverized coal-fired power plants was carried out at low mix ratios.(6), (9) For co-firing at 1-5% (thermal percentage), woody biomass is introduced into the pulverizer along with the coal to be pulverized. With this method, the amount of woody biomass that can be co-fired depends on the design margin of the existing pulverizer, and growing needs for greater co-firing ratios cannot be met. Consequently, we proceeded with pulverizer development with the goal of raising the in-furnace co-firing ratio to 50% (thermal percentage) by separately pulverizing the woody biomass.

4.1 Pulverizer

When woody biomass is substituted for coal, the pulverizer does not have to grind the corresponding quantity of coal, and thus when taking into account the time and money for retention of spare parts and pulverizer maintenance, it is desirable to also use the coal pulverizer for the woody biomass. Consequently, a coal pulverizer was modified for use with woody biomass, while also allowing for the modification to be reversed to return the pulverizer to coal grinding if necessary. **Figure 4** illustrates a coal pulverizer. Coal is supplied through a central fuel feeding pipe, and the centrifugal force of a rotating pulverizing table causes the coal to move to the outer edges of the table. There, coal is pulverized by being ground between pulverizing rollers and the table. Pulverized coal and coal from the fuel feeding pipe are dried by hot air emitted from air ports along the outer periphery of the table and then blown upwards. However, large particles that have not been fully pulverized and are unable to ride the rising air current fall back onto the table by their own weight (this is called primary classification), and are ground again. The fine particles riding the air current reach the top of the pulverizer, and are subjected to secondary classification by a revolving current created by a rotating classifier. Pulverized coal that passes through the classifier is sent directly to a pulverized coal burner, while the coarse coal powder that was unable to pass through goes back down into the pulverizer and falls onto the table.

In the woody biomass grinding tests, measured weights of

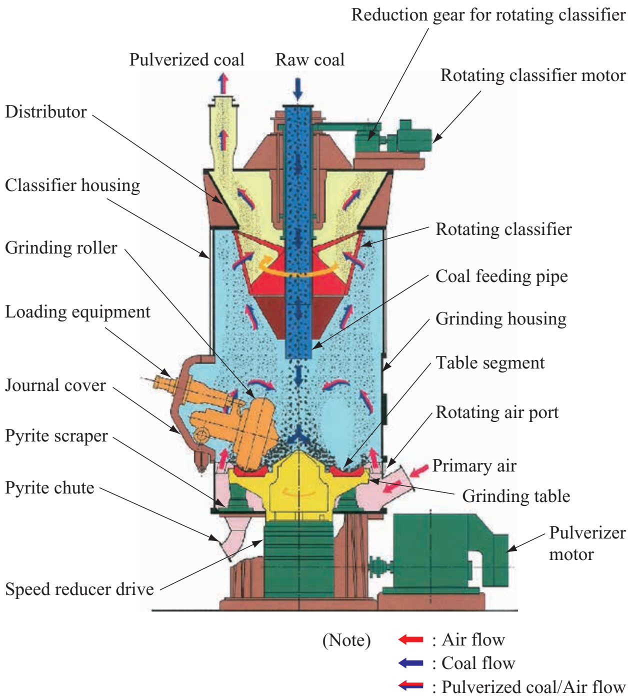

Fig. 4 Coal pulverizer

wood chips and wood pellets (**Fig. 5**) were supplied to the feed pipe instead of coal, and the upper limit of the supply rate for stable grinding or "the grinding limit" was sought. Stable pulverizer operation was evaluated according to the pulverizer differential pressure (the difference in pressure at the pulverizer inlet and inside the pulverizer). When grinding cannot keep up with the supply rate of the woody mass, more and more non-pulverized and partially pulverized woody biomass circulates inside the pulverizer, and the pulverizer differential pressure continually rises.

