Co-firing characteristics of wood pellets on pulverized coal power plant

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Abstract. Co-firing testing of the wood pellets was carried out in Pulverized Coal Boiler type tangential firing with a capacity of 315 MWe to determine the effects on the performance, emission, and characteristics of the operational boiler parameters such as mill outlet temperature (MOT) and furnace exit gas temperature (FEGT). Fuel was mixed on stockpile with a fuel composition of 5% wood pellets and 95% coal. Fuel was initially filled in four bunkers for each mill operated. The co-firing testing was carried in six hours and the data was collected for four hours after the stabilization period. To observe the further impact on the performance, emission and characteristics of operational boiler parameters, two different fuel (100% coal fuel and 5% wood pellets – 95% coal fuel) were set up through the boiler. The result shows that co-firing by 5% of wood pellets contributed to the decreasing FEGT by 150°C from 1,192°C to 1,177°C equal to 1.27% lower than the existing condition. The mill outlet temperature is relatively the same for two types of fuel with mill current slightly increasing by 0.70 Ampere. Emissions of SOx increased by range from 8.22% to 20.51%. NOx content in flue gas on the air heater inlet side is almost the same of 310 mg/Nm³ and only an increase of 3.62% on the air heater outlet side. This test also affected specific fuel consumption which has increased by 4.40% from 0.556 kg/kWh to 0.580 kg/kWh.

1. Introduction

In line with the Government’s policies in the field of electricity and climate change, Indonesian Energy Generation is directed towards Renewable Energy (RE). To increase environmentally clean energy utilization, the Government and PLN have targeted 23% of all power plants to be REs by 2025 [1]. Even though there are still many challenges and constraints to be confronted, the opportunity to develop RE is still wide open, especially in areas with considerable EBT potential.

The utilization of new renewable energy continues to be increased by the Ministry of Energy and Mineral Resources (ESDM). One that is encouraged in the 2019-2038 RUKN (National Electricity General Plan) is through the co-firing method in steam power plants by utilizing biomass as a substitution of coal. Two raw materials use on co-firing methods, waste pellets and wood pellets by a ratio from 1% to 5%. Wood forest products if equivalent to the amount of electricity produced, the total potential of wood to be made into wood pellets is 1,335 Mega Watt electrical (MWe). The potential is spread across Sumatra (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 [2].
The co-firing technologies of biomass classified under three types: direct co-firing, indirect co-firing, and parallel co-firing [3,4]. Among the three co-firing technologies, one that can be implemented quickly and does not require a lot of investment costs is direct co-firing methods. Thus, this direct co-firing option applies to a limited range of biomass types and at very low biomass-to-coal co-firing ratios cause has the highest risk of the boiler unit such as the heating surface reduced because it is covered by alkali or other agglomeration/ corrosion-causing agents in the biomass. Furthermore, the different combustion characteristics of coal and biomass may affect the stability and heat transfer characteristics of the flame [5]. The optimum cofiring ratios of biomass and coal must be determined considering costs and performance of the power plants. However, the co-firing level in most commercial applications is up to 5% -10% (as energy content) [4].

To find out the impact of direct co-firing on the pulverized boiler an experimental study was carried out by testing using 5% wood pellet fuel on a boiler capacity of 315 MWe. This study aims to determine the effects on the performance, emission, and characteristics of the operational boiler parameters such as specific fuel consumption (SFC), emission of SO\textsubscript{x} and NO\textsubscript{x}, mill outlet temperature (MOT) and furnace exit gas temperature (FEGT).

2. Experimental methods

2.1. Boiler and fuel characteristic

The pulverized coal boiler is sub-critical type DG 1025/17.4-II13, steam drum boiler with natural circulation, single furnace, four-corner tangential firing, single-reheat, and balanced draft. The boiler supported by Primary Air Heaters (PAH) and Secondary Air Heater (SAH) as shown in Figure 1. The bottom ash was removed from the furnace passing the submerged scraper conveyor (SSC) hopper and fly ash was captured by electrostatic precipitator (ESP). Fuel was fed into the coal bunker by stacker reclaimer and forwarded to furnace through five coal feeders.

