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Analysis of Mixing Coal and Biomass Fuels on Industrial Boiler Performance

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ABSTRACT

The aim of this study is the experimental investigation and characterization of the effects of using biomass mix and coal fuels boilers on the efficiency and environmental impact of industrial boiler combustion. As global emphasis on sustainability increases, there is a significant shift towards eco-friendly technologies, particularly in energy generation. Biomass from agricultural waste presents a viable alternative to traditional fossil fuels, which are known for their high carbon emissions and detrimental environmental effects. The experimental data collected relates to the coal boiler and biomass mix fuel boiler, and boiler performance parameters. Two different methods for controlling coal and biomass mix fuel feed are considered. One method involves manually controlled biomass mix feed through the boiler control system and one more for use full coal boiler. The boilers control system regulates the intake of coal and biomass mix fuel into the furnace based on combustion chamber temperature and pressure parameters. The experimental results reveal that coal-fired boilers maintain a higher average efficiency of 82% compared to boilers using a biomass mix, which exhibited efficiencies around 80% depending on the biomass content. The results shows that the biomass mix boiler does not significantly affect the combustion process but reduces fuel consumption, better than coal boiler. The findings are expected to provide valuable insights for industry stakeholders and policymakers, promoting the adoption of more sustainable and cost-effective fuel alternatives in industrial applications.

1. INTRODUCTION

Sustainability has become a global standard for achieving sustainable development through the role of the private sector. As an eco-friendly technology, this biomass boiler uses rice husks as raw material. These agricultural wastes are sourced from various regions in Central Java Province, including from the agricultural lands surrounding the Biomass Boiler facility, where this region is one of the largest contributors to national rice production. This biomass boiler can reduce carbon emissions by 8,300 tons of CO2, equivalent to the carbon emissions absorbed by planting 120,000 trees, thereby reducing the carbon footprint generated from the production process in factories by up to 32%.

In addition to environmental impacts, the construction of this boiler also creates social and economic impacts for the surrounding community through locally

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sourced fuel, and by providing rice husk ash produced back to farmers, which is useful as organic fertilizer. The rice husk ash produced during the production process of the Biomass Boiler contains a significant amount of silica and has a highly advantageous effect on enhancing agricultural productivity, perhaps boosting it by up to 10 tons per hectare. Moreover, the project possesses the capacity to provide employment prospects and invigorate regional economies, rendering it an exemplar of sustainable development (Bukit et al., 2022).

Most research indicates that biomass boilers are a solution to replacing coal usage to address air pollution. The operational costs of mini biomass boilers consist of fuel costs and electricity costs for the control system, pump ignition, and blower operation. The largest operational cost is fuel cost. Therefore, to reduce boiler operational costs, the fuel cost can be lowered by utilizing available and environmentally friendly materials. As an agrarian country, potential fuels that can be utilized as biomass fuels include agricultural waste such as wood branches/firewood, husks, coconut shells, and charcoal.

In this study, we analyze boiler performance using wood pellets and coconut shell fuel. Additionally, boiler performance tests are conducted using biomass mix with coal. The boiler performance tests include the capacity/amount and quality of steam produced, and the energy efficiency of boilers for each type of fuel. The results of this study are expected to provide a basis for the wider application of boilers in industries with the selection of available fuel types. This research topic aligns with the industrial engineering agenda where sustainability and green manufacturing in the industry are aimed at national self-reliance and welfare (Caposciutti et al., 2022). The findings of this study can provide valuable information for companies in making strategic future decisions for certain demographics and countries with emerging markets.

This research aims to fill the gap and is based on data collected through direct experiments in the industry to analyze the performance of biomass-fueled boilers in the context of the latest strategic moves for sustainable development. This study empirically investigates the effects of sustainable development on sectors, specifically focusing on their environmental and economic repercussions. The objective of this research is twofold: firstly, to investigate biomass boilers in Indonesia, and secondly, to provide a framework for establishing recommendations for additional environmentally sustainable goods.

Furthermore, the objective of this project is to use state-of-the-art technology in biomass combustion in order to improve efficiency and further decrease emissions. Our goal is to enhance the combustion process by utilizing sophisticated sensors and control systems. This will result in the optimization of biomass consumption, making it economically feasible and environmentally sustainable. This comprehensive strategy aims to provide a detailed plan for future industrial methods, promoting creativity in environmentally friendly production and supporting worldwide initiatives to address climate change.