4.2 Grinding test results

First, in order to evaluate the grinding performance of the coal pulverizer, the grinding limit was sought when loading woody biomass without modification. **Figure 6** shows the result. In the case of using the test pulverizer with a standard grinding capacity of 3 t/h, the stable grinding limit was 2.1 t/h when grinding bituminous coal with a Hardgrove

(Note) Pen length : 140 mm

Fig. 5 Woody biomass

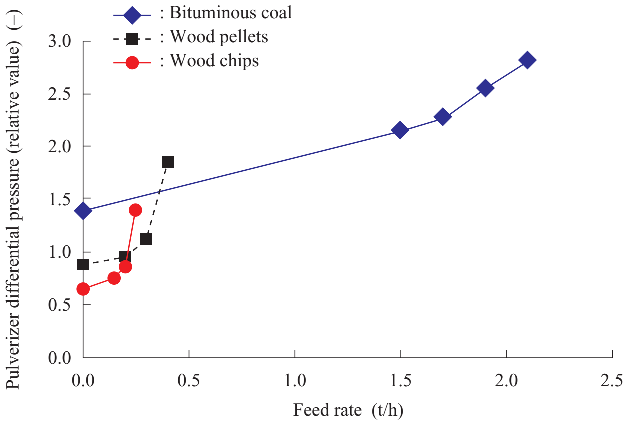

Fig. 6 Limit of grinding

Grindability Index (HGI) of 60. For woody biomass, it was ascertained that the stable grinding limits for chips and pellets are 250 kg/h and 300 kg/h, respectively. This is due to the differences in the grindability of coal and woody biomass. With woody biomass, the grinding capacity is reduced to approximately 1/10 of that of coal.

Since woody biomass has high volatile matter content and good burnout, woody biomass with a particle size of 1 mm or less exhibits combustion performance that is equivalent to that of pulverized coal.[11] For this reason, the target particle size was set to 1 mm or less for woody biomass ground in the pulverizer. With wooden chips, since it is necessary to grind or cut them by several centimeters down to the millimeter level, one would imagine that chips will need to pass under the rollers many times inside the pulverizer. On the other hand, pellets are by nature compressed masses of wood powder that is already on the millimeter level, and conceivably may be ready for combustion after being broken up with the rollers. Consequently, in the case of wood pellets, it was reasoned that a drastic reduction in the holding time inside the pulverizer may be possible. A flow-acceleration ring that restricts the area of the upward airflow was installed inside the pulverizer, and the shape of the air ports was modified. Carrying out such modifications in stages enabled grinding at the same or better rates as coal (**Fig. 7**). **Figure 8** illustrates a wood pellet pulverizer based on this modification policy.

To investigate whether load changing in a plant should be conducted primarily with coal or wood pellets during actual plant operation when co-firing coal and wood pellets

