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Investigating the Performance of a 50MW CFB Boiler in a Coal-Fired Power Plant through Co-Firing with Gamal Biomass and RDF

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ABSTRACT

The co-firing program at coal-fired power plants (CFPP) is part of PT PLN (Persero)'s short-term strategy to support Indonesia's Net Zero Emission (NZE) target by 2060. Biomass and Refuse-Derived Fuel (RDF) are among the promising co-firing fuels. Biomass is considered carbon-neutral, while RDF helps reduce environmental waste. This study evaluates the technical effects of co-firing Gamal and RDF at blending percentages of 5%, 15%, and 30%, focusing on boiler performance and plant efficiency. SteamPRO software by Thermoflow was utilized to simulate and analyze the power plant's thermodynamic performance under each co-firing condition. The simulations show that fuel specification or fuel composition and calorific value significantly affect key performance parameters. Co-firing with Gamal increases the Net Plant Heat Rate (NPHR) from 3034 kcal/kWh (baseline) to 3065, 3136, and 3264 kcal/kWh for 5%, 15%, and 30% co-firing, respectively. Plant efficiency correspondingly declines from 28.35% to 28.05%, 27.42%, and 26.35%. Boiler efficiency also drops from 83.69% to 82.98%, 81.47%, and 78.92%. RDF, in comparison, results in smaller deviations, with NPHR reaching only 3062 kcal/kWh and plant efficiency decreasing slightly to 28.08% at 30% co-firing. The lower calorific value of Gamal (2481 kcal/kg) increases the total fuel flow and raises auxiliary power consumption in the draught system, especially in the PA, SA, and ID fans, whereas RDF causes only minimal deviations. Emission results show that Gamal, with 0.07% sulfur, reduces SO_2 emissions from 0.474 to 0.4326 kg/MWh at 30% co-firing, while RDF increases it to 0.4905 kg/MWh due to higher sulfur content (0.42%). Uncorrected CO_2 emissions rise with Gamal but decrease after applying the carbon-neutral factor, from 984 to 730 kg/MWh at 30%. These results emphasize the importance of co-firing fuel specification selection and blending percentage optimization to balance performance and environmental outcomes.

Keywords: Biomass, Coal Fired Power Plant, Co-firing, Gamal, Refused Derived Fuel

INTRODUCTION

As a result of ongoing economic growth, rapid population increase, and accelerated technological development, energy demand in Indonesia continues to rise significantly (Muzayanah & al., 2022). Meeting these growing energy needs has become a fundamental pillar in supporting national development and accelerating regional advancement across the archipelago. As Indonesia is projected to become one of the major global economic powers in the coming decades Nugroho (2017), the availability and reliability of energy supply play a crucial role in achieving that vision. In this context, energy fulfillment is not only a matter of infrastructure development but also a strategic priority aligned with the national goal Ali & Kim (2024) of realizing "Indonesia Emas 2045."

However, efforts to meet increasing energy demand must also consider environmental challenges, particularly those related to greenhouse gas emissions (EPA, 2025). The electricity sector, which contributes significantly to national emissions due to the dominance of fossil fuels such as coal for power plant (RUPTL, 2021), has come under increasing pressure to transition toward cleaner and more sustainable practices (IESR, 2022). This is in line with the Government of Indonesia's commitment to achieving Net Zero Emissions (NZE) by the year 2060 (Kurniawan et al., 2024). In support of this goal, PLN—Indonesia's state-owned electricity company—has developed a set of strategic plans, comprising both a Short-Term Plan (2021–2030) and a Long-Term Plan (2031–2060), that emphasize sustainable and decarbonized energy production.

