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Combustion Efficiency Analysis of Lignite and Anthracite Coal in Co-firing Technology with Biomass: A Literature Review

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ABSTRACT

Coal is a non-renewable natural resource widely utilized as the main fuel for power generation, contributing approximately 80% of energy demand. However, dependence on coal presents significant challenges, such as future supply limitations, negative environmental impacts, and the need for diversification of energy sources. Co-firing technology, which involves the joint combustion of coal and biomass, is emerging as an alternative solution to improve combustion efficiency while reducing environmental impacts. This study aims to analyze the combustion efficiency of two types of coal, namely lignite and anthracite, combined with various types of biomass, such as sawdust, rice husk, wheat straw, tobacco, sawdust, and sunflower seed shells. Based on a literature review of previous studies, the analysis shows that lignite coal has higher combustion efficiency than anthracite when blended with biomass. The highest efficiency was recorded at 92% in the mixture of lignite with sunflower seed shells, supported by the reactive nature of lignite and the characteristics of biomass with high volatility and low ash content. In contrast, anthracite coal recorded its highest combustion efficiency of 85.5% when combined with sawdust biomass, attributed to the less reactive nature of anthracite and the high temperature required for complete combustion. Overall, co-firing technology has proven effective in improving combustion efficiency and utilizing biomass as a sustainable alternative fuel. The successful implementation of this technology highly depends on proper biomass selection, optimization of mixture proportions, and control of operating conditions. With a well-planned approach, co-firing can be a strategic solution to reduce greenhouse gas emissions while supporting the transition to a more efficient and environmentally friendly energy system.

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INTRODUCTION

Economic development and the growing global population have resulted in a substantial increase in the demand for electrical energy. Currently, the majority of the world's electricity is produced by burning fossil fuels, with coal being the predominant source (Zaman & Suedy, 2020). Coal is finite natural resource that is extensively used as the main fuel in thermal power plants, particularly in highly industrialized nations (Mohamed, 2024).

In Indonesia, coal plays a critical role in the electricity sector and serves as one of the main sources of state revenue. Approximately 80% of domestic coal consumption is used to meet the needs of electricity generation (Haq et al., 2022). However, reliance on coal as the primary energy source presents significant challenges, including the limited future energy supply, negative environmental impacts, and the need for energy diversification.

The combustion of coal produces greenhouse gas emissions, including carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NO_x), all of which contribute to environmental degradation (Ding et al., 2024). To address these challenges, cofiring coal with biomass is emerging as a promising alternative. This technology not only reduces the environmental impact of coal combustion but also helps decrease greenhouse gas emissions (Nainggolan et al., 2023; Matei et al., 2010; Aufi et al., 2023). Biomass, as a renewable energy source, is abundantly available in forms such as sawdust, corn cobs, bagasse, palm empty fruit bunches, rice husks, and wheat straw (Basar et al., 2022). The types of coal analyzed in this study include lignite and anthracite. Both types of coal have distinct characteristics. Lignite is a low-rank coal with relatively low energy content but is considered more environmentally friendly due to its low sulfur content (Samudro, 2016). In contrast, anthracite is a high-rank coal with higher energy content but also higher sulfur content (Yunianto & Septiani, 2015). Based on previous relevant studies that have been conducted, the biomass used in coal blends is sunflower seed shells, sawdust, sawdust, tobacco, sawdust and wheat straw. This study aims to evaluate the combustion efficiency of previous studies based on the biomass used.

METHODOLOGY

The literature review is the process of compiling and analyzing literature relevant to the research topic. Summaries of scientific papers from national and international journals were used to conduct this research. The reason of the writing survey is to provide a comprehensive summary of existing research, which underlies the formation of theoretical and methodological frameworks in new research (Creswell, 2014). The following are the stages of the research conducted as shown in **Figure 1.**

