



Analysis of Biomass Co-Firing Performance at the Labuhan Angin Steam Power Plant

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Abstract. This study analyzes the performance of biomass co-firing technology at the Labuhan Angin Steam Power Plant (PLTU), focusing on the use of palm kernel shells and sawdust as alternative fuels to partially replace coal. The primary objective is to evaluate the combustion performance of these fuel mixtures, particularly in terms of energy efficiency and exhaust emissions, including CO₂, NO_x, and SO₂. A descriptive-comparative quantitative method was employed, using secondary data sourced from the operational co-firing trial report at Labuhan Angin PLTU. Key parameters examined include thermal efficiency, fuel consumption, biomass-to-coal mixing ratio, and emissions generated during combustion. The results indicate that co-firing with palm kernel shells leads to a decrease in combustion temperature and fluctuations in furnace pressure, although these remain within safe operational limits. For sawdust, a slight decline in thermal efficiency was observed as the biomass ratio increased; however, combustion remained stable up to a 5% mixing ratio. Moreover, SO₂ emissions decreased with higher biomass content, suggesting potential for reduced atmospheric pollution. In contrast, reductions in NO_x emissions were minimal, and particulate emissions tended to rise with increasing biomass ratios. Overall, the findings demonstrate that co-firing with palm kernel shells and sawdust can be effectively implemented at Labuhan Angin PLTU, provided that operational adjustments are made to maintain combustion efficiency and meet emission standards. The study also highlights the importance of careful technical management to mitigate potential negative impacts on combustion stability and emission profiles.

Keywords: *Co-firing, Biomass, PLTU, Palm Kernel Shell, Sawdust*

1 Introduction

Fossil fuels are derived from organic materials that have decomposed over millions of years beneath the Earth's surface and are non-renewable in nature (Maulana, Dewanto, & Abriyansyah, 2020). As of 2023, Indonesia's national coal production continued to increase, reaching 775.2 million tons up 13% from the previous year. The installed capacity of national power plants was recorded at 72.9 GW, with coal-fired power plants contributing 34.7 GW, operated by PT PLN (Persero), Independent Power Producers (IPP), PPU, and IO. Figure 1.1 shows a consistent increase in coal-fired electricity production by PLN, which

reached 119,520 GWh (or 68% of total generation) in 2019 (Secretariat General of the National Energy Council, 2020).

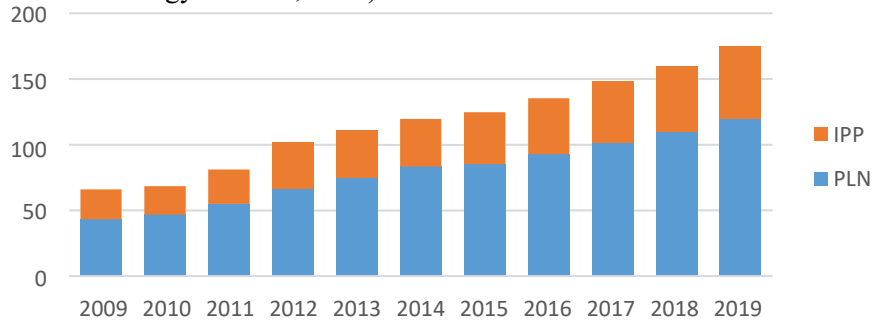


Figure 1 Coal - Fired Power Plan Electricity Production
Source: (HEESI, 2019)

The continued reliance on fossil fuels for electricity generation is unsustainable, as these resources are finite and will eventually be exhausted. Therefore, the transition toward alternative energy sources, particularly those that are renewable and environmentally friendly, is essential. Among the key environmental concerns is CO₂ emission, which is a significant contributor to climate change both globally and in Indonesia. A large share of these emissions originates from coal combustion in industrial sectors, especially power plants that utilize boilers (Labiba & Pradoto, 2018).