Among the priority strategies outlined in the Short-Term Plan is the adoption of co-firing, a method that blends biomass or waste-derived fuels with coal in existing coal-fired power plants (CFPP). Co-firing is recognized as one of the most feasible and cost-effective approaches for reducing carbon emissions without requiring a complete overhaul of existing generation infrastructure (Schmidl & al., 2019). If using biomass, from a carbon accounting perspective, biomass is considered carbon-neutral, as the CO_2 released during combustion is offset by the CO_2 absorbed during the growth cycle of the biomass (Zhang & al., 2023). Gamal has the potential to be used as one of the co-firing fuels, making it a viable and appropriate feedstock for bioenergy production (Hudaedi et al., 2018; Oyelere & Oluwadare, 2019). Furthermore, the use of waste materials as alternative fuels offers an additional environmental benefit by diverting waste from landfills and reducing the environmental burden associated with unmanaged solid waste (Prihandoko et al., 2023). This benefit becomes increasingly important as the volume of municipal solid waste continues to grow over time due to population growth, urbanization, and changing consumption patterns (SIPSN, 2023).

Given these potential benefits, the implementation of co-firing must be carefully evaluated, particularly with respect to its effects on power plant performance, in order to prevent a reduction in efficiency or even a de-rating of maximum power output (Reza et al., 2021). Key parameters such as Net Plant Heat Rate (NPHR) (Prasojo et al., 2025), overall plant efficiency Dwiaji (2023), boiler efficiency Wang et al. (2021), total fuel flow Mehmood et al. (2012), auxiliary power consumption on draught system (Sargent, 2023), and the intensity of SO_2 and CO_2 emissions (Kumar et al., 2025) must be analyzed to assess the viability of co-firing under various operational scenarios. Several PC boiler manufacturers have reported that CFPP with PC boilers are capable of burning only up to 5% biomass, whereas CFB boilers can accommodate up to 30%, which is significantly higher (Reza et al., 2021). Therefore, in this study, a CFB boiler type is selected due to its higher co-firing capacity, with the expectation that it will produce more representative data.

Co-firing has been studied as a fuel strategy for CFPP, and several studies have been conducted, using saw dust (Faras et al., 2022), palm kernel shell Ansar et al. (2023) (Dian et al., 2023), rice husk Cahyo et al. (2024), corn cob Hidayat et al. (2024), acasia wood bark (Cahyo et al, 2024), calliandra Sa'u et al. (2024), refused derived fuel (Fadli et al., 2019) Fitrianingrum & Surjasatyo (2023), etc. Co-firing with wood chips decreases plant capacity by 0.74%, while co-firing with industrial pellets results in a 1.41% reduction (Knapp et al., 2019). Similarly, another study found that the implementation of co-firing with 5% sawdust increased the Gross Plant Heat Rate (GPHR) from 2,649 kCal/kWh to 2,705 kCal/kWh and the Net Plant Heat Rate (NPHR) from 2,790 kCal/kWh to 2,853 kCal/kWh, indicating a decrease in plant efficiency (Ilham & Suedy, 2022). An increase in the Plant Heat Rate or a decrease in plant efficiency theoretically results in a higher amount of fuel required to maintain the same power output (Reza et al., 2021). Consistent with this, another study showed an increase in specific fuel consumption (SFC) during co-firing, reaching 0.7071 kg/kWh compared to 0.7059 kg/kWh when using 100% coal (Cahyo et al., 2024). The higher fuel flow to the boiler furnace theoretically demands a greater supply of combustion air, which subsequently impacts the draught system components in CFPP, including the Primary Air Fan, Secondary Air Fan, and Induced Draft Fan (Liu et al., 2020). For the emissions, due to the differences in the fuel specifications between coal and co-firing fuels, the resulting emissions are naturally expected to differ as well, the study shows that co-firing biomass with coal in large-scale combustors can significantly reduce SO_2 emissions compared to pure coal combustion (Roy et al., 2024). Another study evaluated the emissions of acid gases such as SO_2 and CO_2 from the co-firing of coal with raw and torrefied biomass, showing that blending coal with biomass can drastically reduce SO_2 and CO_2 emissions compared to pure coal combustion (Rokni et al., 2018).

