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Technical and Environmental Performance Evaluation of Fuel Switching from Coal to Biomass Wood Chip in Circulating Fluidized Bed Boiler

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ABSTRACT

Presidential Regulation No. 112 of 2022 regulates the preparation of a road map to accelerate the termination of operating time for steam power plants (PLTU). Biomass's potential to reduce emissions compared to coal explains why PLTU was chosen for this study. The operation of a PLTU requires the replacement of non-renewable electricity fuel sources with renewable ones. PLTUs are dominated by the use of coal. In accordance with presidential regulations, this research carried out fuel switching from coal to biomass. This research was conducted at PLTU Bolok, Kupang Regency. PLTU Bolok has a capacity of 2×16.5 MW. Fuel switching from coal to wood chip biomass in a Circulating Fluidized Bed (CFB) type boiler was carried out directly (direct co-firing), with five combustion treatments, namely, 100% coal and 0% biomass, 75% coal and 25% biomass, 50% coal and 50% biomass, 25% coal and 75% biomass and 0% coal and 100% biomass. The results of this research show that the performance of the biomass fuel switching caused the PLTU unit to experience a derating of 2 mW/hour. The results of other parameter analysis are FEGT 845.33 °C, furnace pressure -35 Pa and furnace temperature 947.04 °C. NO_x emissions were reduced by 11.3 mg/Nm^3, SO_2 by 45.8 mg/Nm^3 and CO_2 12.5 mg/Nm^3. The environmental benefit is the reduction emissions.

Keywords: fuel switching, biomass woodchips, coal, boiler CFB

INTRODUCTION

The government through the Ministry of Energy and Mineral Resources (KESDM) stated that Indonesia will seek breakthroughs in the use of biomass, and one of the programs being encouraged is the use of co-firing biomass as a substitute for coal in power plants [1]. PT PLN (Persero)'s Electricity Supply Business Plan (RUPTL) 2021–2030 provides the basis for achieving net zero carbon neutral emissions by 2060 and is committed to achieving a new renewable energy (EBT) mix of 23% by 2025, and the use of EBT in more than 50% of the new power plant plans [2], [3]. This strategic direction is aligned with Indonesia's international climate commitment under the Paris Agreement, ratified through Law No. 16 of 2016 [4].

PT PLN (Persero) is implementing a co-firing program with a percentage of 5% biomass at 32 existing PLTUs, which will be expanded to 52 PLTUs with a ratio of 10–20% biomass, while for newly designed PLTUs, a minimum co-firing of 30% biomass is required [5]. On the one hand, the government, through Presidential Regulation No. 112 of 2022, regulates the preparation of a road map to accelerate the end of operation of steam power plants (PLTU) or retirement of PLTU, so in its implementation it requires the replacement of electricity generated from fossil fuel with EBT plants, by considering the conditions of supply and demand for electricity [6].

Globally, similar efforts are being made to reduce coal dependence in the power sector by co-firing biomass due to its carbon neutrality and local resource availability [7], [8]. Studies have shown that co-firing not only lowers greenhouse gas emissions but also allows a gradual transition without significant modifications to existing infrastructure [9], [10]. In addition to its environmental benefits, biomass integration in thermal power generation also presents economic advantages in operating cost and fuel diversification, especially in isolated grids [11]. Recent findings suggest that implementing co-firing also helps reduce pollutants like mercury and volatile organics, which are harder to control in conventional coal combustion [12]. Moreover, biomass-coal co-combustion has been proven viable at an industrial scale across various sectors, including cement and power generation [13].

Presidential Decree No. 112 of 2022 implies that many coal-fired PLTUs are threatened with retirement, including those owned or managed by the PLN group, if they continue to use coal fuel. PLTUs will start to be retired in 2025 and continue until 2050 through the Just Energy Transition Program (JETP) scheme [6]. In this study, the importance of biomass co-firing to increase the EBT mix and implement green power plants is emphasized.