The increasing energy demand over the years places additional pressure on the already limited fossil fuel reserves. Fossil energy—formed from decayed organisms millions of years ago—remains the dominant energy source, particularly in developing countries (Rachmat, 2018). Prolonged use of fossil fuels not only threatens energy security but also poses serious environmental risks. As such, efforts to diversify energy sources by integrating renewable alternatives are increasingly important (Dwiyanto, 2023).

Co-firing technology has emerged as a viable innovation to mitigate emission levels. In general, co-firing can reduce the output of SO₂ and NO_x emissions during combustion due to the lower sulfur content and combustion temperature of biomass compared to coal (Sung et al., 2016). Consequently, reducing coal dependency through co-firing is considered a strategic step in energy and environmental policy.

According to the National Electricity General Plan, PLN aims to implement co-firing technology in 52 steam power plants by 2024, with a combined co-firing capacity of 18 GW (Ariyanto & Mustakim, 2023). Besides reducing carbon emissions, the co-firing initiative can also encourage community involvement in biomass cultivation. Since 2020, 28 PLTUs have adopted co-firing using two main categories of biomass: waste and forestry residues. These are processed into various forms such as sawdust, woodchips, briquettes, pellets, and solid recovered fuel (SRF) derived from waste (Untoro, 2023; Mujiono & Akbar, 2023).

Among the potential biomass sources in Indonesia are palm kernel shells. As the world's largest producer of palm oil, Indonesia generates vast quantities of palm kernel shell waste, which often goes unused despite its energy potential. Similarly, sawdust an abundant byproduct of the wood processing industry is frequently underutilized and can pose environmental problems if left unmanaged.

In regions like Deli Serdang Regency and Tapanuli in North Sumatra, the wood processing industry produces significant volumes of sawdust, which can serve as an alternative fuel for PLTUs. Utilizing this waste not only helps reduce pollution but also supports local energy sustainability efforts.

Based on these considerations, this study aims to conduct a technical analysis of the co-firing application using biomass, particularly palm kernel shells and sawdust, as supplementary fuels to coal. The analysis is based on experimental co-firing data from the Labuhan Angin Steam Power Plant, focusing on combustion performance in terms of energy efficiency and compliance with emission standards.

2 Literature Review

2.1 Technology Burning combination Coal with Biomass

Combustion of Coal with Biomass is a combination of Coal and Biomass combustion. Biomass can be used for combustion in boilers with three types of technologies, namely Direct co-firing, Indirect co-firing, Parallel co-firing (Xu, Yang, Zhou, & Zhao, 2020). This combination of Coal and Biomass combustion technology is considered the easiest to apply and the cheapest. There are several ways to combine Coal and Biomass combustion technology as shown in Figure 2.

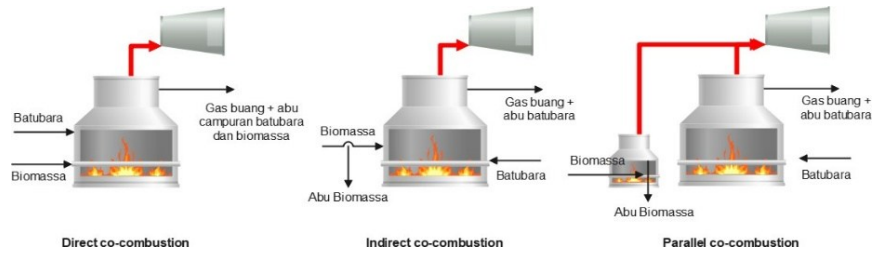


Figure 2 Concept Of Combustion Technology
 Source: (Dam-Johansen, Frandsen, Jensen, & Jensen, 2013)

Coal Combustion with *Direct Biomass* is a simple technology where Biomass is directly mixed with Coal before being used for boiler combustion (Agbor, Zhang, & Kumar, 2014) as in Figure 2. Direct co-combustion is the most common option applied to combustion in boilers between fossil fuels and Biomass or waste (Variny et al., 2021) . Previously, Biomass which still has a large size was chopped first to produce the same size as the Coal size used for combustion in the boiler.