Another study also showed that co-firing using palm kernel shell could improve power plant efficiency and reduce specific fuel consumption (SFC). The SFC decreased by 1.8%, from 0.871 kg/kWh to 0.856 kg/kWh at the power plant (Cahyo et al., 2022). This result presents an output that contrasts with several findings previously discussed. Differences in fuel specifications may lead to varying impacts on the efficiency and performance of the power plant.

Therefore, this study is intended to analyze the impact of co-firing gamal biomass or waste at different blending percentages, specifically 5%, 15%, and 30%, on the efficiency and performance of CFPP boilers, based on the fuel specifications provided by XYZ in the feasibility study report, with a focus on parameters such as Net Plant Heat Rate (NPHR), overall plant efficiency, boiler efficienct, total fuel flow, auxiliary power consumption on draught system, and the intensities of SO_2 and CO_2 emissions.

The outcomes are expected to provide valuable insights for decision-makers and power plant operators in optimizing the implementation of co-firing as part of Indonesia's broader energy transition strategy.

METHOD

In this study, the co-firing method applied is direct co-firing, which involves the simultaneous combustion of biomass or waste fuel together with coal in the boiler of a coal-fired power plant (CFPP) and is commonly practiced in Indonesia.

To assess the impact of co-firing on the efficiency and performance of the CFPP boiler, this study uses SteamPRO by Thermoflow, a well-known simulation software widely used in the thermal power plant industry. The independent variable in this study is the co-firing percentage using either Gamal or Refuse-Derived Fuel (RDF), applied separately without mixing. The co-firing blending percentage are set at 5%, 15%, and 30%, aiming to achieve a net power output of 50 MW.

The dependent variables used in this study are as follows:

a. The type of CFPP used is a Circulating Fluidized Bed (CFB) boiler, operating under Turbine Maximum Continuous Rating (TMCR) conditions and utilizing 100% coal as fuel, with the basis of the simulation presented in **Table 1**.

Table 1. Operating Basis and Performance Parameters of Coal-Fired Power Plant using 100% Coal Fuel

Parameter	Unit	Value
Net Power	Mega Watts	50
Auxiliary Power	Mega Watts	10.88
Net Plant Heat Rate	kCal/kWh	3034
Plant Efficiency	%	28.35
Boiler Efficiency	%	83.69
Site Relative Humidity	%	75
Site Temperature	ºC	30

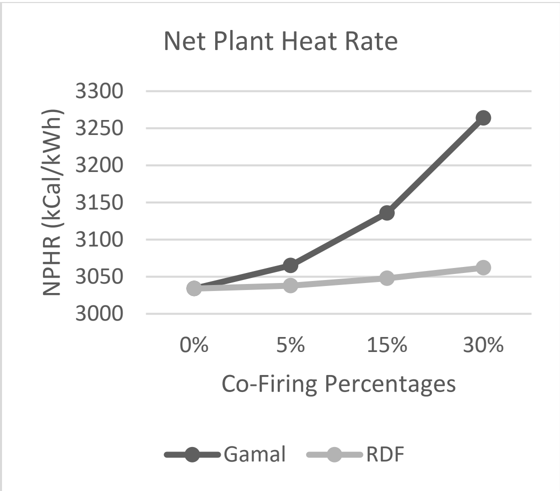
b. The fuel specifications used in this study are taken from the Feasibility Study reports by XYZ. The fuel specifications are provided in **Table 2**.