PLTU Bolok was chosen because of the readiness of the generating equipment and the availability of biomass raw materials to supply to PLTU Bolok [14]. Biomass's potential to reduce emissions compared to coal explains why PLTU was chosen for this study [15], [16]. PLTU Bolok is one of 52 PLTUs that are expected to implement the co-firing program. PLTU Bolok is a power plant that uses fossil energy in the form of coal and has a capacity of 2×16.5 MW, located in Kupang district, East Nusa Tenggara.

The technical feasibility of biomass combustion is supported by the characteristics of biomass such as lower sulfur content and better emission profile, although challenges such as high moisture content and lower calorific value remain [17]. This research aims to present the results of evaluating the performance of power plants using a fuel switching scheme, namely from coal to biomass. It is hoped that this research can be used as a lesson learned that fuel changes can be made at PLTU for generator operations [18], [19]. This research uses wood chip biomass with five (5) treatments, namely 100% coal and 0% biomass, 75% coal and 25% biomass, 50% coal and 50% biomass, 25% coal and 75% biomass, and 0% coal and 100% biomass.

The purpose of this study is to evaluate the technical and environmental performance of fuel switching from coal to wood chip biomass in a circulating fluidized bed boiler, as part of the broader transition from fossil energy to green energy.

METHODS AND EXPERIMENTAL SETUP

Biomass co-firing combustion for sustainable circulating fluidized bed boiler operations at PLTU Bolok is carried out without modification and without the addition of additives. The biomass used in the PLTU Bolok is wood chip biomass from kedondong wood which is adjusted to the potential availability on Timor Island. The delivery process from the supplier partner is carried out by truck. Biomass is put into sacks, then stacked and covered with tarpaulin on top, then placed in the biomass shelter. Furthermore, it is transported using a belt conveyor to the coal bunker. The following is a description of the research on the biomass fuel switching stages:

1. Receiving wood chips, this stage is the stage of receiving and collecting wood chips by recording the level of moisture, calorific value, and weight;
2. Drying the wood chips, this stage is the stage where the wood chips are dried through a drying and decomposition process using heavy equipment, by recording the humidity level before and after drying;
3. Carrying out transportation to the fuel silo, this stage is the stage where the dried wood chips are stored in the coal shed and transferred to the fuel silo via a crusher using a belt conveyor, with equipment capacity recorded;
4. Preparing for combustion, this stage prepares the main steam pressure boiler according to turbine needs;
5. Feeding wood chips to the furnace, this stage is the stage where the wood chips are then put into the furnace via a coal feeder, by recording the equipment capacity;
6. Carrying out combustion tuning, this stage is the stage where the air requirements for combustion are adjusted which are fed by wood chips to the furnace, adding fuel, balancing the fuel and air requirements (AFR);
7. Monitoring, controlling and recording operating parameters, this stage is the stage where during the process, furnace parameters are continuously monitored and regulated, including controlling the negative influence of wood chips related to chlorine content, slagging index, fouling index and alkaline content, to maintain equipment safety, reliability and efficiency;

8. Carrying out analysis of combustion results, this stage is the stage where analysis is carried out regarding the results of recording parameters, control and control results, as well as combustion results are analyzed after co-firing operations to evaluate operation and maintenance patterns to ensure safety, reliability and efficiency of the plant stay awake;
9. Burning emissions, this stage is the stage where measurements are taken at sampling points for measuring emissions including NO_x and SO_2 which are compared with the provisions of the Minister of Environment Regulation number 15 of 2019; and
10. Carrying out daily evaluations, this stage is the stage where monitoring, controlling and recording operational parameters is carried out.