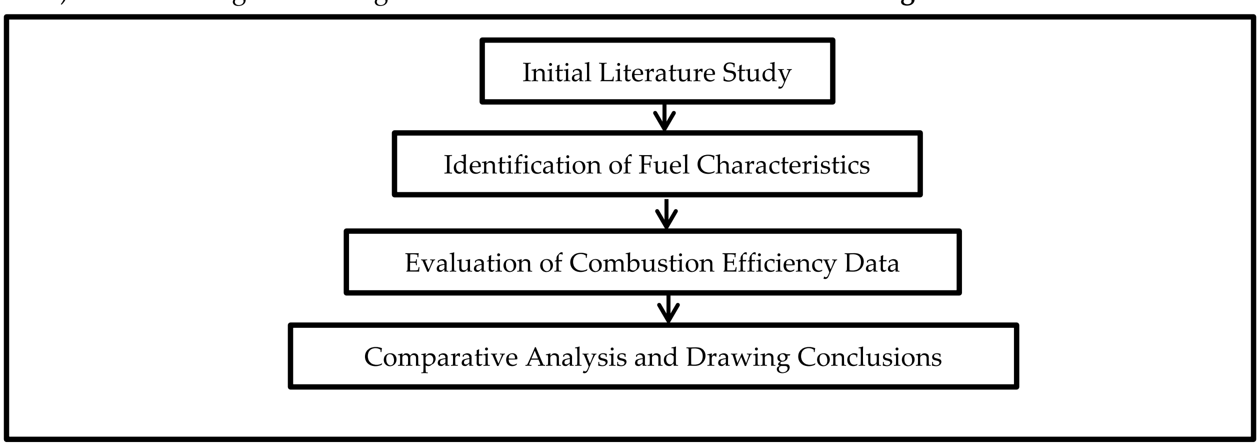

Figure 1. Research Stages

The research phase began with an initial literature study, which included collecting and analyzing literature related to co-firing technology, characteristics of lignite and anthracite coal, and various types of biomass that have been used in previous studies. The next stage is fuel identification, which is carried out by assessing the physical and chemical characteristics of coal and biomass-based on available data. This analysis includes important parameters such as heating value, ash content, volatility and combustion reactivity. Next, the combustion efficiency data was evaluated by comparing the combustion efficiency results of various types of coal and biomass through a review of previous research data, including an analysis of the factors that affect combustion efficiency. The last stage is a comparative analysis and conclusion drawing, which is carried out by analyzing the combination of coal and biomass to determine the pair that produces the highest combustion efficiency. The results of this analysis are then used to develop practical recommendations that can be applied to power plants to improve energy efficiency and reduce environmental impacts. Similar studies related to the combustion of mixtures between lignite coal and several biomasses are listed in **Table 1**.

Table 1. Similar Research on Combustion of Lignite Coal with Biomass

Research Name	Year	Research Results
Haykiri & Yaman	2009	Recommendations using the Co-firing Method Using Sunflower Seed Shells
Varol, et. al.	2010	Recommendations Using the Co-firing Method Using Wood Powder
Liu, et. al.	2023	Recommendation using the Co-firing Method Using Sawdust

Similar studies related to the combustion of anthracite coal blends with several biomasses are listed in **Table 2**.

Table 2. Similar Research on Combustion of Anthracite Coal with Biomass

Research Name	Year	Research Results
Li, et. al.	2011	Recommendation using the Co-firing Method Using Tobacco
Hao, et. al.	2018	Recommendation using the Co-firing Method Using Sawdust
Ye, et. al.	2022	Recommendations using the Co-firing Method Using Wheat Straw

RESULT

Co-firing technology has proven to be an effective solution to improve coal combustion efficiency, especially when combined with biomass. Based on previous studies, the combination of lignite and anthracite coal with various types of biomass shows mixed results in terms of combustion efficiency, depending on the nature of the fuels used. Lignite coal, which is a low rank coal with low carbon content and high moisture content, requires combustible additives such as biomass to improve combustion performance. On the other hand, anthracite coal, a high-rank coal with high carbon content but low volatility, faces challenges in achieving efficient combustion, thus requiring biomass to accelerate the oxidation reaction. The following types of lignite coal and several types of biomass used for blended combustion based on previous journals are listed in **Table 3**.

Table 3. Lignite Coal with Several Types of Biomass

Research Name	Type of Biomass	Blending Ratio (%) (Biomass:Coal)	Combustion Efficiency
Haykiri & Yaman	Sunflower Seed Shells	10:90	92%
Varol, et. al.	Wood Powder	75:25	88,1%
Liu, et. al.	Sawdust	30:70	90%

Based on research by H. Haykiri-Acma and S. Yaman in 2009, the highest combustion efficiency was achieved at 92% with a mixture composition of 10% sunflower seed shell biomass and 90% lignite coal.

This high efficiency is as result of its low ash content the biomass and the calorific value of the biomass which is close to the calorific value of lignite, thus creating an optimal synergy in the combustion process. Sunflower seed shell biomass also contains a high level of volatile matter content, which helps to accelerate the combustion process and enhance the burnout efficiency characteristics of lignite coal. In addition, using biomass in relatively small proportions can minimize operational risks, such as slagging or fouling.