Table 2. Fuel Properties and Composition of Coal, Gamal Biomass, and Refuse-Derived Fuel (RDF) Based on Ultimate and Proximate Analysis

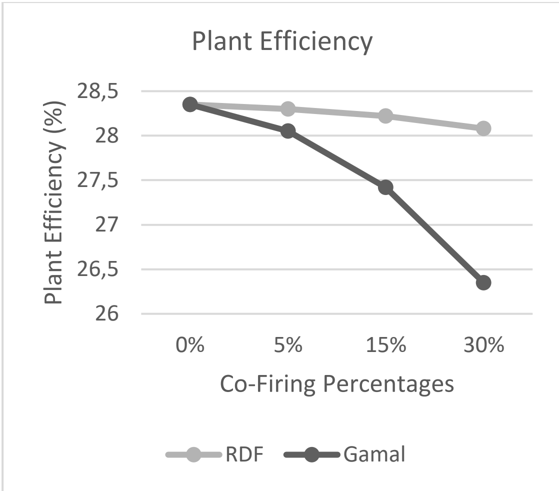
Parameter	Unit	Coal	Gamal	RDF
LHV	kcal/kg	3822	1772	3600
HHV	kcal/kg	4200	2481	4019
Ultimate Analysis				
Moisture	%	35	47	25
Ash	%	4.41	0.6	12
Carbon	%	43.72	22.92	39
Hydrogen	%	3.33	8.34	5.2
Nitrogen	%	0.61	0.15	1.1
Sulfur	%	0.4	0.07	0.42
Oxygen	%	12.53	67.92	17.28
Total	%	100	100	100
Proximate Analysis				
Moisture	%	35	47	25
Ash	%	4.41	0.6	12
Volatile Matter	%	29.69	46	50
Fixed Carbon	%	30.9	6.4	13
Total	%	100	100	100

RESULT AND DISCUSSION

By using Thermoflow SteamPRO software to process simulation data of a 50 MW-class coal-fired power plant using a Circulating Fluidized Bed (CFB) boiler type, the effects of co-firing using Gamal biomass or Refuse-Derived Fuel (RDF) at various blending percentages on boiler efficiency and performance have been identified. The graphs of NPHR, plant efficiency, and boiler efficiency are presented sequentially in **Figure. 1** and **Figure. 2**.



(a)



(b)

Figure 1. Effect of Co-Firing Percentages on (a) Net Plant Heat Rate and (b) Plant Efficiency

The Net Plant Heat Rate (NPHR), expressed in kcal/kWh, is a key performance indicator that reflects the efficiency of a power plant, the lower the NPHR, the more efficient the plant. **Figure 1(a)** shows that the NPHR value under the baseline condition using 100% coal (0% co-firing) is 3034 kcal/kWh. When gamal biomass is introduced as a co-firing fuel, a gradual increase in NPHR is observed as the co-firing percentage rises. At 5% co-firing, the NPHR increases to 3065 kcal/kWh, at 15% it reaches 3136 kcal/kWh, and at 30% it climbs to 3264 kcal/kWh. **Figure 1(b)** illustrates that the plant efficiency declines from the baseline value of 28.35% to 28.05% at 5% co-firing, 27.42% at 15%, and further drops to 26.35% at 30% co-firing. This trend indicates that higher proportions of gamal reduce combustion efficiency, which may be attributed to its lower calorific value and differing combustion characteristics compared to coal. As a result, more fuel energy is required to produce the same amount of electricity, leading to a higher heat rate.

A different trend is observed with the use of Refuse Derived Fuel (RDF) as the co-firing fuel. At 5% RDF, the NPHR is 3038 kcal/kWh, at 15% it rises slightly to 3048 kcal/kWh, and at 30% it reaches 3062 kcal/kWh. The plant efficiency remains close to the baseline, recorded at 28.3% for 5% co-firing, 28.22% at 15%, and slightly decreases to 28.08% at 30%. These increases are relatively modest compared to those observed with gamal, suggesting that RDF has better compatibility with coal in terms of combustion stability and heating value. These findings suggest that RDF has combustion properties more compatible with coal, resulting in a less significant impact on plant efficiency and making it a more favorable co-firing option in terms of performance retention.