Boiler biomass involves using organic materials, such as agricultural wastes, wood waste, and other biomass sources, as fuel in boilers to generate electricity. Biomass boilers provide a renewable and sustainable option to replace fossil fuels, so helping to decrease greenhouse gas emissions and minimize environmental harm. Indonesia has a large amount of biomass resources, which offers a great potential for utilizing biomass boilers as a clean energy option (Dathe Tracyand Dathe, 2022).

Coal boilers have traditionally served as a typical means of generating energy, especially in countries that heavily depend on coal for producing power. Nevertheless, the adverse environmental consequences of burning coal, such as substantial carbon emissions and air pollution, have sparked an increasing inclination towards shifting to more environmentally friendly energy sources such as biomass. Biomass boilers exhibit reduced carbon emissions in comparison to coal boilers, owing to the carbon-neutral nature of biomass fuels, which absorb carbon dioxide throughout the process of plant growth. Coal combustion emits substantial quantities of greenhouse gases and pollutants, hence exacerbating air pollution and climate change (Douvartzides et al., 2022).

Biomass is an energy source that can be collected and replenished in a sustainable manner, unlike limited coal reserves. Coal is an exhaustible fossil fuel, which raises concerns about the exhaustion of resources and the deterioration of the environment due to mining activities (Feoktistov et al., 2022).

Biomass boilers can attain similar levels of efficiency as coal boilers, thanks to technological improvements that enhance combustion processes and energy generation (Nocoń et al., 2024). Coal boilers exhibit superior energy density and power production in comparison to biomass boilers, but progress in biomass boiler technology is diminishing this disparity in performance.

Biomass fuels are frequently obtained from local sources and are typically more economical than coal, hence offering economic advantages to places that possess ample biomass resources. The transportation and storage expenses associated with coal can be substantial, particularly in regions lacking nearby coal mines, which can have a considerable impact on the cost-effectiveness of coal boilers (Ke et al., 2022).

This research intends to compare biomass and coal boilers to demonstrate the environmental sustainability and operational efficiency advantages of biomass energy. Gaining knowledge about the distinctions between these two types of boilers helps enhance decision-making processes for moving towards cleaner and more sustainable energy solutions in Indonesia and other regions.

Boiler biomass utilization offers a promising avenue for sustainable energy production, particularly in countries rich in biomass resources like Indonesia. While there is a growing body of research highlighting the benefits of biomass energy, there remains a lack of comprehensive studies focusing specifically on boiler biomass in the Indonesian context. Existing literature often touches on general biomass utilization or renewable energy sources without delving deeply into the optimization and challenges of boiler biomass systems ((Isniah et al., 2020; Jin and Kim, 2022; Ke et al., 2022; Sumardiyanto and Chin, 2023).

In comparison to coal boilers, which have been extensively studied and well-documented in terms of their environmental impact and operational characteristics, there is a noticeable gap in research that directly compares boiler biomass with coal boilers in Indonesia. The lack of in-depth comparative studies hinders the ability to fully assess the potential of boiler biomass as a viable alternative to coal-fired systems in the country. The existing literature review reveals a significant research gap in the specific area of boiler biomass utilization and its comparison with coal boilers in Indonesia. While studies on biomass energy and coal-fired power generation exist, there is a need for more focused research that addresses the following aspects:

1. Comprehensive analysis of the technical, economic, and environmental performance of boiler biomass systems compared to coal boilers.
2. Examination of policy frameworks and regulatory mechanisms that support the adoption of boiler biomass for energy generation in Indonesia.
3. Assessment of the challenges and opportunities associated with scaling up boiler biomass projects in the Indonesian energy sector.
4. Exploration of innovative technologies and best practices for optimizing boiler biomass efficiency and sustainability.

By identifying these research gaps, this study aims to contribute to the existing literature by providing a detailed analysis of boiler biomass utilization in Indonesia and filling the void in comparative studies between boiler biomass mix and coal-fired systems. Addressing these gaps can help inform policymakers, researchers, and industry stakeholders on the potential of biomass energy as a sustainable alternative to coal in the Indonesian energy landscape.2.