2.2 Coal

In Coal there are different chemical elements where these chemical elements cause Coal to burn and produce energy. These chemical elements are as shown in Table 1.

Table 1 Property Value Range of Each Coal Type

Item	Anthracite	Bituminous	Subbituminous	Lignite
Moisture (%)	3 - 6	2 - 15	10 - 25	25 - 45
Volatile matter	2 - 12	15 - 45	28 - 45	24 - 32
Fixed carbon (%)	75 - 85	50 - 70	30 - 57	25 - 30
Ash (%)	4 - 15	4 - 15	3 - 10	3 - 15
Sulfur (%)	0.5 - 2.5	0.5 - 6	0.3 - 1.5	0.3 - 2.5
Hydrogen (%)	1.5 - 3.5	4.5 - 6	5.5 - 6.5	6 - 7.5
Carbon (%)	75 - 85	65 - 80	55 - 70	35 - 45
Nitrogen (%)	0.5 - 1	0.5 - 2.5	0.8 - 1.5	0.6 - 1
Oxygen (%)	5.5 - 9	4.5 - 10	15 - 30	38 - 48
Btu/lb	12,000 - 13,500	12,000 - 14,500	7500 - 10,000	6000 - 7500
Density (g/mL)	1.35 - 1.70	1.28 - 1.35	1.35 - 1.40	1.40 - 1.45

Source: (Speight, 2015)

Table 1 shows that each type of coal has different elements. In this study, the type of coal used is Lignite coal. Lignite coal is a type of coal that has the lowest quality among other types of coal.

2.3 Biomass - Palm Kernel Shell

Palm kernel shells have quite a large potential if used as fuel because the calorific value they have is quite high, on par with lignite coal. The following are the results of proximate and ultimate analysis of palm kernel shells.

Table 2 Proximate and ultimate analysis of palm oil shells

Analysis/Parameters	Palm kernel shell	Lignite coal
Proximate (%weight)		
Water content	6.12	17.5
Flying substances	56.64	37.2
Ash	10.62	6.3
Fixed carbon	26.62	40.3
Low Heating Value	4594	5324
Ultimate (% weight)		
C	48.48	57.0
H	6.32	6.5
O	43.59	28.3
N	0.21	1.1
S	0.01	0.5

The table above shows that there is no significant difference between palm shell biomass compared to lignite coal, both in terms of calorific value, proximate analysis and ultimate analysis. Based on the results of the analysis, palm shell biomass can be used as an alternative fuel in the rubber industry to replace coal.

2.4 Sawdust Biomass

In this study, biomass in the form of wood in the form of *sawdust was used*. The chemical content of sawdust is presented in Table 3.

Table 3 Chemical Composition and Calorific Value of Sawdust

SAWDUST	Unit	ARB	ADB	DB	DAFB
Proximate Analysis					
Total moisture	%wt	16.85			
Moisture in analysis	%wt		4.54		

Ash content	%wt	0.98	1.13	1.18	
volatile matter	%wt	66.11	75.90	79.51	80.46
Fixed carbon	%wt	16.05	18.43	19.31	19.54
Total sulfur	%wt	0.01	0.01	0.01	0.01
Gross calirific value	kCal/kg	4036	4634	4854	4913
Ultimate analysis					
Hydrogen	%wt	4.56	5.24	5.49	5.55
Carbon	%wt	45.11	51.80	54.26	54.91
Nitrogen	%wt	0.38	0.44	0.46	0.46
Oxygen	%wt	32.09	36.85	38.60	39.06

Source: (Sucofindo, 2021),

Information: ARB: As Received Basis, ADB: As Dried Basis, DB: Dried Basis, DAFB: Dry As Free Basis

3 Methodology

This study uses a quantitative descriptive-comparative approach to analyze the performance of Labuhan Angin PLTU in implementing biomass co-firing technology, especially by comparing two types of biomasses, namely sawdust and palm shells. The quantitative approach was chosen to measure variables objectively and numerically, while the descriptive-comparative approach was used to describe actual conditions and compare data between types of biomass without direct manipulation of the variables. This study is non-experimental and uses secondary data from co-firing trial reports that have been carried out by the PLTU technical team as part of efforts to diversify energy and reduce carbon emissions.