Another effect observed alongside changes in NPHR and plant efficiency is the variation in boiler efficiency resulting from the implementation of co-firing as shown in **Figure 2**. Under baseline conditions (100% coal), the boiler efficiency is recorded at 83.69%. When co-firing with Gamal biomass, a consistent decline in boiler efficiency is observed as the blending percentage co-firing increases: 82.98% at 5%, 81.47% at 15%, and 78.92% at 30%. This reduction is likely due to the lower heating value and combustion stability of Gamal biomass compared to coal, which leads to less efficient energy conversion within the boiler. In contrast, co-firing with Refuse-Derived Fuel (RDF) results in a relatively smaller decline in boiler efficiency. The values are 83.61% at 5%, 83.44% at 15%, and 83.19% at 30%, all of which remain close to the baseline. This suggests that RDF has combustion properties more comparable to coal, resulting in a more stable boiler performance even at higher co-firing percentage. These findings reinforce the importance of fuel characteristics in determining boiler thermal performance during co-firing applications.

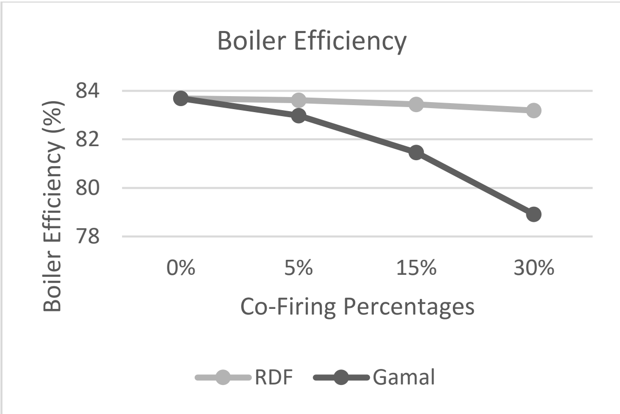


Figure 2. Impact of Co-Firing Percentage on Boiler Efficiency Using Gamal Biomass and RDF

The increase in NPHR or the decrease in plant efficiency is primarily caused by the lower calorific value of Gamal biomass or RDF compared to coal, which has a calorific value of 4200 kcal/kg. RDF, with a calorific value of 4019 kcal/kg, results in NPHR and efficiency values that are not significantly different from those obtained using 100% coal, due to the relatively small difference in calorific value. In contrast, co-firing with Gamal biomass, which has a calorific value of 2481 kcal/kg, leads to a more noticeable difference in NPHR and efficiency, as the gap in calorific value is substantially larger.

An increase in Net Plant Heat Rate (NPHR) and a corresponding decrease in plant efficiency indicate that more energy input is required to produce the same amount of electrical output. This condition leads to a higher total fuel flow rate entering the boiler to compensate for the reduced conversion efficiency. In other words, as the system becomes less efficient, particularly under co-firing scenarios with lower-calorific-value fuels such as Gamal biomass or RDF, the boiler must process a greater volume of fuel to maintain the same power output. This increase in fuel demand not only affects the combustion process but may also have implications for operational costs and emissions. The detailed total fuel flow rates under each co-firing condition are presented in **Table 3**.

Table 3. Total Fuel Flow Rate at Different Biomass Co-Firing Percentages for Coal-Gamal and Coal-RDF Combinations

Biomass Co-Firing Variation	Total Fuel Flow (t/hour)	
	Coal + Gamal	Coal + RDF
0%	36,1	36,1
5%	37,09	36,2
15%	39,26	36,41
30%	43,02	36,73

The implementation of co-firing directly influences the total fuel flow rate entering the boiler, as presented in **Table 3**. Under baseline conditions with 100% coal, the total fuel flow is 36.1 tons/hour for both cases. When co-firing with Gamal biomass, a significant increase in total fuel flow is observed as the co-firing percentage rises: 37.09 t/h at 5%, 39.26 t/h at 15%, and 43.02 t/h at 30%. This sharp increase reflects the impact of Gamal's relatively low calorific value, which necessitates a larger mass of fuel to meet the same energy demand and maintain constant power output. The inverse relationship between fuel calorific value and required fuel flow rate becomes evident in this case. On the other hand, co-firing with Refuse-Derived Fuel (RDF) results in a more modest increase in total fuel flow: 36.2 t/h at 5%, 36.41 t/h at 15%, and 36.73 t/h at 30%. The minor variation in these values compared to the baseline condition can be attributed to RDF's higher calorific value, which is relatively closer to coal. Consequently, the substitution of RDF does not require a significant increase in fuel volume.