2. METHODS

In this research, the authors conducted a comprehensive literature review and based on this, we carried out an experimental investigation and characterization of the effects of using biomass and coal fuels on the efficiency and environmental impact of industrial boiler combustion. The experimental data collected relates to the control of biomass mix fuel feed and boiler performance parameters (Kong et al., 2022; Kuptz et al., 2022; Lawal et al., 2017). Two different experiments to control biomass mix and coal fuel feed were considered.

Table 1. comparison of Boilers

Boiler Type	Average Boiler	Percentage Biomass (%)	Calories value (kJ/kg)
	efficiency (%)		
Coal Boiler	82	0	5550
Biomass mix Coal	80	10	4950
Biomass mix Coal	75	20	4500

We conducted pre-experiments data between January to March 2024, and found a composition that suits to continue this research. The illustration shows a comparison between coal-fired boilers and biomass-coal-mixed boils based on average boiler efficiency, biomass percentage, and caloric value. Coal-Fired Boilers have the highest average efficiency of 82% with a calorie value of 5550 kJ/kg and without biomass mixtures. When 10% of

the biomass is mixed, the efficiency of the boiler decreases to 80% with a calorie value of 4950 kJ/kg. Furthermore, when the percentage of biomass increases to 20%, boiler efficiency further drops to 75% with a caloric value of 4500 kJ /kg, as we can see in table 1. This suggests that an increase in the percentual biomass in the fuel mixture of a boiler reduces the efficiencies and calorie values of boilers. And Next, in the experiment, we used two kinds of boilers with two types of fuel, consist of 100% coal and 10% biomass with a 90% coal mixture (biomass mix).

Furthermore, we conducted independent t tests to determine if there was a significant difference in the fuel consumption of boilers that used a mix of biomass and coal.

3. RESULT AND DISCUSSION

The utilization of biomass boilers represents a significant opportunity for Indonesia to enhance its renewable energy capacity and reduce carbon emissions in the power generation sector. Biomass boilers offer a sustainable alternative to traditional fossil fuel-based boilers, utilizing organic materials such as agricultural residues, wood waste, and other biomass sources to produce heat and electricity. In this study, we conducted a comprehensive analysis of the current status, prospects, and challenges of biomass boiler utilization in Indonesia, aiming to provide valuable insights for policymakers, researchers, and industry stakeholders (Prasmoro and Hasibuan, 2018).

Current Status of Biomass Boiler Utilization: Our research findings indicate that Indonesia has a substantial biomass resource base, including agricultural residues, forestry waste, and palm oil residues, which can be effectively utilized in biomass boilers for energy production. The country's diverse biomass sources present a unique opportunity to diversify its energy biomass mix and reduce dependence on fossil fuels. However, the current utilization of biomass boilers in Indonesia remains limited, with a significant portion of biomass resources underutilized or inefficiently managed (Hariana et al., 2023).

For three primary variables of steam boiler, fuel consumption, and boiler ratio, the descriptive statistical analysis is performed on two types of boilers to determine the differences in efficiency and performance between the two types of boilers., as recommended by previous studies by Jin and Kim (2022); Lawal et al., (2017). Several other tests, including reliability and convergent validity, were prepared. Subsequently, the correlation between latent variables could be measured. The key findings from this study reflect that companies currently have a high awareness of energy issues and a strong belief that renewable energy technologies can be used as tools to support competitive and sustainable growth.

