Characteristics of Co-firing Solid Recovered Fuel with sub-bituminous Coal on Pulverized Coal Boiler Power Plant 300 MWe

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Abstract. The biomass co-firing test was conducted at a pulverized coal power plant with a capacity of 300 MWe to determine the effect of co-firing on the operating parameters, such as Mill Outlet Temperature (MOT), Furnace Exit Gas Temperature (FEGT), Specific Fuel Consumption (SFC) and environment. Biomass Solid Recovered Fuel (SRF) and coal was mixed in a stockpile with a composition of 5 % SRF and 95 % coal. Fuel mix was fed into the four operating bunker mills. The load stabilization process duration is 1 h after the biomass is fed to the boiler by keeping the loading constant at the maximum capacity rate. The data was recorded for 2 h with a retrieval interval of every 15 min. The results showed that the FEGT value during co-firing was 0.7 % lower than during coal firing. The mill outlet temperature ranges from 58 ºC to 60 ºC in both test conditions. NOx emissions increase by 10.1 %, and SO2 emissions increase by 5.5 % during co-firing than coal-firing conditions. There is no significant change in SFC where the value equals 0.54 kg kWh^{-1} on both tests.

Keywords: Biomass, clean energy, emission, solid recovered fuel, renewable energy.

1 Introduction

In line with the objective of the national energy mix, PLN (*Perusahaan Listrik Negara*) has targeted all of its power plants to utilize renewable energy by 23 % by 2025 [1–3]. The potential for new and renewable energy in Indonesia's territory is quite large, and the utilization is not optimal, so that the opportunity to develop renewable energy is still wide open, especially on biomass energy [4, 5]. However, there are still many challenges and obstacles to be faced.

Several co-firing methods are used to combust a mixture of biomass with coal, including direct co-firing, indirect co-firing and parallel co-firing [6 ,7]. The three methods are the easiest and the minimum in providing supporting facilities: the direct co-firing

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method. Mixing is done in the fuel handling facilities found in the steam-electric power station (*Pembangkit Listrik Tenaga Uap*/PLTU) facility and is a direct co-combustion method. Generally, there is no investment cost in special equipment with this method, but it carries the highest risk of disrupting the combustion capability of the boiler unit. The cause of the disturbance is a high level of corrosion due to the build-up of alkalis or agglomerations on the boiler surface, which reduces heat output and uptime. In addition, the different combustion characteristics of coal and biomass can affect the stability and heat transfer characteristics of the flame [8]. Thus, this direct co-combustion option can be applied to a limited range of biomass types and at very low fuel mix co-combustion ratios. However, co-firing in most commercial applications ranges from 5 % to 10 % [9].

PLN has initiated the SRF setup to review several strategic aspects of its utilization to support the 23 % energy mix target by 2025. SRF is a processed product from municipal waste that is standardized to meet the requirements for use according to the equipment type and the user's environment. A sorting and percentage process is carried out between inorganic and organic specified. The previous study uses biomass as a coal substitution to apply renewable energy utilization in existing steam power plants through the co-firing method. Two raw materials are used as a mixture, namely waste and waste/forest products in the form of wood, with a mixing ratio of 1 % to 5 %. Waste as raw material for pellets currently has a volume of 20 925 t d^{-1} with the resulting processing caloric value of around 2 900 cal g^{-1} to 3 400 cal g^{-1} [10].

This study aims to determine the effect of direct co-firing on pulverized coal boilers on operational parameters, performance and emissions characteristics such as Specific Fuel Consumption (SFC), SO_2 and NOx emissions, Mill Outlet Temperature (MOT) and Furnace Exit Gas Temperature (FEGT). Testing was done using 5 % SRF fuel on a boiler with a capacity of 300 MWe without modification on fuel feeding and combustion process equipment.

2 Experimental method

2.1 Boiler model and fuel characteristics

The co-firing test was carried out on a Pulverized Coal (PC) boiler model of N315-16.7/538/538-8, subcritical natural circulation with a capacity of 300 MWe. The combustion type is a direct firing coal pulverizing system with primary cold air at medium speed. Boilers are supported by Primary Air Heater (PAH) and Secondary Air Heater (SAH), as shown in Figure 1.

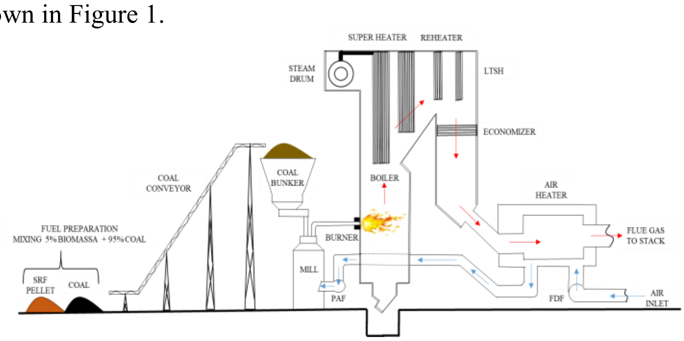

Fig. 1. The layout of the pulverized coal boiler. 5 % SRF biomass fuel and 95 % coal is blended at the coal yard and put into the coal bunker to be forwarded to the furnace using five coal feeders.

