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A study of co-firing palm kernel shell on the Nagan Raya coal-fired power plant

KhairilAnsar, Ahmad Syuhada, Sarwo Edhy Sofyan*
Magisters Program, Department of Mechanical Engineering, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia
*Corresponding author: sarwo.edhy@usk.ac.id

Abstract

Co-firing biomass with coal in existing utility boilers is seen as one strategy for promoting renewable energy with low upfront costs and little to no impact on the boiler's high efficiency. The purpose of this research is to analyse the fuel characteristics and performance of palm kernel shell co-firing at Nagan Raya Coal-Fired Power Plant (CFPP) at various percentages of palm kernel shell combination. The analysis is conducted based on the operational data obtained from Nagan Raya power plant. In this study, the characteristics of fuel and the performance of a power plant are analysed based on percentages of fuel variations, namely 100% coal, 95% coal-5% palm kernel shell, and 90% coal-10% palm kernel shell. The results reveal that co-firing's biomass ratio boosted operation parameters, including main steam pressure, temperature, and flow rate. Subsequently, co-firing with 90% coal-10% palm kernel shell has enhanced the power plant output to 90.7 MW compared to those with 100% coal, 95% coal-5% palm kernel shell, namely 89.3 MW and 90.4 MW, respectively.

Keywords:
Co-firing, palm kernel shell, coal-fired power plant, fuel characteristics, performance.

1 Introduction

Renewable energy potential in Indonesia is expected to replace fossil energy sources such as coal, particularly in the production of electricity [1]. The government has set a target of 23% utilisation of renewable energy in the national energy mix by 2025, as stated in Presidential Regulation of the Republic of Indonesia Number 22 of 2017 concerning the National Energy General Plan (RUEN). To reach the energy mix target, one of the techniques for growing the renewable energy mix is the co-firing programme, which is one of the State Electricity Company's (PLN) breakthrough programmes for increasing the renewable energy mix[2].

The co-firing of biomass in coal-fired power plants has emerged as a promising strategy for addressing both Greenhouse Gas (GHG) emissions and the rising demand for renewable energy.Co-firing of biomass is a technique that combines coal and biomass fuel in a specific proportion. Biomass co-firing technology in Coal-Fired Power Plant (CFPP) has been widely implemented in various countries and is recognised as an important technology for reducing the use of fossil fuels, especially because it is relatively simple to implement, responds rapidly, and requires little investment capital[3][4][5].

The PLN has so far implemented this co-firing technology in 40 CFPP locations, out of a target of 52. By burning 542 thousand tonnes of biomass, PLN's co-firing programme was able to produce 575.4 GWh of clean energy while reducing carbon emissions by 570 thousand tonnes of CO_2.

The co-firing of various types of biomass with coal has been studied by Larina et al.[6]. This study aims to investigate the effect of mixed fuel composition on boiler efficiency, combustion characteristics, the best-mixed fuel composition, boiler operating parameters, slagging, and fouling issues[6]. Although co-firing biomass with coal appears to be viable, it generates a large amount of ash with varying properties, which causes problems in boilers such as fouling, slagging, corrosion, bed agglomeration, sintering, clinkering, and other concerns [7]. Assessments of slagging and fouling tendencies are crucial for ensuring long-term combustion efficiency. Slagging and fouling occur when ash particles become molten and stick to the boiler surface. At lower temperatures, inorganic vapours can condense into solid particles, coating their surfaces in a sticky molten film [8]. Before fuel blends with a qualified calorific value are fed into a boiler coal power plant, small-scale testing to detect slagging and fouling tendencies should be carefully undertaken.

The co-firing of biomass and coal in the power generation sector offers environmental and financial benefits. Since co-firing does not require substantial capital expenditures or new CFPP infrastructure, it is considered economically viable [9]. Co-firing with a 10% combination of wood pellets and coal can reduce GHG emissions by 9%, as shown by Life Cycle Assessment (LCA) modelling[10].

Cahyo et al. [11] discovered that co-firing 5% Palm Kernel Shell (PKS) in both power plants reduces SO_2 emissions while increasing NOx emissions. The amount of SO_2 and NOx emissions still fulfils Indonesia's emission requirements (maximum value: 550 mg/Nm^3). A short-term study found that co-firing with 5% palm kernel shell has no negative effects onCirculating Fluidized Bed(CFB) boiler power plants. More research is needed on the potential of alkali metals in biomass to generate rust, the capacity of biomass to foul and clump together, and how these factors affect power plant dependability.

