Performance and Emission Characteristic of Co-firing of Wood Pellets with sub-Bituminous Coal in a 330 MWe Pulverized Coal Boiler

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***Abstract*—A co-firing test of wood pellets with the sub-bituminous coal was carried out in a pulverized coal (PC) boiler with 330 MWe capacity to evaluate the effects on its performance and emission characteristics. Co-firing was done directly into the furnace. Wood pellets were fed manually on the conveyor after transfer tower-1. The ratio of fuel mix flow attained by setting the fuel flow in the coal feeders. Three different flow ratio percentages (1%, 3%, 5% of wood pellets) set up through the coal feeder. The study showed that co-firing wood pellets with a ratio of up to 5% in the PC boiler contributed to decreasing furnace exit gas temperature by 29.4 ^{0}C. Furthermore, the specific fuel consumption increase by 7.4 tons/hour, and flue gas emission of CO, NO_x, SO_2, all decreased. There is no significant change in mill outlet temperature (MOT).**

Keywords*— *co-firing, wood pellets, FEGT, performance, emission, Mill Outlet Temperature

I. Introduction

In 2018, the energy production from coal-fired power plants was 58.36% of the total energy production of the state-owned electric utility company group [1]. To reach the renewable energy mix target of 23 % by 2025 and to reduce the greenhouse gas emission produced by a coal power plant, one of the strategic plans of the utility company was to use co-fired fuel in its power plant [2]. There are three basic co-firing methods for pulverized coal power plant, that is direct co-firing which feed the biomass to the furnace, indirect co-firing which use gasification process of the biomass to produce fuel gas in the furnace, and parallel combustion which use separate combustor [3][4]. Biomass co-firing is one of the methods that can be applied in almost all coal-fired power plants, without significant modification and investments. The majority of power plants were operated with biomass co-firing ratios less than 10% on a heat input basis since it proved it does not pose any threats or significant problems to the boiler performance. For higher co-firing ratios, an indirect co-firing method is better recommended [5].

Combustion with biomass is the cheapest method for greenhouse gas reduction [6]. Tillman et al. [7], shows that although the co-firing caused a decrease of the boiler efficiency, the environmental benefits by reducing power plant emission has made the biomass as one of renewable energy option to be used in existing coal power plants. In work done by Ayhan et al. showed that the use of co-firing biomass with coal could reduce the level of NO_x, SO_2, and CO_2 emission from a pulverized coal power plant [8].

Based on its geographical location, Indonesia has considerable biomass potential. However, the study of biomass for fuel power plants has not optimally. In the last three years (2015-2017), the growth of renewable energy plants has decreased. Growth in renewable energy power generation capacity is only 3.6 % annually. This achievement is even lower than the target of the Strategic Plan of Directorate General EBTKE in 2015-2019 of 10 % per year [9]. This condition requires a real action to accelerate the distribution of renewable energy to reach the national target of 23% by 2025.

The use of wood pellets, which has a total potential of 132 PJ, could increase the value of forest resources and government revenue [10]. Wood forest products, equivalent to the amount of electricity produced, have the total potential of wood to be made into wood pellets is 1,335 Mega Watt electrical (MWe). The potential spread across Sumatera (1,212 MWe), Kalimantan (44 MWe), Java, Madura and Bali (14 MWe), West Nusa Tenggara and East Nusa Tenggara (19 MWe), Sulawesi (21 MWe), Maluku (4 MWe) and Papua (21 MWe) with a calorific value of 3,300 - 4,400 kCal/kg [11]. The availability of abundant biomass feedstock is a significant factor for conducting experimental studies of the use of biomass as a fuel mixture for coal-fired power plants.

This study aims to investigate the effect of co-firing of wood pellets with sub-bituminous coal on the PC boiler performance and emission characteristics. Direct co-firing run with a percentage of wood pellets 1%; 3% and 5%. There are no modifications to the boiler and fuel system. All tests are at the same maximum load point. Testing conduct on a pulverized coal power plant with a capacity of 3 x 330 MWe, which is located in West Java, Indonesia, and owned by a utility company. It has been operating since 2010 and designed using coal with a lower heating value of 4,200 kCal/kg for its fuel. The result evaluates by comparing the operational parameters of the boiler furnace and mill operating parameters and gas emissions products of CO, NOx, and SO_2 on both testing conditions when using coal fuel and mixing of coal and biomass fuel.