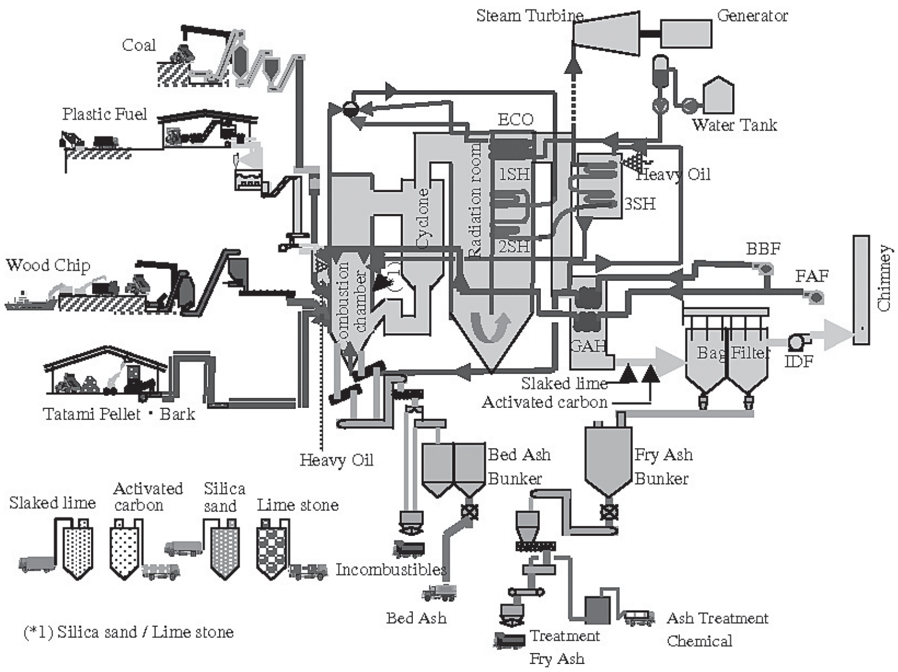

FIGURE 1. CFB PLTU co-firing scheme (KISHU PAPER Co., Ltd, 2011) [5]

Based on FIGURE 1, it can be seen that number 1 is a reference description regarding coal shelter, number 2 is biomass shelter and number 3 is the CFB boiler system. The following is a scenario for changing fuel (fuel switching) from 100% coal to 100% biomass in TABLE 1:

TABLE 1. Fuel Switching Process

Treatment	Explanation
1	100% coal & 0% biomass
2	75% coal & 25% biomass
3	50% coal & 50% biomass
4	25% coal & 75% biomass
5	0% coal & 100% biomass

The research was conducted as a case study at PLTU Bolok, a 2×16.5 MW facility located in Kupang district, East Nusa Tenggara. PLTU Bolok is included in the isolated electricity system on the island of Timor and is a baseload generator, and it is designed to use low-rank coal with calories of 4225 kcal/kg.

The quality standards for PLTU emissions refer to the Minister of Environment Regulation number 15 of 2019 as shown in TABLE 2. Mixing coal with wood chips in co-firing affects the exhaust gas emissions produced; therefore, emissions are measured to observe the changes that occur during co-firing combustion.

TABLE 2. PLTU emission quality standards

No	Parameter	Unit	Maximum level Coal	Maximum level Diesel Oil
1	*Sulfur Dioxide* (SO_2)	mg/Nm^3	550	650
2	*Nitrogen Dioxide* (NO_x)	mg/Nm^3	550	450
3	*Particulate Mattert* (PM)	mg/Nm^3	100	75
4	Mercury (Hg)	mg/Nm^3	0.03	-

RESULTS AND DISCUSSION

The fuel switching research from coal to biomass that has been carried out does not require additions or modifications to equipment, and the operating parameters of the boiler are still within safe operating limits. Apart from that, based on data on the electrical energy produced by the amount of fuel used, a comparison of prices between coal and biomass fuel shows that the basic cost of supply (BPP) is reduced by implementing fuel switching.

This research was carried out in stages, starting from trials at 5%, and continuing with research at 25%, 50%, 75%, and 100% biomass (fuel switching). The load for gradual combustion of up to 100% biomass (fuel switching) is unstable at a full load of 16.5 mW. This causes load derating of 12.34% when fuel switching is 100% biomass. The results of the implementation can be shown in TABLE 3.

Based on TABLE 3, the technical evaluation of boiler safety is considered to still meet normal operating limits, the O_2 parameter between the use of coal and biomass fuel is higher in biomass so that the potential for adding fuel to increase combustion in fuel switching is higher than the use of coal, but still within safe operating limits and without the need for modification or investment in additional equipment even if a derating of 2 mW/hour occurs. Judging from the environmental evaluation, emissions from fuel switching operations still meet the Minister of Environment Regulation No. 15 of 2019, so that fuel switching is technically and environmentally safe without additional CAPEX and meets standards.