To reduce coal consumption, co-firing's technology and effectiveness are continuously improving. The boiler's efficiency can be affected by the type of biomass and the composition of the mixture used. In co-firing applications, the pre-mixing conditions of biomass and coal are crucial performance determinants [12]. Consideration must be given to biomass with a high moisture content, a low calorific value, and inadequate grindability[13]. Consequently, optimising biomass quality is essential for sustaining combustion performance.

According to estimates, Indonesia has the capacity to convert more than 32 GW of biomass into electrical energy from sources such as sugarcane, coconut, corn, wood, rice, cassava, and municipal trash [14]. In Indonesia, the direct cofiring technique has been used to evaluate a variety of biomass materials, including wood pellets [15], palm kernel shells [16], and wood powder[17]. Rice husk, a tough layer of residue from the rice milling process that typically makes up 20%–21% of the weight of processed rice [18], is one of the various biomasses that exist in Indonesia and has the potential to be used in CFPP's co-firing [19].

Palm kernel shells have the potential to be converted into downstream goods. The potential production of palm kernel shells in Indonesia alone is 11 million tonnes per year, but only about 3.5 million tonnes are exported in semi-processed form[20].There are approximately 26.7 metric tonnes of Palm Kernel Shell (PKS) for every 100 metric tons of Crude Palm Oil (CPO) that is produced as a byproduct of the mechanical separation process of palm nuts at a palm oil mill[21]. A study conducted by Putra et al. [22] shows that the steam power plant can generate 1.16 MW per ton of palm kernel shell.

Based on a comprehensive examination of the existing literature, it appears that no studies have been conducted thus far to investigate the performance of the Nagan Raya power plant when employing co-firing techniquesunder different ratios of coal-palm kernel shell fuel mixture. Thus, this research aims to analyze the fuel characteristics and performance of co-firing palm kernel shell at the Nagan Raya Coal-Fired Power Plant (CFPP) using different proportions of palm kernel shell.

2 Research Methods

In this study, the performance of the co-firing of the Nagan Raya CFPP is studied. The CFPP is located in Nagan Raya Regency, Province of Aceh. The power plant, possessing a maximum output capacity of 2×100 MW, incorporates the use of palm kernel shells for co-firing purposes. This study utilised the direct co-firing approach for its experimentation. Before supplying the boiler with fuel, a blend of coal and other combustible materials is created. To achieve the simultaneous combustion of biomass and coal, the two are mixed together using either the same or separate equipment. The experimental testing was performed on an existing Circulating Fluidized Bed (CFB) boiler of the CFPP.

The data used in this study includes coal and biomass characteristics as well as operational parameters. The fuel's characteristic test (for both coal and palm kernel shell) was carried out by PT Surveyor Indonesia. The analysis results were as presented in Table 1. In this study, the characteristics of coal and biomass used for co-firing are discussed. In addition, the calorific value of fuels (coal and coal-biomass blends) is compared. The calculation of the calorific value of the mixed fuel in this study was calculated using the Eq 1.

$$CV_{mixture} = X_1 \cdot CV_{coal} + X_2 \cdot CV_{palm\ shell} \quad (1)$$

where X_1 is the percentage of coal used (%), CV_{coal} is the calorific value of coal (kcal/kg), X_2 is the percentage of palm kernel shell used (%), and $CV_{palm\ shell}$ is the calorific value of palm kernel shell (kcal/kg).

Table 1. Characteristics of palm kernel shell

Parameter	Unit	Coal	Palm kernel shell
Ultimate			
Carbon	%	-	46.23
Hydrogen	%	3.28	4.63
Nitrogen	%	-	0.5
Sulphur	%	-	-
Oxygen	%	-	30.04
Proximate			
Total moisture	%	34.77	17.35
Ash content	%	3.46	1.18
Volatile matter	%	32.18	64.41
Fixed Carbon	%	29.59	17.06
Total Sulfur	%	0.27	0.07
Gross calorific value	kcal/kg	4238	4154
Hardgrove grindability index		55	<32

The power plant performance evaluation was carried out based on the data collected from the Production Activity Control and Monitoring Centre of CFPP Nagan Raya (refer to Fig. 1). Subsequently, the main steam temperature, pressure, flow rate, fuel's gross calorific value, and power output of CFPP are evaluated and analysed based on the percentage of coal-biomass blends, namely 100% coal, 95% coal-5% palm kernel shell, and 90% coal-10% palm kernel shell.