The increase in total fuel flow rate due to co-firing not only affects the Net Plant Heat Rate (NPHR) and boiler efficiency but also influences the boiler's draught system. In a coal-fired power plant, this system comprises the Primary Air Fan (PA Fan), Secondary Air Fan (SA Fan), and Induced Draft Fan (ID Fan). As the co-firing percentage increases, more air is required for combustion, which leads to a higher workload for each fan. This results in increased auxiliary power consumption. The detailed impact on fan power consumption under each co-firing condition is presented in **Table 4**.

Table 4. Power Consumption of Draught System Components (PA Fan, SA Fan, and ID Fan) under Various Biomass Co-Firing Scenarios

Biomass Co-Firing Variation	Draught System (kW)		
	PA Fan	SA Fan	ID Fan
0%	756,7	334,8	542,4
5% RDF	759,2	335,6	545
5% Gamal	770,4	342,1	570,4
15% RDF	761,2	337,2	550,3
15% Gamal	800,1	358,3	635,3
30% RDF	765,9	339,7	558,5
30% Gamal	851,8	387,4	762,7

Table 4 shows the impact of biomass co-firing on the power consumption of the draught system, which includes the Primary Air Fan (PA Fan), Secondary Air Fan (SA Fan), and Induced Draft Fan (ID Fan). Under baseline conditions (0% co-firing), the PA Fan consumes 756.7 kW, the SA Fan 334.8 kW, and the ID Fan 542.4 kW. When co-firing with RDF, the increase in fan power consumption is relatively modest across all components. At a 30% RDF co-firing percentage, the PA Fan increases slightly to 765.9 kW, the SA Fan to 339.7 kW, and the ID Fan to 558.5 kW.

In contrast, co-firing with Gamal biomass results in a significantly higher increase in fan power demand. At 30% Gamal co-firing, the PA Fan consumes 851.8 kW, the SA Fan 387.4 kW, and the ID Fan 762.7 kW. These increases are notably higher than those observed with RDF, indicating that Gamal requires more airflow support during combustion, likely due to its lower calorific value, higher moisture content, and bulkier physical form.

These findings highlight that the selection of biomass fuel not only affects combustion characteristics but also has a substantial impact on auxiliary power consumption, particularly in the draught system. Co-firing with RDF presents a more efficient alternative in this regard, causing less strain on fan operation compared to Gamal.

The data presented in **Figure 3** illustrate the SO_2 and CO_2 emission intensities measured at the stack of the coal-fired power plant (CFPP). It is important to note that these values do not account for the carbon-neutrality factor typically associated with biomass fuels such as Gamal. This exclusion is due to the current lack of standardized regulations or official methodologies that govern the calculation of emission reductions in CFPPs utilizing co-firing at various blending percentage. As such, the emissions shown represent the direct output at the stack, regardless of the carbon-neutrality factor contribution from biomass.

The SO_2 emission intensities presented in **Figure 3(a)** demonstrate contrasting trends between co-firing with Gamal biomass and Refuse-Derived Fuel (RDF). Under baseline conditions with 100% coal, the SO_2 emission intensity is 0.474 kg/MWh. When co-firing with Gamal, a consistent reduction in SO_2 emissions is observed as the co-firing percentage increases: 0.4681 kg/MWh at 5%, 0.4552 kg/MWh at 15%, and 0.4326 kg/MWh at 30%. This decreasing trend is primarily attributed to the lower sulfur (S) content in Gamal biomass, which is approximately 0.07%, compared to 0.4% in coal. As a result, blending Gamal with coal significantly reduces sulfur input into the boiler, leading to lower SO_2 formation during combustion.