The results of the economic analysis show that the cost of electricity generation when fuel switching from coal to biomass dropped from 1100 Rp/kWh to 720 Rp/kWh, or equivalent to 34%. In addition, it has the potential to extend the life of the PLTU from an estimate of 2030 to 2039, or 9 years longer when compared to using 100% coal or equivalent to the potential income from electricity sales of 1,075,323,810 kWh / unit.

TABLE 3. Technical and environmental evaluation

No	Parameter	100% Coal	100% Biomass	Remarks
1	Temperature furnace (°C)	957	947.04	The furnace temperature was observed to be above normal operating limits, namely 900-950 °C, but had not yet reached the critical boiler safety point, namely 990 °C
2	Pressure Furnace (Pa)	-84	-35	The pressure still meets the normal operating limits of -50/-150
3	FEGT (°C)	841.56	845.33	The temperature still meets the normal operating limits of 700-900 °C
4	Temperature cyclone (°C)	967.6	943.9	The cyclone temperature using biomass is in the normal operating range, namely 850-950 °C
5	Main steam temperature (°C)	485.24	480.82	The temperature still meets normal operating limits, namely 460-485 °C
6	Main steam pressure (MPa)	4.21	4.56	The pressure still meets the normal operating limits of 4.60-4.90 Mpa
7	Level drum (mm)	-94.3	-30.4	The drum level still meets the normal operating limits of -50/+50 mm
8	O_2 content (%)	7.3	13.3	O_2 content still meets normal operating limits, 8-15%
9	Winbox pressure (kPa)	8.71	9.21	The pressure still meets the normal operating limits, namely 8-15 kPa
10	Load (mW)	16.2	14.2	There was a derating of 2 MW/hour or the equivalent of 12.34% due to a decrease in fuel heat in biomass from 4225 kcal to 3250 kcal
11	Emission NOx (mg/Nm^3)	58.3	47	Fulfills environmental ministerial regulation number 15 of 2019, namely 550 mg/nm3
12	Emission SO_2 (mg/Nm^3)	46.3	0.5	Fulfills environmental ministerial regulation number 15 of 2019, namely 550 mg/nm3
13	Emission CO (mg/Nm^3)	16.5	4	Fulfills environmental ministerial regulation number 15 of 2019, namely 550 mg/nm3
14	EAF (%)	89.7	92	Increases 2.6 %
15	EFFOR (%)	0.265	0.571	Increases 699 kCal/kWh
16	NPHR	4677	5376	Increases 699 kCal/kWh
17	SFC	0.98	1.46	Increases 0.48 Kg/kWh

CONCLUSIONS

Replacing coal fuel with biomass provides non-financial benefits, resulting in a decrease in EAF of -3.70% and an increase in EFOR of 0.31% due to the planned outage of Main Inspection Unit 1 for 30 days in the second semester of 2022. So the decrease in EAF is not caused by the implementation of biomass fuel switching. SCF has increased from 0.98 to 1.46 kg/kWh, because the biomass calorific value of 3250 kCal/kg is smaller than the coal calorific value of 4225 kCal/kg, so it requires a larger volume of biomass [20]. Apart from that, there was a reduction in NO_x emissions from 58.3 mg/Nm^3 to 47 mg/Nm^3 or the equivalent of 18.4%. SO_2 emmisions were reduced from 46.3 mg/Nm^3 to 0.5 mg/Nm^3, or by 98.9%. CO_2 IR was reduced from 16.5 mg/Nm^3 to 4 mg/Nm^3, or by 75.7%.

Further research is expected with a larger boiler capacity, above 50 mW, and using biomass wood chips. Biomass treatment is needed to reduce moisture content in wood chips to increase the calorific value so that it approaches coal, either drying treatment with natural drying or using a dryer machine. Boiler modification is needed through the retrofitting of the biomass feeding system, including biomass silo, automation control & DCS system, and flue gas recirculation fan, so that biomass fuel switching can be maintained sustainably.

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