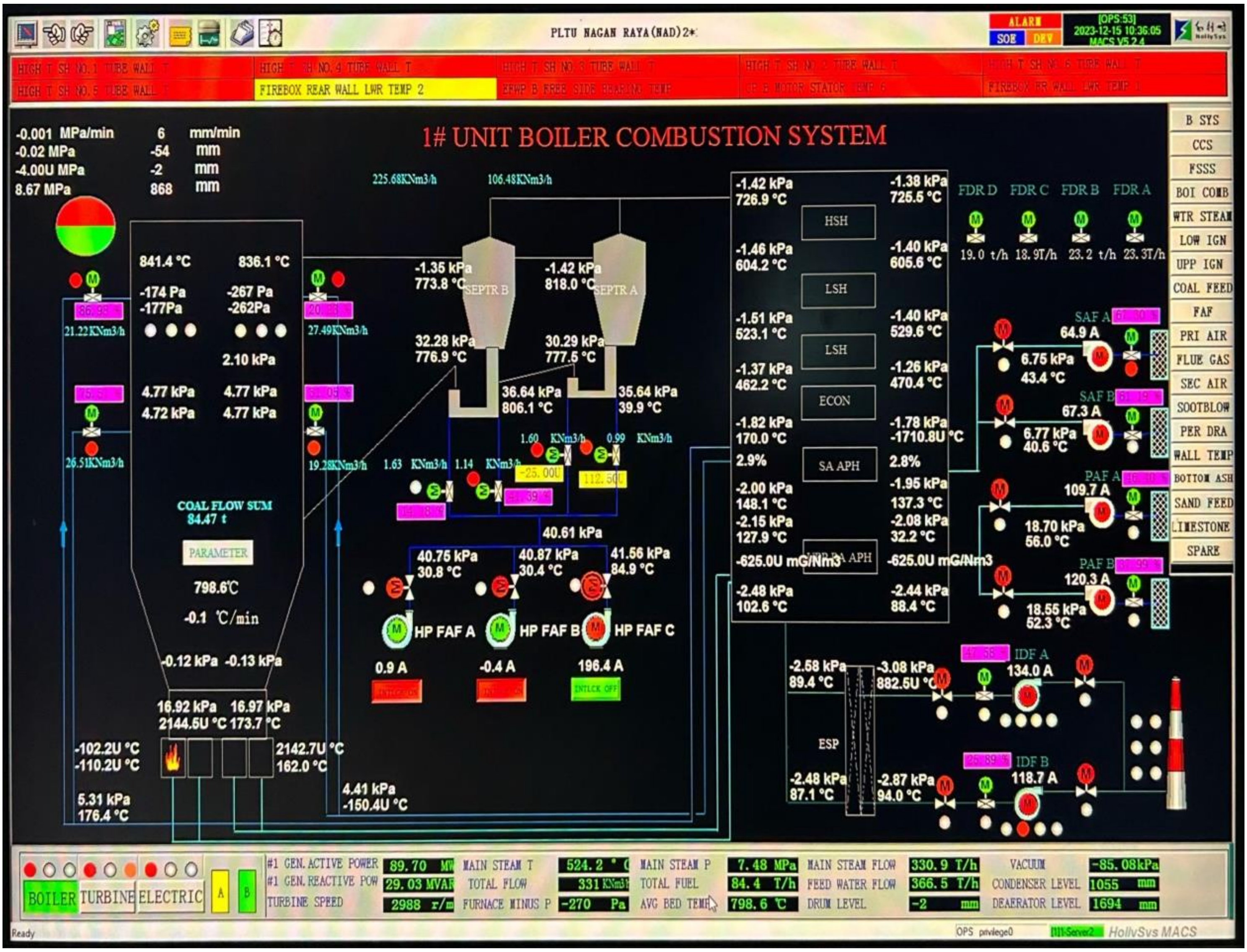

Fig. 1. Process control screencourtesy of Nagan Raya Coal Fired Power Plant.

3 Results and Discussion

3.1 Characteristics of Fuel in the Nagan Raya CFPP

The characteristics of the coal and palm kernel shell used in the Nagan Raya power plant are shown in Table 1. The characteristics of coal and palm kernel shell biomass were compared by comparing the results of the ultimate and proximate analyses. In comparison to coal, palm kernel shell has a lower calorific value, ash content, and moisture content. Meanwhile, palm kernel shell has a substantially higher volatile matter content than coal. As can be seen from the table palm kernel shells have a 17.4% moisture content and a 2.2% ash content lower than coal's. These results have also been confirmed by Cahyo et al. [11]. Palm kernel shell exhibits a comparatively higher volatile matter content in comparison to coal, hence rendering it more amenable to combustion. In terms of gross calorific value, it shows that coal has slightly (2%) higher energy compared to palm kernel shell. The gross calorific value of palm kernel shell used in this study (4154 kcal/kg) is slightly lower than that reported by Loh et al. [21] namely 4700-4900 kcal/kg.