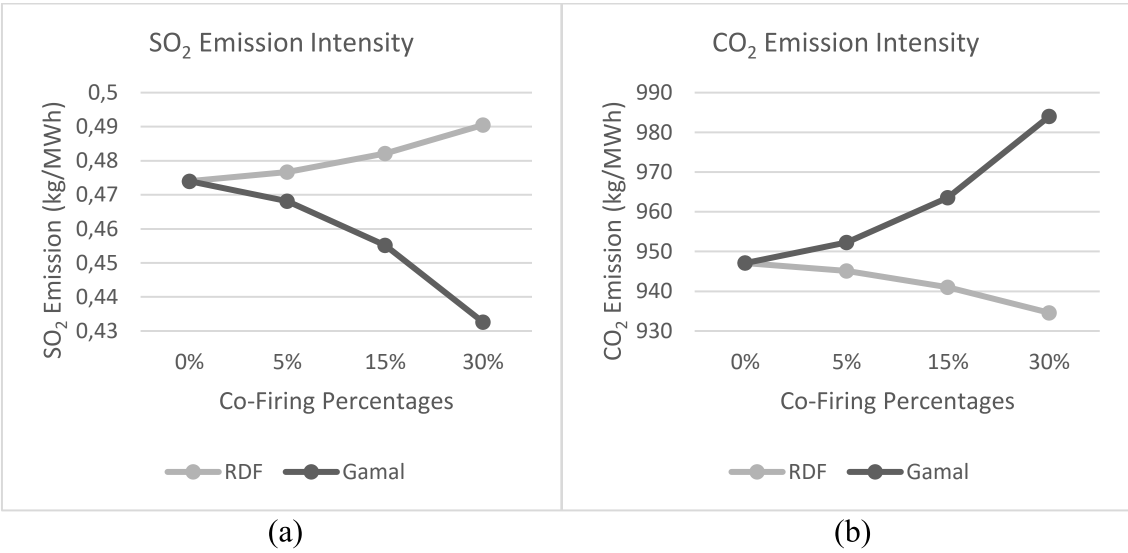


Figure 3. Effect of Co-Firing Percentage on
(a) SO_2 and (b) CO_2 Emission Intensity for Gamal and RDF Blends

In contrast, RDF co-firing exhibits an increasing trend in SO_2 emission intensity: 0.4767 kg/MWh at 5%, 0.4821 kg/MWh at 15%, and 0.4905 kg/MWh at 30%. This increase is consistent with the higher sulfur content found in the RDF used in this study, which reaches 0.42%. Therefore, unlike Gamal, co-firing with RDF introduces more sulfur into the combustion system than coal alone, resulting in elevated SO_2 emissions.

These findings highlight that the sulfur content of the fuel play a critical role in determining the environmental benefit of co-firing, particularly in terms of SO_2 emission reductions. While Gamal presents a clear advantage in this regard, RDF may require further pretreatment or the application of flue gas desulfurization (FGD) technologies to mitigate its sulfur-related emission impacts.

The CO_2 emission intensities presented in **Figure 3(b)** reflect different trends depending on the type of biomass used for co-firing. Under baseline conditions with 100% coal, the CO_2 emission intensity is recorded at 947.1 kg/MWh. When co-firing with RDF, a consistent decrease in CO_2 emissions is observed as the blending percentage increases: 945.1 kg/MWh at 5%, 941.0 kg/MWh at 15%, and 934.6 kg/MWh at 30%. This reduction is attributed to the lower carbon content of RDF, which is approximately 39%, compared to coal at 43.72%.

Consequently, less carbon is introduced into the combustion process, resulting in lower CO_2 emissions per unit of energy produced.