The data analyzed are quantitative historical data from operational monitoring during the co-firing process, which have gone through an initial validation process. The analysis was carried out using descriptive statistical methods to determine trends and average values of power plant performance parameters, as well as comparative analysis to compare the performance of the PLTU on each type of biomass. The results of this analysis will be further studied by comparing them to national and international literature studies, in order to assess the effectiveness of co-firing implementation at the Labuhan Angin PLTU and formulate strategic recommendations based on empirical evidence for optimizing the co-firing program.

4 Results and Discussion

4.1 Technical Performance Analysis

4.1.1 Co-Firing of Palm Kernel Shell Biomass

co-firing technology using palm shell biomass at the Labuhan Angin PLTU shows changes in characteristics in a number of technical parameters of boiler operation. One of the main aspects that has changed is the temperature in several important areas of the combustion system.

Table 4 Technical Performance of Palm Kernel Shell Co-firing

Category	Parameter	Unit	100% Coal	97% Coal + 3% Biomass	95% Coal + 5% Biomass
Furnace Temperature	Bed	°C	849.4	837.3	831.2
	Seal Pot L	°C	813.2	805.6	794.2
	Seal Pot R	°C	800.1	799.3	803.1
Furnace Exhaust Gas Temperature	Furnace Exit L	°C	762.0	749.3	751.0
	Furnace Exit R	°C	752.6	743.4	748.9
Exhaust Gas Temperature	Cyclone Outlet L	°C	705.8	714.6	678.6
	Cyclone Outlet R	°C	700.6	706.1	698.9
	Air Heater Outlet L	°C	133.3	132.1	133.7
	Air Heater Outlet R	°C	133.3	128.9	136.3
Furnace Pressure	Furnace Pressure	Dad	-203.2	32.3	-221.6

Operational data shows that co-firing with palm kernel shells causes a decrease in the average furnace bed temperature from 849.4°C (100% coal) to 837.3°C (3% mixture) and 831.2°C (5% mixture). The exhaust gas temperature at the cyclone outlet decreased, indicating that the calorific value of the biomass is lower than that of coal, although the temperature remains safe and the thermal performance of the plant is not significantly affected. Due to the different combustion characteristics of biomass, the pressure in the furnace fluctuates, rising to 32.3 kPa at 3% co-firing, then dropping to -221.6 kPa at 5%.

Overall, the implementation of palm kernel shell biomass co-firing up to 5% at the Labuhan Angin PLTU still shows good technical stability. Although there are changes in temperature and pressure parameters, all are still within the system design limits, so they do not trigger major disturbances. Optimization such as air

ratio settings and fuel flow control are needed to maintain operational efficiency and stability. These findings support previous studies stating that low-scale co-firing can be implemented effectively without sacrificing plant performance.

4.1.2 Co-Firing Sawdust Biomass

As part of the transition towards more environmentally friendly power generation, Labuhan Angin PLTU tested co-firing technology with sawdust biomass as a partial coal substitute. The trial aimed to assess operational stability and impacts on energy efficiency and environmental parameters. Data from various mixture ratios were analyzed to evaluate the technical feasibility of sawdust co-firing on a commercial scale. The results of the analysis are presented in tabular form to facilitate interpretation and decision making.