The SRF pellets composition consist of 78.6 % water hyacinth and 21.4 % garbage. The source of SRF fuel is obtained from several locations, namely the Saguling Biomass Operating System (BOSS), the GCB Ciliwung Centre and the RDF Plant from PT SBI. In general, SRF can be characterized by energy content in the range of 10 MJ kg^{-1} to 25 MJ kg^{-1} (ar: As Received Basis) so that it can be used as a companion fuel for industrial processes, combustion stability, increasing ignition and combustion of low-class fuels such as biomass, peat or low-quality coal [11]. An analysis of fuel specifications as received (AR basis) is shown in Table 1.

Table 1. Fuel analysis results during the co-firing test. The test uses two different fuels. The first test uses coal fuel (100C), while the second test uses a fuel mixture consisting of SRF pellets and coal with a composition ratio of 5 % for SRF pellets and 95 % for coal (5WP95C).

Analysis	Parameter	Coal (100C)	Biomass SRF (100BS)	Fuel mix (5BS95C)
Proximate analysis (% wt)	Moisture	29.86	20.89	29.51
	Volatile matter	32.01	36.11	31.32
	Fixed carbon	32.76	7.92	32.24
	Ash	5.37	35.08	6.92
Ultimate analysis (% wt)	Carbon	49.21	22.55	48.14
	Hydrogen	3.40	2.80	3.36
	Oxygen	10.76	17.30	10.75
	Sulfur	4.67	2.09	5.62
Trace element	Mercury	0.045	0.020	N/A
	Chlorine	N/A	0.245	N/A
Hardgrove grindability index		59	34	57
Ash fusibility temperature				
Deformation temperature (°C)	Reducing	1 450	1 130	1 296
	Oxidizing	1 450	1 165	1 331
Spherical temperature (°C)	Reducing	1 450	1 175	1 318
	Oxidizing	1 450	1 270	1 351
Gross caloric value (kcal kg^{-1})		4 679	2 201	4 512

2.2 Co-firing test methods

The method used in the co-firing test is direct co-firing. SRF biomass fuel and coal are blended in the stockpile. After obtaining a uniform fuel mixture, the fuel mixture is fed into coal feeder B; C; D and E are to be flowed into the coal bunker then into the mill, while coal feeder A is not operated. Before entering the boiler, the fuel mixture is subjected to a grinding process in the pulverized mill to obtain a fineness size of 200 mesh with a percentage of more than 70 %. Examination of the fineness sample can be taken at the mill outlet pipe.

The generator loading is controlled under steady-state conditions at 300 MWe for 6 h. The operational data is retrieved 2 h after the stabilization period, automatically recorded by the data acquisition system. During the test, the Furnace Exit Gas Temperature (FEGT) was taken with a portable infrared camera. FEGT data was collected nine times for each test on four taping measurements at the furnace top. Any changes in the plant operating parameters, especially the plant output temperature, are continuously observed. Exhaust gas emission testing is carried out by collecting data through the Continuous Emission Monitoring System (CEMS) facility monitored at DCS. The data observed included Nitrogen Oxide (NO_x), Sulfur Dioxide (SO_2), and oxygen (O_2). SO_x could not be observed because the reading on CEMS looks stagnant at 500 and needs improvement. Fuel sampling is carried out in the coal feeder. In addition, exhaust emissions are measured with a portable exhaust gas analyzer at the taping point location of the air heater.

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3 Result and discussion

3.1 Boiler pulverizer characteristics

Mill Outlet Temperature (MOT) on pulverized boilers must continuously be monitored for indications of earlier combustion at the mill. Because hot air has flowed from the Forced Draft Fan (FD Fan) through the air preheater for the pulverized fuel drying process, there is a potential for an explosion due to burning fuel during the milling process before entering the boiler.

During testing, the average temperature inside the mill outlet temperature (MOT) during co-firing ranges from 58 ºC to 60 ºC, which differed by just under 1 % compared to coal-fired operations. The results illustrate that 5 % SRF co-firing does not affect the MOT, as shown in Figure 2. Furthermore, the mill motor current during co-firing shows a slight increase of 1 A due to a mixture of SRF biomass in fuels with a low Hardgrove Grindability Index (HGI) value.