Conversely, co-firing with Gamal biomass leads to a steady increase in CO_2 emission intensity: 952.3 kg/MWh at 5%, 963.6 kg/MWh at 15%, and 984.0 kg/MWh at 30%. Although biomass is generally considered carbon-neutral from a life-cycle perspective, the values presented here represent direct emissions measured at the stack and do not account for carbon-neutralily factor. The rise in CO_2 emissions with Gamal co-firing is explained by its significantly lower calorific value (2481 kcal/kg). These factors result in a higher total fuel mass flow rate to maintain the same net power output of 50 MW, thereby increasing the amount of carbon entering the boiler and contributing to elevated CO_2 emissions.

The emission intensity shown in **Figure 3 (b)** represents the total CO_2 emission measured at the stack and does not incorporate any correction factors related to biomass co-firing or carbon-neutral emission assumptions. To further analyze the impact of biomass substitution, **Table 5** presents the CO_2 emission intensity values before and after applying the carbon-neutral emission correction factor for biomass. These values are calculated under the assumption that the carbon (C) content in the biomass is fully oxidized to carbon dioxide (CO_2), based on a stoichiometric combustion reaction. This approach allows for a more comprehensive understanding of the theoretical emission reduction potential when accounting for biogenic carbon sources. Under baseline conditions (0% co-firing), there is no change in emission intensity, with both values recorded at 947.1 kg/MWh. When biomass is introduced at a 5% co-firing percentage, the uncorrected emission intensity slightly increases to 952.3 kg/MWh due to the additional fuel mass required. However, after accounting for the biogenic carbon contribution of biomass, the corrected emission intensity drops to 910.3 kg/MWh.

Table 5. Comparison of CO_2 Emission Intensity Before and After Applying the Biomass Carbon Neutrality Correction Factor across Co-Firing Levels

Biomass Co-Firing Variation	CO_2 Emission Intensity (kg/MWh)	
	Before Correction	After Correction
0%	947,1	947,1
5%	952,3	910,3
15%	963,6	838
30%	984	730

As the co-firing percentage increases, the emission reduction becomes more significant. At 15% co-firing, the emission intensity decreases from 963.6 kg/MWh (uncorrected) to 838 kg/MWh (corrected), while at 30%, it drops further from 984 to 730 kg/MWh. These reductions confirm the role of biomass in lowering net CO_2 emissions when carbon-neutrality principles are applied. The greater the proportion of biomass in the fuel mix, the larger the contribution of biogenic carbon, thus leading to more substantial emission reductions in corrected values.

CONCLUSION

This study demonstrates that the composition and calorific value of co-firing fuels, specifically Gamal biomass and Refuse-Derived Fuel (RDF), significantly affect the performance and efficiency of coal-fired power plants (CFPP). Both Gamal and RDF have lower calorific values compared to coal, resulting in an increased Net Plant Heat Rate (NPHR) and decreased plant and boiler efficiency. The simulations show that co-firing with Gamal, increases the Net Plant Heat Rate (NPHR) by up to 7.6% and decreases plant efficiency from 28.35% (100% coal) to 26.35% at 30% blending percentages. In contrast, RDF causes only minor efficiency loss, with NPHR increasing by less than 1% at the same blending percentages. These findings underscore that the extent of heat rate degradation depends strongly on the fuel's energy content, with Gamal having a more pronounced impact due to its substantially lower heating value. The lower heating value of *Gamal* increases total fuel flow by up to 19.2%, raising the draught system load and power consumption, whereas RDF causes only a slight increase in fuel flow and fan power consumption. Emission analysis shows that Gamal reduces SO_2 emissions due to its low sulfur content, while RDF increases SO_2 emissions. Gamal also reduces CO_2 emissions by 22.9% when carbon-neutral corrections are applied, while RDF causes only a slight increase in CO_2 emissions. The study concludes that RDF offers better operational stability, while Gamal provides greater potential for emission reductions, provided combustion challenges are managed. Ultimately, the efficiency and performance of CFPPs depend heavily on the characteristics of the fuels used.

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