Table 5 Technical Performance of Co-firing with sawdust

Parameter	0% Sawdust	1% Sawdust	3% Sawdust	5% Sawdust
Steam Power Plant Load (MW)	Stable	Stable	Stable	Most stable
SFC (kg/kWh)	0.77–0.80	0.78–0.81	0.76–0.83	0.75–0.80
Furnace Temperature (°C)	Stable	A little bit volatile	Stable	Most stable
Coal Flow (t/h)	Highest	Decrease	Decrease	The lowest
Excess O ₂ (%)	4.4–5.4	4.4–5.6	4.2–6.5	4.5–5.8

Co-firing test of sawdust biomass at PLTU Labuhan Angin evaluated combustion efficiency, flame stability, combustion chamber temperature, and boiler performance. With varying blending ratios (BR) of sawdust at 1%, 3%, and 5%, the addition of sawdust reduces the calorific value of the mixture, thereby increasing fuel consumption to produce equivalent energy. However, the volatile matter content of sawdust accelerates combustion, improves efficiency, and reduces SO₂ and NO_x emissions, particularly at higher blending ratios.

The technical performance at BR 3% and 5% sawdust is relatively stable, with good load (MW) and furnace temperature stability at BR 5%, indicating that sawdust co-firing does not cause major disturbances to the power plant system. Overall, sawdust shows potential as an alternative biomass for co-firing, provided that the fuel characteristics are in accordance with the combustion system and good operational integration is carried out. The successful implementation of sawdust co-firing is highly dependent on mature technical design and optimal operational parameter settings.

4.2 Technical Characteristics Interaction

4.2.1 Technical Characteristics Co-Firing of Palm Kernel Shell Biomass

The implementation of palm kernel shell biomass *co-firing* in Labuhan Angin PLTU not only has an impact on the technical aspects of combustion but also shows a significant influence on the characteristics of the emissions produced. One of the main parameters in environmental evaluation is the concentration of SO₂ emissions.

Table 6 Technical Performance of Palm Kernel Shell Co-firing

Category	Parameter	Unit	100% Coal	97% Coal + 3% Biomass	95% Coal + 5% Biomass
Emission	SO ₂	mg/m ³	519.17	493.54	470.21
	NO _x	mg/m ³	182.87	167.96	209.32
	Particulates	mg/m ³	78.25	82.17	86.13

Based on the available data, it can be seen that SO₂ emissions when using pure coal reached 519.17 mg/Nm³. When co-firing with 3% biomass, this figure decreased to 493.54 mg/Nm³, and again decreased to 470.21 mg/Nm³ in a mixture of 5% biomass. This decrease in emissions is in line with the much lower sulfur content in palm kernel shells compared to coal, so that partial substitution of fossil fuels with biomass can help reduce the release of SO₂ gas into the atmosphere.

Meanwhile, for NO_x emissions, the data shows a relatively consistent, though not very significant, downward trend. NO_x emissions were recorded at 182.87 mg/Nm³ at 100% coal condition, decreased to 167.96 mg/Nm³ at 3% co-firing, and increased to 209.32 mg/Nm³ at 5% co-firing. This decrease can be attributed to the slightly lower combustion temperature due to the addition of biomass, thus reducing the formation of thermal NO_x.

The results of particulate emissions (PM) testing in sawdust biomass co-firing showed a slight increase, with particulate values increasing from 78.25 mg/Nm³ in pure coal to 82.17 mg/Nm³ in 3% co-firing, and 86.13 mg/Nm³ in 5% co-firing. This increase was caused by the ash content in palm kernel shells which is easily carried by exhaust gas. Therefore, particulate control needs to be considered by increasing the efficiency of the filtration system, such as electrostatic precipitators (ESP), in order to continue to meet emission quality standards. Despite the increase in particulate emissions, the use of sawdust biomass in co-firing has a positive impact on reducing emissions of hazardous gases such as SO₂ and NO_x. This finding is in line with previous studies showing that biomass

co-firing can reduce acid gas emissions but requires more attention to particulate emission control.