II. EXPERIMENTAL SETUP

A. Pulverized Coal Boiler

The Pulverized Coal (PC) Boiler layout used to carry out the tests shown in Fig. 1. The PC boiler consists of drum type sub-critical with natural circulation, single furnace, single reheat, balanced draft, outdoor arrangement, and coal-fired. Advanced wall firing and staging air technology have been adopted by working with standard low NOX DRB-XCL coal-fired burners. Two air pre-heaters support the boiler. Fuel was fed from the coal bunker to the boiler furnace through five coal feeders. The bottom ash removed from the furnace passing the submerged scraper conveyor (SSC) hopper, while fly ash captured by electrostatic precipitator (ESP).

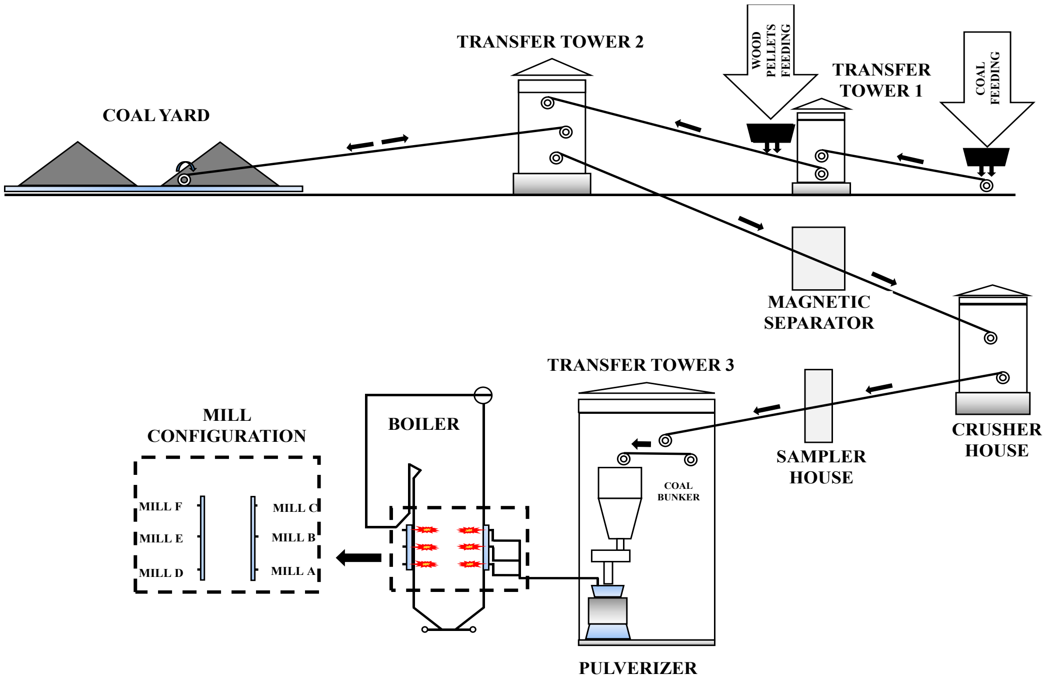


Fig. 1. Pulverized Coal Boiler Co-Firing Layout and Mill Configuration.

B. Fuel Characteristic

In the co-firing performance test, the coal bunker B fills up by mixed fuel consist of wood pellets and coal while the other coal bunker fills up with full sub-bituminous coal. The fuel analysis showed in Table 1. The volatile matter content of wood pellets is higher than coal, while the ash and sulfur content of wood pellets is lower than coal.

TABLE I. FUEL ANALYSIS

Fuel Analysis	Parameter	Coal	Wood Pellet
Proximate Analysis (% wt)	Moisture	29.93	8.76
	Volatile Matter	29.60	75.25
	Fixed Carbon	35.54	14.59
	Ash	4.93	1.40
Ultimate Analysis (% wt)	Carbon	50.59	46.80
	Hydrogen	3.21	5.47
	Oxygen	10.32	37.28
	Nitrogen	0.68	0.26
	Sulfur	0.33	0.03
Gross Calorific Value (kcal/kg)		4.797	4.149

(a) (b)

Fig. 2. (a) Wood pellets before Fed to the Transfer Tower-1
(b) Sampling of Fuel mix (Coal-Wood pellets) at Inlet Mill.

Visually, the dimensions of the wood pellets are still intact when fed to the transfer tower 1 (see Fig. 2 (a)), but after mixing with coal during the passage to the pulverizer inlet, the biomass fuel has changed to a smaller size, as shown in Fig. 2 (b).

C. Co-firing Methods

Tests were undertaken in four conditions of fuel, as shown in Table 2. The co-firing ratio of fuel mix flow achieved by setting the fuel flow in the coal feeders B. Wood pellet was fed on the conveyor after transfer tower 1 manually, as shown in Fig 1. The operational parameter data collected for 4 hours after stabilization periods.