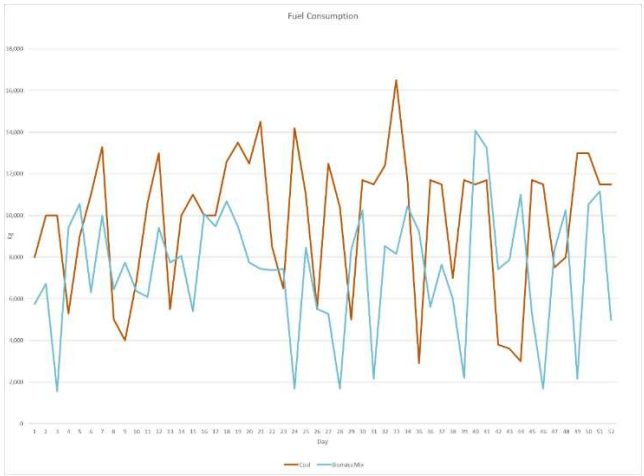

Figure 1. Fuel Consumption Comparison

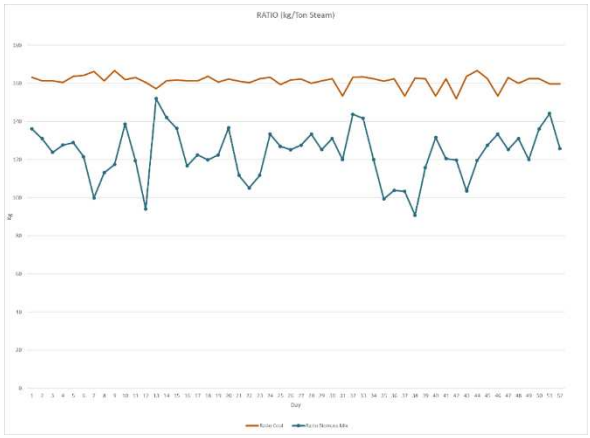

Figure 2. comparison of Ratio

To test the significant difference between the fuel usage of coal and biomass mix boilers, we used independent t tests. T-statistic: 3.807, P-value: 0.00024,

because the p-values are much smaller than 0.05, we can conclude that there is a significant difference between coal and biomass mix boiler fuel usage. This means that both types of boilers have statistically different average fuel consumption. Coal boilers have a higher average coal usage than Biomass mix boils, with larger variations. Biomass mix boiler shows a more varied efficiency ratio. Both types of boils do not show high reliability based on Cronbach's Alpha values. There are significant differences in fuel usage between coal and biomass mix boilers.

Descriptive statistical analysis is carried out on two types of boilers, namely coal boiler and biomass mix boiler, for three main variables: steam boiler, fuel usage, and boiler ratio. These descriptive stats provide a general overview of the distribution and variability of each variable.

For coal steam boilers, the average steam produced is 60.75 with a standard concentration of 20.60. This indicates a considerable variation in the number of steams produced, with a minimum value of 18 and a maximum of 101. The median of the coal steam boiler is 67.5, indicating that half of the value is below 67.5 and the other half is above. Coal boiler usage indicates an average usage of 9790.38, with a crude residual of 3324.79. The recorded minimum value is 2900 and the maximum is 16500, indicating a wide range of coal uses. The median coal usage is 11000, which means half of the usage value is below this figure 1.

The ratio of coal boilers has an average of 161.25 with a crude resonance of 3.32. The range of values of this ratio is quite narrow, from a minimum of 152 to a maximum of 167. The median of these ratios is 162, indicating a relatively symmetrical distribution around the average value.

Steam boiler biomass mix shows an average steam of 61.17 with a 25.15 raw resonance, slightly higher than a coal boiler. Steam values range from a minimum of 13 to a maximum of 110, with a median of 66, which means half of the value is below and the other half above this value.

The fuel use of the boiler biomass mix has an average usage of 7434.33 with a crude waste of 2976.47. This fuel consumption ranges from a minimum of 1560 to a maximum of 14080, with a median of 7750. These figures indicate that the fuel consumption of the boiler biomass mix tends to be lower, and more variable compared to the coal boiler. The boiler biomass mix ratio has an average of 123.23 and the raw reservoir of 13.37. The ratio values range from a minimum of 91 to a maximum of 152, with a median of 124.5. This suggests that the Boiler Biomass mix has a greater variation in ratio compared to the coal boiler (figure 2). From this descriptive statistical analysis, coal boilers have higher coal usage and larger variations in usage compared with boiler biomass mix. The steam produced by both types of boilers has almost the same average, but the boiler biomass mix shows a wider range. These results provide an initial overview of the performance and efficiency differences between the two types of boilers that can be used as a basis for further analysis and operational decision-making.