4.2.2 Technical Characteristics Co-Firing Sawdust Biomass

The co-firing implementation was carried out in stages at sawdust ratios of 0%, 1%, 3%, and 5% with the generator load kept constant at around 65 MW. The process includes filling the silo, stabilizing the unit, observing parameters, and taking technical data every hour as well as sampling fuel, FABA (Fly Ash & Bottom Ash), and flue gas. Although the addition of sawdust was carried out up to 5%, the stability of the unit loading was maintained. At 5% sawdust, the load tends to be the most stable when compared to 0%, 1%, and 3%.

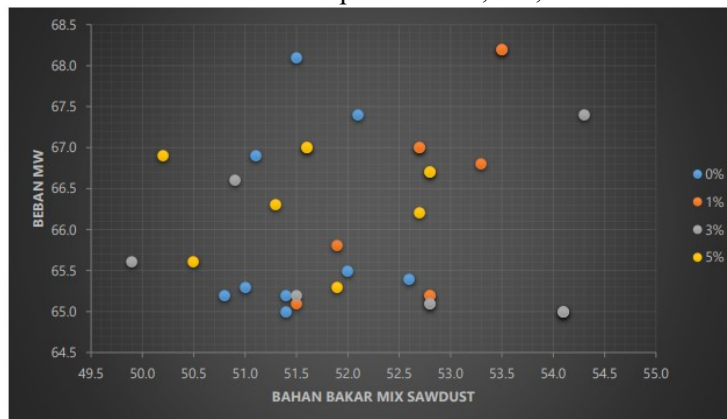


Figure 3. Coal Flow vs Load (mix sawdust combination)

Based on coal consumption and electricity load data from 10:00 to 18:00. In conditions without biomass (0%), coal consumption ranges from 53.4 to 55.8 tons/hour to produce an average electricity load of around 64.9 to 66.2 MW. When biomass is added by 1%, coal consumption decreases to 50.8 to 52.6 tons/hour but is still able to produce electricity loads in the equivalent range, namely between 65.0 to 68.1 MW.

A more significant reduction in coal consumption was seen at 3% and 5% biomass blends. At 3% blend, coal consumption ranged from 51.5 to 53.5 tons/hour, while at 5% blend, coal consumption dropped further to 50.2 to 52.8 tons/hour. Although there was a slight variation in the electrical load, most of it remained in the range of 65 to 67 MW. This indicates that the technical characteristics of the co-firing process, such as combustion efficiency, flame stability, and boiler adaptability to various fuel types, performed quite well up to the 5% blend level. In other words, the system was able to maintain the performance of the power plant while reducing the consumption of coal—a fossil fuel that indirectly contributes to carbon emission reduction.

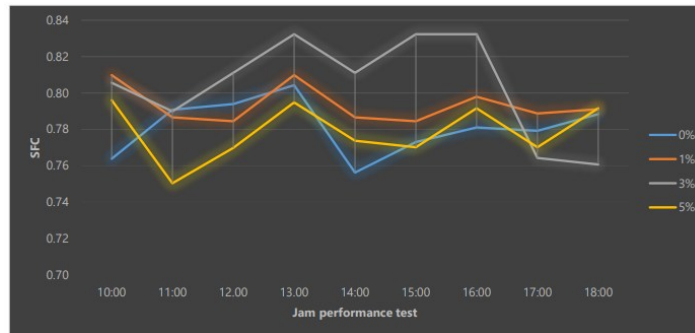


Figure 3 Specific Fuel Consumption

The interaction between sawdust biomass and coal in co-firing at the PLTU is seen through the measurement of Specific Fuel Consumption (SFC), which shows fluctuations throughout the day, with a consistent pattern based on the percentage of sawdust mixture. The use of pure coal (0%) shows a lower SFC value, indicating better combustion efficiency. However, when sawdust is added in a mixture of 1%, 3%, and 5%, the SFC value increases although not significantly, indicating a slight decrease in combustion efficiency. This phenomenon can be explained by the lower calorific value of sawdust compared to coal, as well as a combustion pattern that tends to be fast but less stable. However, at some times, the 5% sawdust mixture shows better performance than the 1% and 3% mixtures, indicating that operational factors and fuel mixing techniques also affect combustion efficiency. Thus, although the increase in SFC is not too significant, this still needs to be considered to optimize co-firing.