Wood pellets usually cylindrical compressed wood fuel products made of by-products of the mechanical wood processing industry. The raw material is mostly dry sawdust, grinding dust, and cutter shavings, while pellets and briquettes can also be compressed from fresh biomass but the raw material must be milled and dried before pelletizing. The diameter of the pellets is usually 8 mm. The moisture content is low, 7 - 12 %. The ash content is also low, about 0.5%. The weight of a bulk density of pellets ranges from 650 - 700 kg/m\textsuperscript{3}. The net caloric value of pellets ranges from 4.7 - 5.0 kWh/kg (4,039 - 4,302 kCal/kg) [6]. Fixed carbon contents for the coals are significantly higher than the biomass fuels. Conversely, volatile matter concentrations for the biomass fuels are much greater. Sulfur concentrations for wood pellets fuels also tend to be much lower. Thus, by co-firing wood pellets with coal, SO\textsubscript{x} emissions are inherently decreased [7]. The fuel specification analysis an air-dried basis (ADB basis) shows in Table 1.
Table 1. Fuel analysis result during the co-firing test. The test used two different fuel, coal fuel (100C) was used on the first test while the fuel mixture consists of wood pellets and coal with a composition ratio of 5% for wood pellets and 95% for coal (5WP95C) was used on the co-firing test.

| Analysis                  | Parameter   | Coal (100C) | Wood Pellet (100WP) | Fuel Mix (5WP95C) |
|---------------------------|-------------|-------------|---------------------|-------------------|
| Proximate Analysis (% wt)| Moisture    | 16.68       | 8.96                | 15.02             |
|                           | Volatile Matter | 39.68       | 72.68               | 41.06             |
|                           | Fixed Carbon | 38.70       | 15.94               | 38.62             |
|                           | Ash         | 4.94        | 2.42                | 5.30              |
| Ultimate Analysis (% wt)  | Carbon      | 56.60       | 46.78               | 56.92             |
|                           | Hydrogen    | 4.08        | 5.28                | 4.16              |
|                           | Oxygen      | 27.20       | 36.54               | 26.81             |
|                           | Sulfur      | 0.32        | 0.02                | 0.27              |
| Hardgrove Grindability Index |            |             |                     |                   |
| Ash Fusibility Temperature|             |             |                     |                   |
| Deformation Temperature (°C) | Reducing    | 1,090       | 1,150               | 1,090             |
|                           | Oxidizing   | 1,150       | 1,170               | 1,150             |
| Spherical Temperature (°C) | Reducing    | 1,120       | 1,170               | 1,120             |
|                           | Oxidizing   | 1,170       | 1,200               | 1,180             |
| Higher Heating Value (kcal/kg) |            | 4,536       | 4,223               | 4,361             |

2.2. Co-firing test methods

Direct co-firing was used in this experiment. Wood pellets and coal blended at the coal yard. After got a uniform fuel mixture, the coal feeder A; C; D and E was filled its fuel by stacker reclaimer while the other coal feeder B was not operated. Before entering the furnace, a 70% volume fraction of mixed fuel size has maintained on 200 mesh by checking sample fineness at outlet mill pipe. Co-firing was done in the furnace.

The power plant load was controlled to steady-state condition on 300 MWe for six hours. The operating data was taken four hours after stabilization periods, automatically recorded by a data acquisition system. During the test, furnace exit gas temperature (FEGT) taken by a portable infrared camera Cyclops type 100L 2F. The FEGT data were taken nine times for each test at the four taping measurements on the top section of the south side furnace. Any changes in the mill operating parameters, especially mill outlet temperature are continuously observed. A sampling of fuel was carried at the coal feeder. Besides, flue gas emission measured by portable flue gas analyzer type Madur GA-40T Plus at taping point location as shown in Figure 2. The detailed layout of the co-firing system showed in Figure 1.
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Figure 1. Co-firing systematic layout. Wood pellets and coal are mixed at the coal yard and forwarded to the coal bunker using a stacker reclaimer. Fuel from bunker forwarded into the furnace by all of the coal feeders was operated during the co-firing test.

Figure 2. This is the traverse point of flue gas emission measurement an air heater. On the inlet side, data collected from measurement at the taping point of ducting between economizer outlet and air heater. Meanwhile, emission data was taken at the taping point of ducting between air heater and electrostatic precipitator (ESP) for the outlet air heater measurement.