3.2 Gross Calorific Value (GCV) of Fuel

Table 2 illustrates the gross calorific value of the fuel used in Nagan Raya CFPP, namely coal and palm kernel shell. As can be seen in Table 2, the Nagan Raya CFPP uses three variations of fuel distinguished by percentage palm kernel shell blending with coal, namely 0%, 5% and 10% of palm coal blend. It has been found that blending coal and palm kernel shell produces a relatively higher gross calorific value for both 5% and 10% coal-palm kernel shell blends compared to the 0% palm kernel shell blend. This tendency is due to the relatively higher inherent gross calorific value of palm kernel shell instead of coal.

Table 2. Gross calorific value

Fuel composition	Gross calorific value (kcal/kg)
0 %	4238
5 %	4244.8
10 %	4251.7

3.3 Main Steam Temperature, Pressure and Flow Rate

Table 3 summarises the main steam temperature, pressure and flow rate generated based on the percentage variation of the coal-palm kernel shell blend at Nagan Raya CFPP. As can be seen from the table, the co-firing of biomass in the CFPP influences the main steam temperature, pressure and flow rate. The co-firing of palm kernel shellscontributes to an increase in the average temperature of the main steam (see Fig. 2(a)). In the, 5% trial, it is found that the average temperature is 530.22ºC, while the 10% trial yields 538.43ºC, which is higher compared to operating conditions with 100% coal (0% palm kernel shell),namely 525.80ºC. It is observed that the co-firing of palm kernel shell has also contributed to an increase in the main steam's pressure and flow rate (refer to Fig. 2(b) and 2(c)). This tendency can be affected by the relatively higher calorific value of the fuel mixture of coal and palm kernel shells that accelerates combustion in the furnace, leading to an increase in the radiant energy of combustion. It is found that at 10% palm kernel shell blend, both the pressure and flow rate of the main steam have increased to 7.4 MPa and 338.68 T/h compared to those at 0% and 5% of palm kernel shell, generating 7.36 MPa, 336.7 T/h, and 7.38 MPa and 337.67 T/h, respectively. This tendency agrees well with Nainggolan et al.'s findings [23].

Table 3. Main steam temperature, pressure and flow rate

Fuel composition	Main steam		
	Pressure(Mpa)	Temp(ºC)	Flow (Tonnes/h)
0% palm kernel shell	7.36	529.3	336.70
5% palm kernel shell	7.38	533.9	337.67
10% palm kernel shell	7.40	534.7	338.68