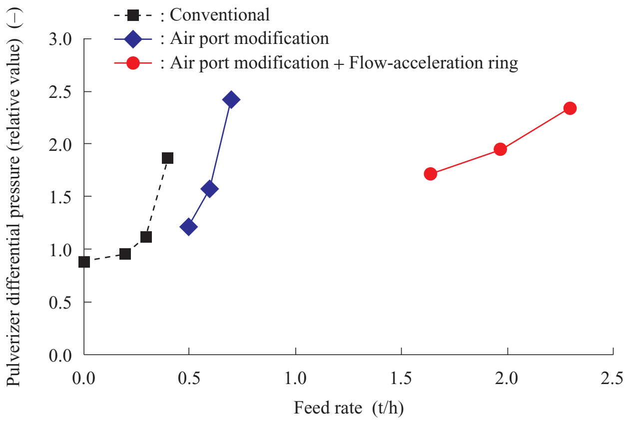

Fig. 7 Increasing wood pellet grinding capacity

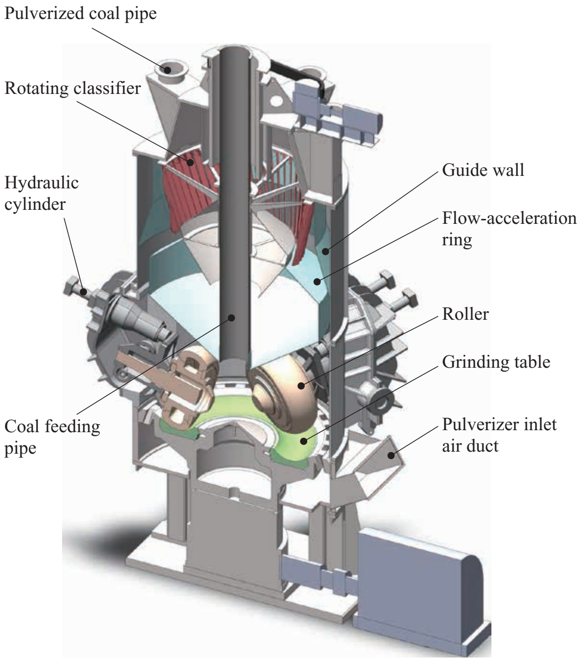

Fig. 8 Wood pellet pulverizer

inside a furnace, a wood pellet load changing experiment was conducted. In this experiment, wood powder from the pulverizer was supplied directly to the burner and burned with the addition of oil for safety. In the experiment, the load was changed at a rate of 1.5%/min over the range of 65-80% of the maximum grinding capacity. As shown in **Fig. 9**, smooth changes in flue gas O_2 as well as pulverizer differential pressure were obtained, which indicates that load changing with wood pellets is possible. Note that smooth load changing was confirmed even at 3%/min. The pulverized coal burner IHI-DF (**Fig. 10**) was used for the burner in this experiment.

5. Burner development

It is known from prior research that wood powder has high volatile matter content and good burnout, but when using a different pulverizer configuration depending on whether coal or woody biomass is to be treated, it is important to know the

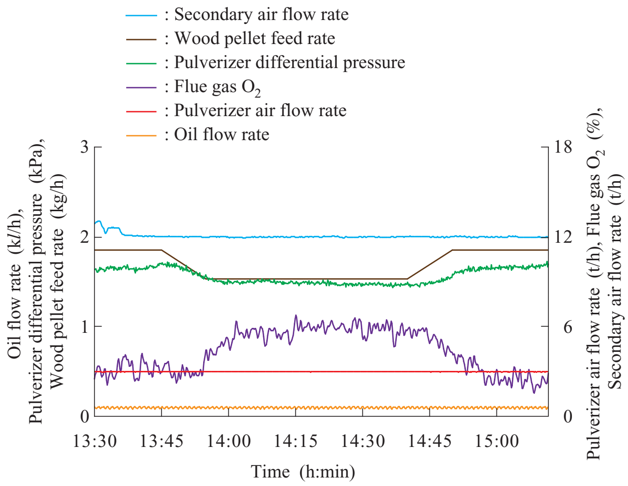

Fig. 9 Operational trends for load changing experiment

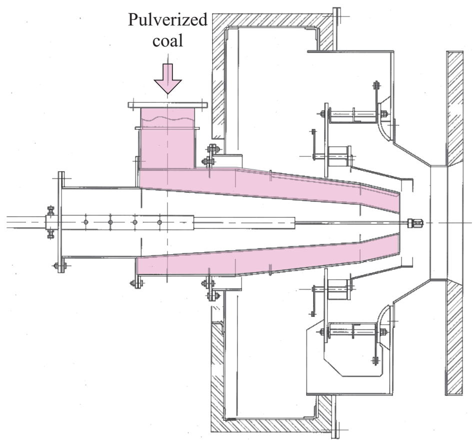

Fig. 10 Pulverized coal burner (IHI-DF burner)

combustion properties of wood powder in a pulverized coal burner. The following describes the development of a woody biomass burner, in which a small-scale combustion furnace with a pulverized coal combustion rate of 150 kg/h and a large-scale combustion test facility with a rate of 1.6 t/h were used to conduct wood powder combustion tests.

5.1 Wood powder combustion properties

Burnout performance for the case of co-firing pulverized woody biomass was evaluated using the small-scale combustion furnace. The woody biomass was co-fired with bituminous coal having a fuel ratio (the ratio of fixed carbon to volatile matter) of 1.69, and the staging ratio (the proportion of staging air versus the total combustion air) was set at 20%. For the pulverized woody biomass, wood powder (**Fig. 11**) from a sawmill was used, and the combustion efficiency and flue gas properties were evaluated for each case of pulverized coal pipe mixing, furnace blow-in, and separate combustion. For pulverized coal pipe mixing, 4.4% (thermal percentage) of wood powder was mixed in the pre-burner pulverized coal pipe, and supplied from the burner. For furnace blow-in, 9.5% (thermal percentage) of wood powder was blown in between the burner and the staging air port. In an actual combustion chamber, the combustion efficiency also varies in the direction of the