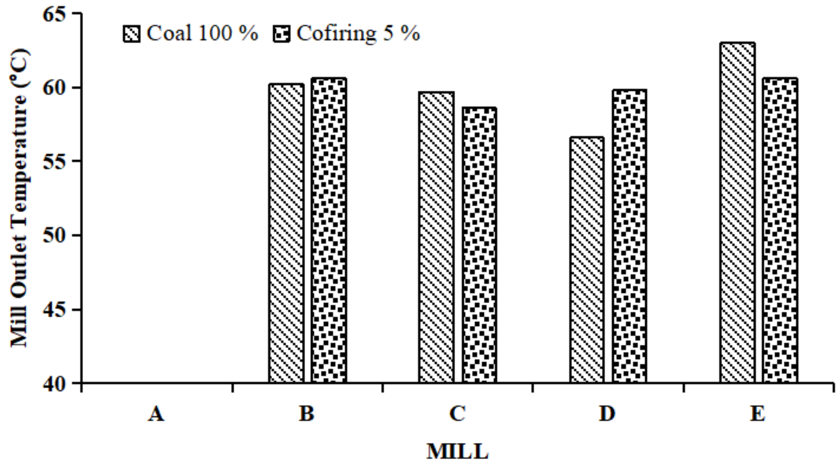

Fig. 2. Comparison of Mill Outlet Temperature (MOT) when co-firing and coal firing shows relatively the same temperature values.

3.2 Furnace temperature characteristic

Furnace temperature observations on testing need to be carried out to determine the difference in temperature during coal firing and co-firing, as shown in Figure 3. It shows a decrease in the average temperature during co-firing by 6 ºC from 908 ºC to 902 ºC or 0.7 % lower than the existing conditions; this is proportional to the calorific value of the biomass coal mixture which is lower than the heating value of coal. The previous study showed the same trend of decreasing FEGT by 15 ºC [9] and 29.4 ºC [12] when co-firing using 5 % wood pellet on PC boiler's typical capacity of 330 MWe.

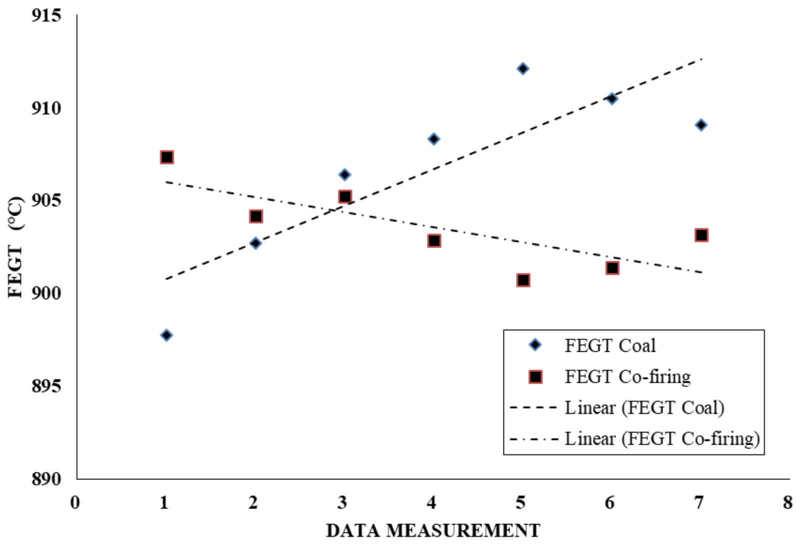

Fig. 3. Comparison of Furnace Exit Gas Temperature (FEGT) during co-firing and coal firing, during the co-firing test of 5 % SRF + 95 % coal, FEGT decreased compared to the existing condition when using coal as fuel.

3.3 Emission characteristics

From the CEMS reading, the NOx emission content in flue gas during co-firing was 193.3 mg Nm^{-3}, on average 10.1 % higher than when coal firing was 173.7 mg Nm^{-3}, while the SO_2 emission content in flue gas during co-firing was 4.81 mg Nm^{-3} was 5.48 % greater than when coal firing was 4.56 mg Nm^{-3}. However, both during co-firing and coal-firing still meet the quality standard of Regulation of Minister of Environment and Forestry No. P.15/MENLHK/SETJEN/KUM.1/4/2019 [13]. For details on the evolution of NOx and SO_2 can be seen in Figure 4 and Figure 5 as follows:

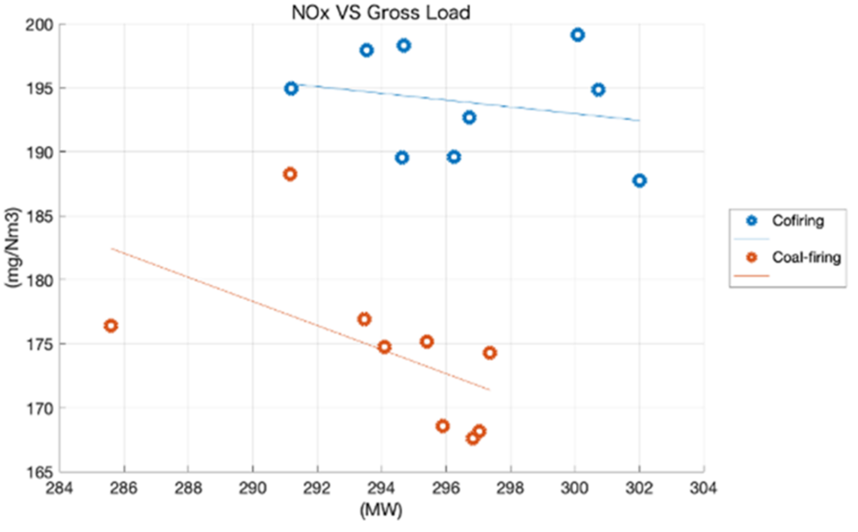

Fig. 4. Effect of co-firing on NOx exhaust emissions to load.

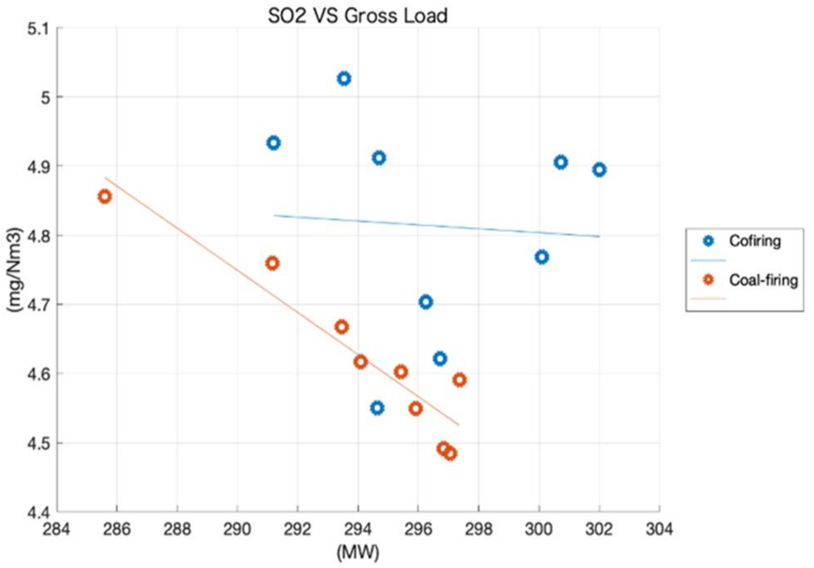

Fig. 5. The effect of co-firing on Flue gas SO2 emissions to load.

3.4 Specific fuel consumption

The average gross power output produced during co-firing is 296.05 MWe. In comparison, during coal firing, it is 295.03 MWe, then the use of net power output (average) of co-firing is 282.48 MWe, while coal firing is 281.61 MWe. The average calorific value of the fuel used during co-firing is 4 512 kcal kg^{-1}, while during coal firing, it is 4 553 kcal kg^{-1}. There is no significant change in NPHR between the two tests, which difference less than 0.01 %, where the NPHR when co-firing is 2 552 62 kcal kWh^{-1} while coal firing is 2 552 73 kcal kWh^{-1}, so that the SFC bruto value between the two tests is the same, namely 0.54 kg kWh^{-1}. Financial calculation using energy production and fuel price data shows that co-firing 5 % SRF increases fuel cost (component C) by 13.3 %. The SRF production costs are much higher than coal, contribute to the increase in the fuel cost [14]. Other studies show that increasing biomass fuel price by 4.44 % contributes to increasing fuel cost by 20.9 % [9].

4 Conclusion

The SRF co-firing with a ratio of 5 % in the pulverized coal boiler contributed to a reduction in FEGT by 6 ºC or 0.7 % lower than the coal fuel condition. The mill outlet temperature is relatively the same at both tests. The NO_x emission content in flue gas during co-firing was 193.3 mg Nm^{-3}, on average 10.1 % higher than when coal firing was 173.7 mg Nm^{-3}, while the SO_2 emission content in flue gas during co-firing was 5.48 % greater than when coal firing. The value of specific fuel consumption (SFC) between the two tests is the same, which is 0.54 kg kWh^{-1}. However, the calculation of the results of the cost of component C has increased by 13.3 % because the value of SRF production costs is much higher than coal. This study results only show the short-term impact of co-firing, so it is necessary to do other study related to the impact on a durability power plant, slagging, fouling and corrosion potency when a power plant operates with a co-firing scenario for a longer duration [15].

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