3. Results and discussion

3.1. Furnace temperature characteristic
During the co-firing test, FEGT was decreased compared to the existing conditions when used coal fuel [7]. Figure 3 below shows that the average FEGT while co-firing condition decreased by 15 °C from 1,192 °C to 1,177 °C equal to 1.27 % lower than the existing condition. The extent of decrease in FEGT depends on the heating value, volatile matter and ash content of biomass fuel. The lower heating value of wood pellets provides a reduction in energy input. While the volatile matter content in wood pellets higher than coal so that wood pellets tend to burn more quickly in the furnace. A high ash content results in more sensible heat leaving the furnace with solid waste.

Furthermore, based on ash fusibility temperature (AFT), especially the deformation temperature characteristic of fuel as shown in Table 1, both of the actual tests used full coal testing and co-firing testing used 5 % wood pellets produced FEGT > 1,150 °C. It means that the current unit operating patterns have the potential for agglomeration, slagging and fouling on the convective area. So it is necessary to reset the combustion parameters so that it can reduce FEGT to lower than AFT of fuel.
Figure 3. The effect of co-firing on furnace exit gas temperature (FEGT). FEGT co-firing test used 5% wood pellets – 95% coal fuel (5WP95C) lower than test used 100% coal fuel (100C).

3.2. Mill outlet temperature
The average Mill Outlet Temperature (MOT) in co-firing conditions ranges from 57 °C to 58 °C (as shown in Figure 4), only differ below 1% while compare to operating using coal. The results illustrate that co-firing 5% of wood pellets do not affect the mill exit temperature. Furthermore, the average of mill current slightly increasing by 0.70 Ampere. When the biomass feed rate is less than 9.68 % of the total fuel mass input and with a normal primary air rate, the current of mill are less than the maximum safety limit value [7].

Figure 4. The effect of co-firing on mill outlet temperature. Both of two condition test on each mill shows a similar value of mill outlet temperature.

3.3. Emission characteristic
SO\(_x\) content in the flue gas during co-firing tests increase 8.22 % to 20.51% compare to an existing condition. On the inlet side of the air heater, an increase occurred from 541 mg/Nm\(^3\) to 585 mg/Nm\(^3\) while on the outlet side also increased from 353 mg/Nm\(^3\) to 426 mg/Nm\(^3\) as shown in Figure 5. Although, the sulfur content of wood pellets lower than coal, the co-firing test produced higher SO\(_x\) in the flue gas. Further research is needed to find the cause of these conditions, whether there is a change in the combustion characteristics of the furnace. Typically, since most biomass fuels have inherently low sulfur concentrations, SO\(_x\) reductions have been observed by many cofiring applications [8]. Furthermore, the co-firing test does not significantly affect the NO\(_x\) content in flue gas produced. NO\(_x\) content value on the inlet side of the air heater while before and after the co-firing test is almost the same of 310 mg/Nm\(^3\) and only an increase of 3.62% on the air heater outlet side as shown in Figure 6.
3.4. Specific fuel consumption
Total energy produced during four hours operated on the 100C fuel test is 1,189,800 kWh equivalent to 297,450 kWh/hours. Total coal consumption during four hours is 661,480 kg equivalent to 165,370 kg/hours. By divided the total fuel consumption to the total energy produced, specific fuel consumption on the 100C test is 0.556 kg/kWh. With the same methods, the co-firing test gains specific fuel consumption of 0.580 kg/kWh. This result shows that the co-firing test used a 5% wood pellet to contribute to increased specific fuel consumption of 4.40 %. To maintain the same energy output, it is necessary to increase the volume of fuel while using fuels with lower heating value such as wood pellets. This increase in SFC even averaged up to 30% in co-firing at the coal-fired power plant to generate the same amount of energy [9].

4. Conclusion
Co-firing wood pellets by ratio 5% in pulverized coal boiler contributed the decreasing FEGT by 15 °C from 1,192 °C to 1,177 °C equal to 1.27 % lower than coal-fired fuel condition. The mill outlet temperature is relatively the same for two types of fuel with mill current slightly increasing by 0.70 Ampere. Emissions concentration of SO₂ increase by range from 8.22 % to 20.51 %. NOₓ content in flue gas on the air heater inlet side is almost the same of 310 mg/Nm³ while an increase of 3.62 % on the air heater outlet side. This co-firing test also affected specific fuel consumption which has increased by 4.40 % from 0.556 kg/kWh to 0.580 kg/kWh. The results of this test are short-term impacts that can be observed, so it is necessary to test the reliability of the power plant by operating with a co-firing scenario for a longer duration.
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