Research conducted by M. Varol and colleagues in 2010 showed that the use of sawdust as biomass with a mixing ratio of 75% biomass and 25% lignite coal resulted in a combustion efficiency of 88.1%. This high biomass ratio indicates that sawdust, with its high volatile matter content and adequate fixed carbon, can support the combustion process effectively and improve overall combustion performance. Research conducted by Li Liu et al, in 2023 showed that the use of sawdust biomass with a mixture ratio of 30% biomass and 70% lignite coal resulted in a combustion efficiency of 90%. This result indicates that the use of biomass at a medium ratio can provide optimal combustion efficiency, making it suitable for practical applications in energy generation systems. Sawdust has a high volatile matter content, which contributes significantly to improving the reactivity of lignite combustion. This volatile content accelerates combustion at an early stage and improves the overall combustion characteristics. In addition, the use of a more conservative biomass ratio, such as 30%, reduces operational risks such as slagging and fouling that are often associated with using larger proportions of biomass. With a combustion efficiency that almost matches that of the sunflower seed shell blend, this sawdust biomass blend offers an ideal balance between high efficiency and operational stability. This combination provides great potential for use on an industrial scale, especially in cofiring-based combustion systems. Meanwhile, the efficiency of anthracite coal can be seen in **Table 4** below.

Table 4. Anthracite Coal with Several Types of Biomass

Research Name	Type of Biomass	Blending Ratio (%) (Biomass:Coal)	Combustion Efficiency
Li, et. al.	Tobacco	90:10	78%
Hao, et. al.	Sawdust	50:50	85,5%
Ye, et. al.	Wheat Straw	60:40	60%

Research conducted by X. G. Li et al. in 2011 showed that blending anthracite coal with biomass from tobacco waste resulted in a combustion efficiency of 78% with a blending ratio of 90% biomass and 10% coal. Although this efficiency is relatively lower than blending low-grade coal with biomass, this result reflects the challenges faced in co-firing anthracite coal which has a high carbon content, is harder to burn, and requires higher combustion temperatures. Tobacco biomass, although it has a high volatile content and can help initiate combustion, does not fully compensate for the less reactive nature of anthracite. However, this study still highlights the environmental benefits of using tobacco biomass, such as the reduction of organic waste and the potential reduction of net carbon emissions. This study shows that although the combustion efficiency in this combination is not optimal, co-firing anthracite with biomass still offers opportunities for fuel diversification and improved energy sustainability, especially if further optimization of the mixture composition and combustion operating conditions is carried out.

Research conducted by Runlong Hao et al. in 2018 using sawdust in co-firing blends with coal showed that a blending ratio of 50% biomass and 50% anthracite coal resulted in a combustion efficiency of 85.5% which is the highest efficiency among other results in this table. Sawdust, which has a high volatile and fixed carbon content, provides a significant synergistic effect with anthracite coal. This mixture shows that a balanced ratio of biomass to coal can maximize anthracite combustion by reducing ignition temperature and increasing burnout speed. This ratio also provides optimal combustion stability, making it an ideal choice for combustion systems designed for high efficiency.

Research conducted by Lian Ye et al. in 2022 showed that blending anthracite coal with wheat straw biomass resulted in a combustion efficiency of 60% at a blending ratio of 60% biomass and 40% coal. Although this is lower than the efficiency of blending biomass with lower-grade coals such as lignite, the result reflects the combustion challenges of anthracite which is less reactive due to its high carbon content and low volatile content. Wheat straw biomass, with its relatively high volatile content and low ash content, plays an important role in supporting the combustion initiation process and providing initial heat to accelerate anthracite combustion. However, the lightweight structure of wheat straw and its lower heating value compared to other biomasses limit its contribution to the overall thermal efficiency. The efficiency achieved is also affected by the difficulty of anthracite to achieve complete combustion under certain blend conditions, which require high temperatures and longer combustion times. Nonetheless, this study highlights the potential for efficiency improvement through the optimization of mixture proportions and control of operating conditions, so this combination remains an opportunity to be utilized in co-firing technologies with the goal of energy sustainability.

Overall, combustion efficiency is influenced by fuel properties, blend composition, and the thermal characteristics of the biomass used. The combination of lignite with biomass demonstrates greater potential than anthracite due to the more reactive nature of lignite. However, with further optimization, the co-firing of anthracite and biomass can be enhanced, especially for energy applications requiring high efficiency and reduced environmental impact. This co-firing technology represents a strategic step in the sustainable energy transition, leveraging existing resources while reducing dependence on pure fossil fuels.

CONCLUSION

Based on the analysis of the combustion efficiency of lignite and anthracite coal in co-firing technology with biomass, in conclusion the combustion efficiency is influenced by the characteristics of the fuel and biomass used. Lignite coal demonstrates higher combustion efficiency than anthracite when combined with biomass, with the highest efficiency reaching 92% when using sunflower seed shell biomass. In contrast, anthracite coal achieves a maximum combustion efficiency of 85.5% when combined with sawdust biomass. This difference is attributed to the less reactive nature of anthracite, which requires higher temperatures for complete combustion. Overall, co-firing technology is effective in enhancing combustion efficiency and utilizing biomass as an alternative fuel. However, its success largely is influenced by the proper selection of biomass and the optimization of operating conditions. A carefully designed strategy for co-firing can be an effective solution to enhance energy efficiency, lower greenhouse gas emissions, and support energy sustainability.

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