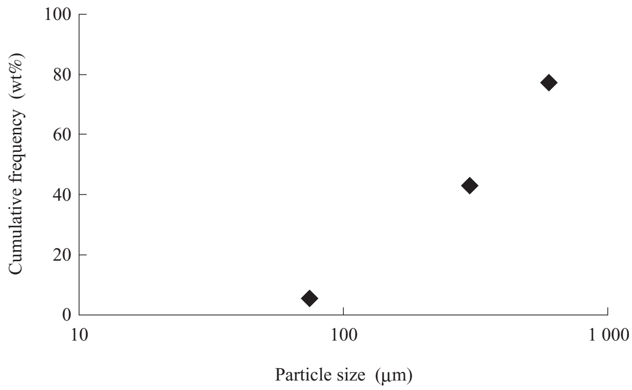

Fig. 11 Particle size distribution of wood powder

furnace width, but in this experiment particle sampling was conducted along the center line of the furnace axis, and the combustion efficiency was computed using ash as tracers. **Figure 12** shows a comparison of the combustion efficiency in the direction of the furnace axis. Although there is some discrepancy near the burner, there is no significant difference between the fuels from the central part of the furnace in the lengthwise direction to the outlet, and particle burnout is the same as pulverized coal.

5.2 Burner for wood powder

For the case of co-firing wood powder in the furnace, in order to achieve both 100% load with coal as well as co-firing with a high ratio of woody biomass, but without increasing the number of burners, we developed a burner capable of separately burning both pulverized coal and wood powder in the same throat. **Figure 13** shows the burner for separately burning both pulverized coal and wood powder. A wood powder nozzle is placed so as to enclose the pulverized coal nozzle, and the nozzles are switched to supply pulverized coal or wood powder, without burning both simultaneously.

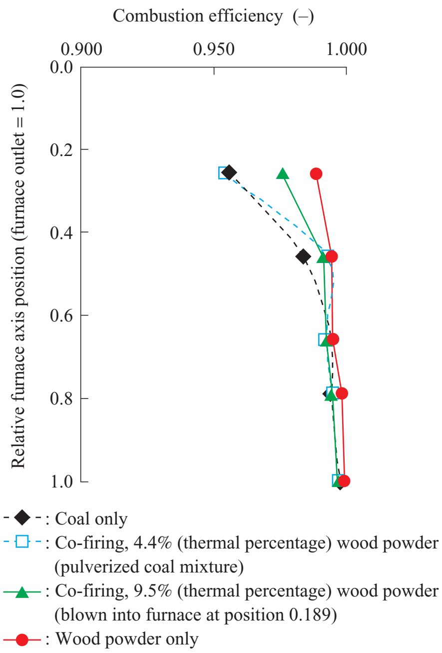

Fig. 12 Combustion efficiency at center line of furnace axis

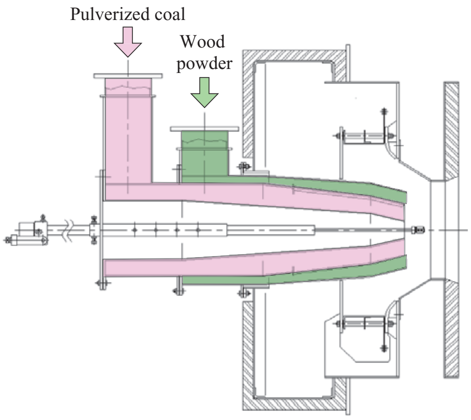

Fig. 13 Burner for wood powder and pulverized coal

This burner and the IHI-DF burner shown in **Fig. 10** were used to conduct separate burning tests for pulverized coal and wood powder. Flame stability was confirmed, and the environmental properties at the furnace outlet were compared. **Table 1** illustrates a comparison of the fuel properties of the coal and wood powder that were used. The wood powder was made of 100% cedar, which produced very little ash compared to coal, and exhibited heat generation at approximately 70% of that of coal. In the combustion test, the weight of the wood powder to be fired was increased to 140% of that of coal in order to equalize the heat input into the furnace between coal and woody biomass. In the test, procured wood powder was supplied directly to the burner. The wood powder contains low levels of nitrogen (N) and sulfur (S) compared to coal, so the staging ratio was set lower in order to reduce NO_x. **Table 2** summarizes the experimental conditions and results.

Since flue gas O_2 levels were inconsistent due to problems with the test facility, additional experiments are being planned. However, the combustion efficiency when burning wood powder alone exhibited a high value, as indicated in the results from the small-scale test furnace in **Fig. 12**.