4.3 Comparative Analysis and Technical-Economic Feasibility

To further strengthen the analysis, a comparative evaluation of emission reductions relative to biomass blending ratios is presented. As shown in Table 6, co-firing 5% palm kernel shell reduces SO_2 emissions by approximately 9.4%, from 519.17 mg/m^3 to 470.21 mg/m^3 . In contrast, the NO_x emissions show mixed trends, with a nominal reduction of 8.1% at 3% co-firing, but a slight increase at 5%, indicating a non-linear behavior that may require burner adjustment or air-fuel ratio optimization. These comparative values illustrate the direct impact of biomass blending ratios on emission performance and underline the need for precise control strategies at higher co-firing percentages.

From a techno-economic perspective, biomass co-firing at 3–5% offers several benefits. Although there is a slight increase in Specific Fuel Consumption (SFC) due to the lower calorific value of biomass, this is compensated by the reduced cost of biomass materials such as sawdust and palm kernel shells often sourced as industrial waste with minimal procurement cost. The reduction in coal use by

up to 5% at 5% biomass blending (as observed in Figure 2) translates to cost savings and a lower carbon footprint. Additionally, the potential for government incentives or carbon credits due to reduced emissions could improve the economic viability of biomass co-firing.

4.4 Carbon Balance Estimation

To estimate the potential contribution of biomass co-firing to emission reduction, a simplified carbon balance can be outlined. Biomass is generally considered carbon-neutral because the CO₂ released during combustion is offset by the CO₂ absorbed during the biomass growth cycle. By substituting 5% of coal with biomass, and assuming an average emission factor of 2.4 kg CO₂/kg of coal, and net zero CO₂ for biomass, the reduction in carbon emissions per hour can be calculated. For example, with a baseline coal use of 55 tons/hour, a 5% reduction equals 2.75 tons of coal saved per hour, corresponding to a reduction of 6.6 tons CO₂/hour. Over 24 hours of operation, this results in a reduction of approximately 158 tons CO₂/day, contributing significantly to the power plant's decarbonization goals.

4.5 Discussion

4.5.1 Technical Performance Analysis

The application of sawdust co-firing technology at the Labuhan Angin PLTU showed stable technical performance up to a blending ratio (BR) of 5%, without a decrease in output power. Specific Fuel Consumption (SFC) remained in the efficient range (0.75–0.83 kg/kWh), and the coal flow rate decreased significantly from 53.4–55.8 tons/hour to 50.2–52.8 tons/hour. This shows the potential for fossil fuel savings without sacrificing system performance. In addition, the furnace temperature remained stable at BR 3% and 5%, and the high volatile matter content of sawdust contributed to accelerating ignition and improving combustion.

However, the moisture content and particle size of sawdust are important factors to maintain combustion stability and avoid system disruption. The excess O₂ parameter is within the safe range (4.2–6.5%), but begins to show fluctuations at the highest BR, indicating the need for more precise air control. The increase in SFC at higher sawdust ratios indicates a decrease in efficiency that needs to be anticipated by setting the optimal mixture ratio so that co-firing remains efficient and environmentally friendly.

4.5.2 Technical Characteristics Interaction

According to Ali's research (2023), the use of palm kernel shells and sawdust in co-firing can increase NO_x emissions due to the nitrogen content in biomass, but lower sulfur content can reduce SO_x emissions. In addition, particulates produced from the combustion of palm kernel shells and sawdust can affect the performance of the electrostatic precipitator (ESP) at the Labuhan Angin PLTU. Therefore, emission analysis is very important to assess the environmental impact of this co-firing technology.