TABLE II. TESTING SAMPLE

Testing Sample	Label	Co-firing Scenario
A	SBC100	100 % Sub Bituminous Coal
B	SBC99WP1	99 % Sub Bituminous Coal – 1 % Wood Pellets
C	SBC97WP3	97 % Sub Bituminous Coal – 3 % Wood Pellets
D	SBC95WP5	95 % Sub Bituminous Coal – 5 % Wood Pellets

D. Emission Measurement

Exhaust gas emissions have been measured at the inlet and outlet side of the air heater using a portable MRU Vario Plus Industrial flue gas analyzer. Data is collected at three measuring points on each side of the air heater, as shown in Fig. 3.

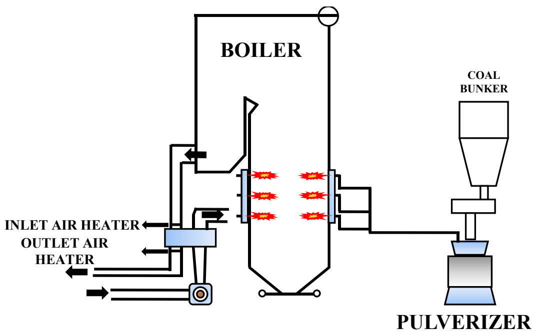


Fig. 3. Traverse Point of Emission Measurement.

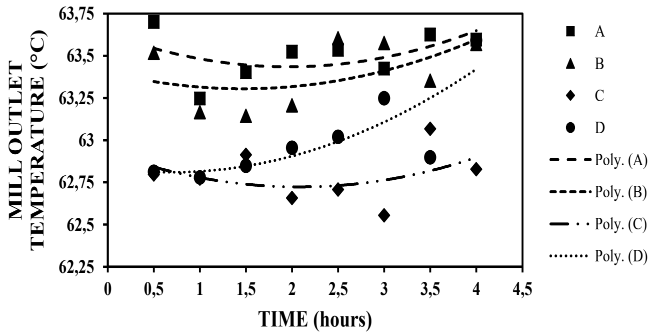


Fig. 5. The Effect of Co-firing on Mill Outlet Temperature.

III. Result and Discussion

A. Furnace Temperature Characteristic

The distribution of the furnace exit gas temperature (FEGT) is shown in Fig. 4. FEGT was reduced line with the increasing percentage of wood pellets. The highest decrease occurred in scenario D, where FEGT decreased by 29.4 ^{0}C from 962.8 ^{0}C to 933.4 ^{0}C. This condition occurred because the volatile matter content in wood pellets was higher than coal, so wood pellets tend to burn more quickly in the furnace. High volatile content, besides decreasing FEGT also advantageous to the ignition of the fuel [12]. Moreover, the lower heating value, high moisture content, and high ash content of biomass fuels contribute to decreasing FEGT [13].

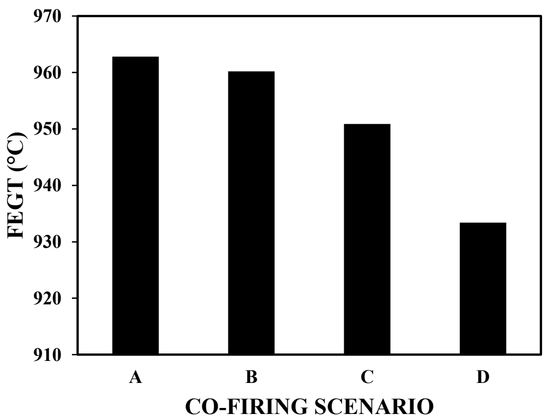


Fig. 4. The Effect of Co-firing on Furnace Exit Gas Temperature.

B. Mill Outlet Temperature

All co-firing scenarios have shown that there is no significant change in mill outlet temperature compared to the conditions when operating using existing coal. The average MOT in co-firing conditions ranges from 62.56 ^{0}C to 63.51 ^{0}C (as shown in Fig. 5), where the MOT when operating using coal is 63.51 ^{0}C. The results from the test indicated that co-firing up to 5% wood pellets do not affect the mill exit temperature, the changes only occur in the ratio of the flow composition of cold air and hot air entering the mill. Changes in the air composition adjust to the moisture content of the fuel mix, where wood pellets have lower moisture content compared to the coal. The other study [14] reveals that co-firing up to 5% on PC boiler 315 MWe relatively no change on mill outlet temperature and slightly increasing mill current by 0.70 Ampere.