Table 1 Fuel properties

Item		Unit	Fuel type	
			Wood powder	Coal
Higher Heating Value		MJ/kg	21.17	29.40
Proximate analysis	Air-dried water content	wt%	5.2	2.02
	Ash		0.4	12.02
	Volatile matter		82.2	34.59
	Fixed carbon		17.4	53.39
Fuel ratio		—	0.21	1.54
Total moisture content		wt%	22.3	6.31
Elemental analysis	C	wt%*1	50.8	69.8
	H		5.81	4.90
	N		0.15	1.34
	S		0.07	0.53
	Combustible S		0.03	0.49
	Noncombustible S		0.04	0.04
	O		42.77	11.41

(Note) *1: Excluding water

Table 2 Experimental conditions and results

Item	Unit	Fuel type	
		Wood powder	Coal
Wood powder combustion rate	t/h	1.8	0
Wood powder-transport air flow rate	t/h	2.55	0
Pulverized coal combustion rate	t/h	0	1.32
Pulverized coal- transport air flow rate	t/h	0	2.44
Secondary air flow rate	t/h	11.0	12.0
Staging ratio	%	6.5	19.4
Flue gas O_2	%	7.4	3.1
Combustion efficiency	%	99.5	96.4

Meanwhile, **Fig. 14** shows flue gas properties, and in accordance with the fuel properties, NO_x emissions were equal to or less than 1/2, while SO_x was not detected. **Figure 15** is a photo of flames from wood powder firing as seen in the wake of the flames. Flame stability was good at the slot opening.

6. Conclusion

Co-firing technology that achieves a high woody biomass-to-coal ratio in a pulverized coal-fired boiler has been developed. This article discussed a pulverizer and a burner for this technology. The pulverizer was realized by modifying a coal pulverizer to enable grinding of large quantities of wood pellets and increase the interior up-flow velocity, as well as by altering the shape of the air port. This modification is reversible, and the pulverizer may be returned to the unmodified coal pulverizer if necessary,

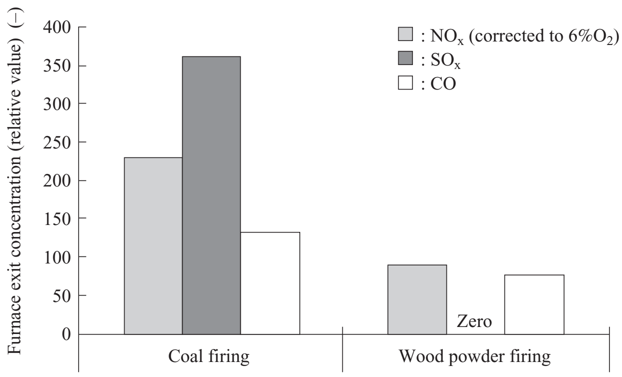

Fig. 14 Combustion performance comparison

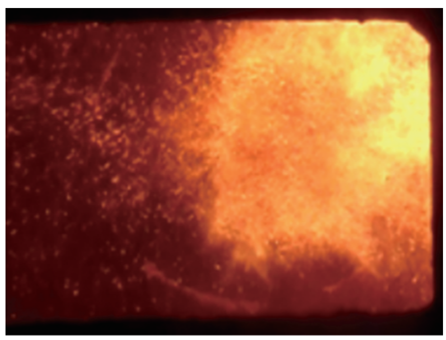

Fig. 15 Photos of flames from wood powder firing

making it useful for not only new plant installations, but also existing installations. The burner is capable of separately burning both pulverized coal and wood powder from the same slot, and was realized by optimizing the blow velocity of the wood powder nozzle. The research findings are summarized below.

(1) By installing a flow-acceleration ring in the coal pulverizer to increase the interior flow speed, and by altering the air port shape, the wood pellet grinding capacity was made equal to or greater than the coal grinding capacity.
(2) In the wood pellet pulverizer, a load changing speed of 1.5-3.0%/min was achieved.
(3) A burner capable of separately burning both wood powder and pulverized coal was developed.

In the future, we will conduct assessments of impacts on related equipment such as the boiler furnace and NO_x/SO_x removal equipment, and aim to realize a complete system.

— Acknowledgements —

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