The use of palm kernel shells and sawdust in the combustion of the Labuhan Angin PLTU can cause technical challenges related to its impact on the generating system. One of the main issues is the formation of scale and slagging on the heating surface in the boiler. The higher alkali and chlorine content in biomass can increase the risk of fouling and corrosion in equipment, especially in the superheater and economizer (Saptyaji & Harnowo, 2021). In addition, the physical properties of palm kernel shells and sawdust which are lighter than coal can cause changes in fuel flow patterns and heat distribution in the furnace. This can affect combustion performance and the service life of boiler components. Therefore, this study will evaluate the potential impact of co-firing on the reliability of the Labuhan Angin PLTU equipment, including a study of mitigation strategies such as the use of additives to reduce scale formation and setting operational parameters to optimize combustion conditions.

Effective biomass supply chain management is essential to ensure sustainable fuel availability in the co-firing system in PLTU. According to Muslim et al., (2024) the application of co-firing with biomass such as sawdust and palm shells can reduce carbon emissions and utilize waste as a renewable energy source. However, it should be noted that co-firing technology is not fully capable of reducing carbon emissions if it is not supported by optimal and sustainable biomass supply chain management.

By understanding the findings of previous research, the development of effective and sustainable co-firing strategies in PLTU can be more focused, so as to achieve optimal energy efficiency and meet applicable emission standards.

Limitations and Challenges

Combustion Temperature Reduction: Co-firing of palm kernel shell biomass and sawdust reduces the furnace and flue gas temperatures because the calorific value of biomass is lower than coal, affecting the heat transfer efficiency.

- Furnace Pressure Fluctuations: Differences in biomass combustion characteristics cause furnace pressure fluctuations, disrupting heat distribution and operational stability.
- Thermal Efficiency Decreases at High BR: Boiler efficiency decreases on co-firing with sawdust above 5% due to decrease in calorific value of the mixture and fuel distribution challenges.
- Biomass Particle Size and Distribution: Non-uniform particle size and suboptimal biomass feeding system cause flame fluctuations, especially at 7% BR sawdust.
- Limitations of Existing Systems: Conventional coal-fired power plants are not designed for large amounts of biomass co-firing, requiring technical modifications and additional investment.
- Inconsistent NO_x and Particulate Emissions: Co-firing can increase NO_x and particulate emissions at certain ratios, even though SO₂ decreases, requiring optimization of emission controls.

4.5.3 Comparison with Previous Studies

The technical performance of co-firing with palm kernel shells (PKS) at the Labuhan Angin PLTU showed consistent results with previous studies, where the decrease in furnace temperature and pressure fluctuations in 3% and 5% biomass mixtures did not significantly affect boiler performance. Although the thermal efficiency decreased slightly, co-firing could reduce SO₂ and NO_x emissions, although better particulate emission management is needed. The decrease in SO₂ emissions in PKS is consistent with the findings showing that biomass co-firing reduces sulfur emissions. However, the increase in particulate matter at higher biomass ratios emphasizes the importance of an efficient emission control system. These findings confirm the technical feasibility of biomass co-firing with appropriate adjustment of operational parameters and emission management.

5 Conclusion

This study aims to analyze the technical performance and emission characteristics of the application of biomass co-firing technology with palm shell and sawdust fuels at the Labuhan Angin PLTU. Based on the results of the analysis, it can be concluded that the application of co-firing with biomass can be carried out efficiently even though there are several technical changes, especially in the temperature and pressure parameters in the boiler combustion system.

In co-firing with palm kernel shells, although there is a decrease in combustion temperature and fluctuation in furnace pressure, these parameters remain within the safe range and do not significantly affect operational performance. Combustion efficiency can be maintained by adjusting the combustion system and adjusting the air ratio. Likewise, with co-firing with sawdust, although there is a decrease in thermal efficiency and fluctuation in furnace temperature, proper control of the combustion system can maintain the stability of the PLTU performance. Overall, co-firing of biomass, both palm kernel shells and sawdust, can be carried out effectively within the range of 5% without disrupting the stability of the operational system, although further monitoring and adjustment of several operational parameters are needed.

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