C. Combustion Characteristic

On the inlet air heater side, an increase in oxygen content in the flue gas is proportional to the increase in the ratio of wood pellets to the fuel. However, the highest increase was only 0.83% in scenario D, as shown in Fig. 6. During the co-firing test, the combustion quality is quite good, where the O_2 content is maintained from 2.5% to 4%. Fig. 6 also shown that there is no increase in flue gas temperature at the inlet side of the air heater.

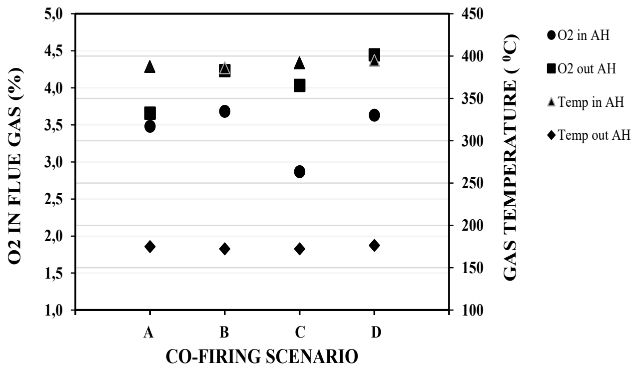
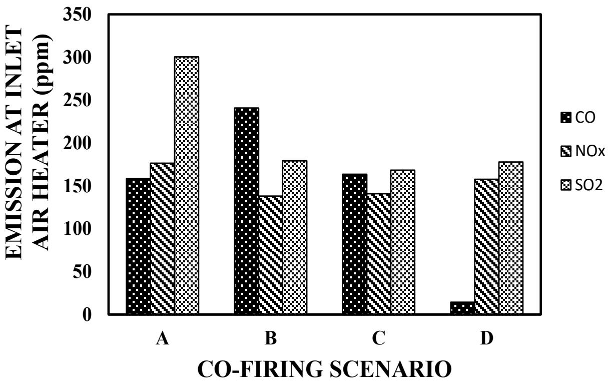


Fig. 6. The Effect of Co-firing on Flue Gas Temperature and O_2 content in Flue Gas.

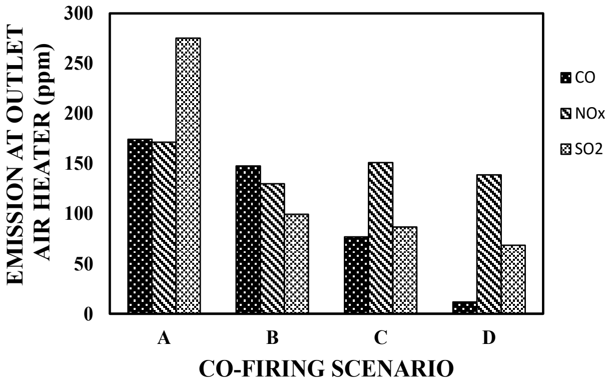
To maintain the load of 310 MW in the stable condition, when co-firing using wood pellets needed more fuel because the heating value of wood pellets is lower than sub-bituminous coal. From the calculation results, fuel consumption during co-firing scenario D increases from 167.71 tons/hour to 175.11 tons/hour. Co-firing 5% wood pellets on the PC boiler contribute to increasing specific fuel consumption by 4.40 % [14].

D. Emission Characteristic

Co-firing with wood pellets contributed to a decrease in emission of CO, NO_x, and SO_2, as shown in Fig. 7, on both sides of the air heater. Lower sulfur content in biomass wood pellets (as shown in Table 1) contributes to SO_2 reduction in the flue gas. The other study reveals that NOx and SOx emissions decreased [4,12,13,14] depend on the nitrogen and sulfur contents on biomass [13].



(a)



(b)

Fig. 7. The Effect of Co-firing on Flue Gas Emission of CO, NOx, and SO_2 on (a) Measured at Inlet Side of Air Heater (b) Measured at Outlet Side of Air Heater.

IV. CONCLUSION

The increased wood pellets ratio up to 5% in co-firing on pulverized power plant with PC Boiler type contributed to decrease furnace exit gas temperature and slightly increase fuel consumption to 7.4 tons/hour and decreased emission of CO, NOx, SO_2. There is no significant change in the mill outlet temperature. Although there is no constraint during co-firing testing in terms of performance and emissions, further research is needed to evaluate the potential corrosion due to chlorine content in biomass, slagging and agglomeration potentials as well as the durability and reliability of unit equipment when the plant operates using co-firing mode continuously in long-term.

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