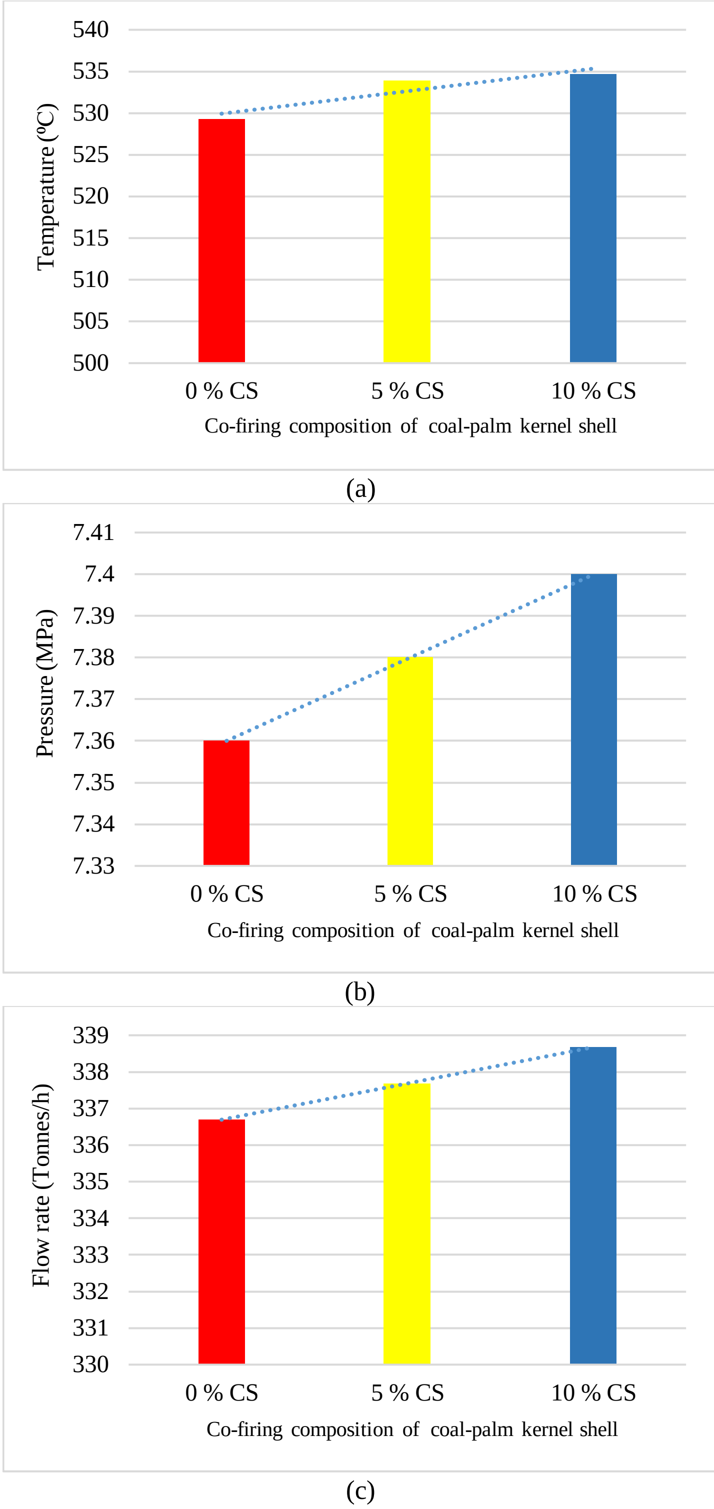

Fig. 2. Main steam. (a) Temperature, (b) presssure, (c) flow rate.

3.4 Power Output of CFPP

The effect of co-firing on the power output of Nagan Raya CFPP is presented in Fig. 3. As can be seen from the figure, the power output of a power plant is affected by the percentage of coal-biomass blend. Nagan Raya CFPP can gain the highest power output at 10% palm kernel shell-coal blend, namely 90.73 MW. Based on the findings acquired, it can be inferred that co-firing can be a solution that not only increases the power output of the CFPP but also reduces the use of fossil fuels, especially coal, for electricity generation. A study conducted by Cahyo et al. [16] shows that the utilisation of 5% PKS in co-firing results in a reduction of fuel expenses of 5.1 Rp/kWh in scenario B (95% sub-bituminous coal-5% palm kernel shell in Power Plant X) and 3.7 Rp/kWh in scenario D (95% sub-bituminous coal-5% palm kernel shell in Power Plant Y). Furthermore, the decreased costs of biomass in comparison to coal played a role in reducing fuel prices.

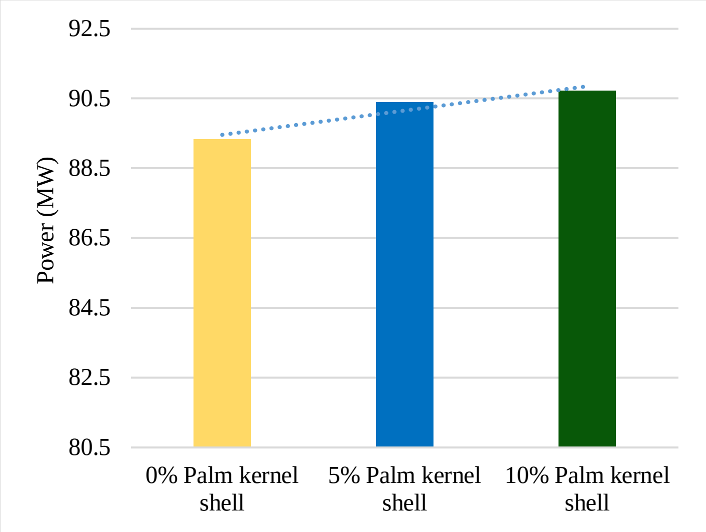

Fig. 3. Power capacity generated by Nagan Raya CFPP.

4 Conclusion

The study demonstrates the potential for energy generation through the co-firing mechanism in a coal-fired power plant. Based on the findings of the conducted research, it can be inferred that the adoption of co-firing is of significant importance in augmenting the proportion of newly derived renewable energy sources. This measure is vital in aiding the government's efforts to expedite the attainment of the renewable energy mix objective of 23% by the year 2025. The research reveals that the higher biomass ratio in co-firing led to a little rise in the operational parameters (such as main steam pressure, temperature and flow rate). Furthermore, it has been observed that the implementation of co-firing has resulted in a notable augmentation of the power generation capacity of the aforementioned power plant. Based on the acquired findings, it can be inferred that the practice of co-firing has the potential to not only enhance the power generation capacity of the generator but also serve as a suitable strategy for mitigating the reliance on fossil fuels, particularly in the context of electricity production.

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