Despite the challenges associated with biomass boiler utilization, there are promising prospects for the development of biomass energy in Indonesia. The government's commitment to promoting renewable energy and reducing greenhouse gas emissions has created a conducive environment for the expansion of biomass boiler projects. Investments in research and technology development, as well as supportive policy frameworks, can further accelerate the deployment of biomass boilers across various sectors, including industrial, and commercial applications (Fikry Zainuddin et al., 2022; Pasha and Chin, 2024; Wang et al., 2023)

Our study identified several key challenges and barriers hindering the widespread adoption of biomass boilers in Indonesia. These include technical constraints related to boiler efficiency and performance, logistical challenges in biomass supply chain management, and financial barriers associated with upfront capital costs and operational expenses. Additionally, regulatory uncertainties and a lack of standardized quality control measures pose challenges for ensuring the reliability and sustainability of biomass boiler operations. To overcome the challenges and maximize the potential of biomass boilers in Indonesia, targeted policy interventions are essential. Policy measures should focus on incentivizing investments in biomass energy projects, providing financial support for technology upgrades and capacity building, and establishing clear regulatory frameworks to ensure the sustainable development of biomass boiler systems. Collaboration between government agencies, industry stakeholders, and research institutions is crucial for driving policy reforms and fostering a conducive environment for biomass energy growth.

Based on our research findings, we propose several recommendations for advancing biomass boiler utilization in Indonesia:

1. Enhance research and development efforts to improve biomass boiler technology and efficiency.
2. Establish public-private partnerships to facilitate investments in biomass energy projects and infrastructure.
3. Implement capacity building programs to train local technicians and operators in biomass boiler maintenance and operation.
4. Strengthen regulatory oversight and enforcement mechanisms to ensure compliance with environmental and safety standards in biomass boiler installations.

Overall, our study underscores the significant potential of biomass boilers in Indonesia's transition towards a more sustainable and low-carbon energy future. By addressing the current challenges and leveraging the country's abundant biomass resources, Indonesia can position itself as a leader in biomass energy innovation and contribute to global efforts in combating climate change and promoting renewable energy.

4. CONCLUSION

In conclusion, the utilization of boiler biomass presents a promising opportunity for Indonesia to enhance its energy sustainability and reduce reliance on fossil fuels. While biomass energy offers numerous environmental and economic benefits, there is a notable lack of in-depth research specifically focusing on boiler biomass systems in the Indonesian context. Existing literature highlights the advantages of biomass energy in general but falls short in providing a comprehensive analysis of boiler biomass and its comparison with coal-fired systems.

The experimental results reveal that coal-fired boilers maintain a higher average efficiency of 82% compared to boilers using a biomass mix, which exhibited efficiencies around 80% depending on the biomass content. Specifically, the performance data indicated that as the percentage of biomass increased, the calorific value decreased, resulting in a drop in overall boiler efficiency. For instance, when the biomass content reached 20%, the efficiency further reduced to 75%, demonstrating the trade-off between the proportion of renewable biomass and operational efficiency.

However, despite the reduction in efficiency, the utilization of biomass significantly lowers fuel consumption and emissions. The biomass mix approach offers a reduction in carbon emissions and provides a pathway toward more sustainable energy practices, with the potential to decrease carbon footprints in industrial settings substantially.

Based on the result analysis, it can be concluded that coal boilers exhibit more coal consumption and more significant fluctuations in usage when compared to boilers that use a mixture of biomass. The average steam production of both types of boilers is nearly same, however, the biomass boiler exhibits a greater variation in steam output. These results offer a preliminary assessment of the disparities in performance and efficiency between the two boiler types, which can serve as a foundation for additional study and decision-making about operations.

Moving forward, addressing the research gap in boiler biomass utilization and comparative studies with coal boilers is crucial for advancing sustainable energy practices in Indonesia. By conducting detailed assessments of the technical, economic, and environmental aspects of boiler biomass systems, researchers can better understand the potential of biomass energy as a cleaner alternative to coal. Additionally, exploring policy frameworks, challenges, and opportunities related to scaling up boiler biomass projects can inform strategic decision-making and promote the adoption of renewable energy sources in the country.

Through targeted research efforts and a focus on optimizing boiler biomass efficiency and sustainability, Indonesia can leverage its abundant biomass resources to transition towards a greener and more resilient energy future. By bridging the gap in knowledge and promoting the benefits of biomass energy, Indonesia can position itself as a leader in sustainable energy practices and contribute to global efforts in combating climate change.

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