Utilization of Additives in Torrefied Rice Husk for High-Calorific Coal Co-Firing

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Indonesia remains heavily dependent on coal for electricity generation, resulting in rising greenhouse gas emissions and severe air pollution. Biomass co-firing has been identified as a promising strategy to reduce coal consumption, with rice husk offering significant potential due to its abundance and relatively high calorific value compared to other agricultural residues. However, its energy performance is still below that of coal, requiring further improvement. Two main approaches have been applied to enhance biomass quality, namely pretreatment and additive addition. Pretreatments such as pyrolysis and gasification often face technical and economic challenges, whereas torrefaction is more advantageous because it increases heating value and reduces moisture under moderate conditions with minimal emissions. In parallel, additives such as crude glycerol, sunflower oil, and waste cooking oil have been shown to enhance the calorific value and combustion properties of biomass pellets. Previous studies, however, indicate that neither pretreatment nor additives alone have achieved substantial improvements. Therefore, this study proposes a combined approach, employing torrefaction together with selected additives to optimize rice husk fuel properties. The integration of these methods offers a practical pathway to improve biomass quality, support coal substitution in co-firing systems, and contribute to Indonesia's transition toward renewable and sustainable energy.

Keywords: Coal, co-firing, rise husk, torrefaction, additives

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Indonesia's reliance on non-renewable energy remains high, with electricity, transportation, and industrial activities still dominated by fossil fuels. The power sector, in particular, depends heavily on coal, which accounted for about 50% of the national energy mix in 2022 (Energy Institute Statistical Review of World Energy, 2023). Coal's share continues to rise, growing at 1.9% annually over the past decade [1], and coal-fired power plants are the largest sources of air pollution, emitting CO_2, particulate matter, NO_x, SO_2, CH_4, VOCs, and hazardous pollutants like mercury and arsenic [2, 3]. Indonesia's CO_2 emissions from coal combustion rose from 40.6 million tons in 2018 to a projected 116 million tons in 2023 (ESDM). This highlights the urgent need to reduce coal dependence.

One widely adopted solution is biomass co-firing, the simultaneous combustion of coal and biomass, which reduces greenhouse gas emissions by utilizing carbon-neutral biomass [4–7]. Among biomass resources, rice husk is especially promising due to its abundance [7, 8]. With rice production reaching 33.7 million tons in 2021, rice husk waste amounted to about 6.1 million tons annually [9], higher than corn cob waste (1.7 Mt) but lower than sugarcane bagasse (13.3 Mt) [10, 11]. Rice husk also offers a relatively high heating value of 4,163 cal/g, exceeding corn stalks, rice straw, and peanut shells, though still below coal at 6,398 cal/g [12, 13].

To enhance biomass heating value, pretreatment and additive methods have been explored. Pretreatments such as pyrolysis, gasification, and hydrothermal processing often face drawbacks including high cost, emissions, or technical limitations [14]. Torrefaction is more promising, as it improves calorific value and reduces moisture at relatively low temperatures with minimal emissions [15]. Additives also show positive results: crude glycerol increased the heating value of tea-waste pellets from 3,750 to 3,905 cal/g [16, 17], sunflower oil raised sawdust pellets from 4,275 to 4,873 cal/g at 12 wt% [17], and tapioca binder boosted sugarcane bagasse from 2,846 to 5,565 cal/g [18, 19]. Although both pretreatment and additives improve calorific value, neither alone has produced significant increases. Therefore, this study applies a combined approach, using torrefaction with selected additives to optimize biomass properties for coal co-firing.

EXPERIMENTAL

This research referenced articles from leading international journals, including Science Direct, SpringerLink, JSTOR, and the Scopus database.

The search for the journals was conducted using various relevant keywords, consisting of renewable energy, coal, biomass, heating value biomass, co-firing, torrefaction, gasification, pyrolysis, and others biomass processing methods.

RESULTS AND DISCUSSION

The addition of waste cooking oil (WCO) to biomass pellets has been investigated as a means of improving their energy and combustion properties. The findings clearly indicate that WCO, when applied at levels between 2 and 12 percent of the pellet weight, results in a remarkable increase in calorific value. At the maximum inclusion level of 12 percent, the calorific value rises by about 12 to 16 percent compared to untreated pellets. This substantial improvement is attributed to the higher carbon and hydrogen content of the oil, which translates directly into better energy density. Beyond the increase in calorific value, another significant advantage of WCO addition is the reduction in ash content. Pellets treated with the highest proportion of oil exhibited ash reductions ranging from 16 to 38 percent, which is particularly beneficial for combustion efficiency. Lower ash means that the combustion equipment requires less frequent cleaning, and it reduces the risks associated with ash melting and slagging inside boilers. Importantly, the addition of WCO did not compromise pellet durability. This suggests that pellets remain mechanically robust during handling, transport, and storage. The dual effect of higher energy value and reduced ash, achieved without sacrificing mechanical strength, positions WCO as a highly effective additive for biomass fuels [20].

The influence of sunflower oil residues as an additive mirrors many of the benefits observed with waste cooking oil, given that both materials are chemically similar in nature. When sunflower oil waste was applied through spraying during pellet preparation, the calorific value also increased substantially, particularly at higher dosages. In the case of a 12 percent addition, the increase in heating value reached up to 16 percent, which is consistent with the results obtained from WCO trials. The ash content showed a notable decrease as well, averaging between 16 and 38 percent reductions at the highest treatment levels. This improvement in ash content plays an essential role in both environmental and operational aspects, since it contributes to cleaner combustion and reduces the release of unwanted particulate emissions. Moreover, the concentration of carbon and hydrogen increased by approximately 7 to 12 percent and 7 to 10 percent, respectively, which further explains the improvement in calorific value. One of the most striking findings is that pellet durability remained unaffected even with the incorporation of sunflower oil. High durability is critical for maintaining pellet integrity throughout the supply chain, and the stability of this property underlines the practical applicability of sunflower oil as an additive. Considering the large volume of sunflower oil waste generated by the food industry, its conversion into a value-added enhancer for bioenergy production presents both economic and environmental advantages [20, 21].

The use of crude glycerol as an additive represents a slightly different approach, since glycerol is a by-product of biodiesel production rather than a waste oil from food processing. Nevertheless, its application in pellet production provides a compelling solution to two issues, namely improving biofuel quality and addressing the disposal problem of surplus glycerol in the biodiesel industry. Studies have demonstrated that incorporating crude glycerol at levels around 7.5 percent by weight with sawdust yields pellets of high quality. These pellets exhibited a drop test resistance close to 90 percent, which, although slightly lower than that of untreated sawdust pellets, is still within acceptable ranges for commercial use. The moisture content remained steady at about 10 percent, and the ash content was low at around 0.75 percent, though slightly higher than that of pure sawdust pellets. Interestingly, the net calorific value of the pellets did not change significantly with glycerol addition, showing only a marginal variation of less than 1 percent [22]. Even though the direct impact on energy density was limited, the mechanical benefits and the sustainable reuse of biodiesel by-products underscore the significance of crude glycerol as an additive.

Other research provides further insight into the effects of crude glycerol. For example, studies using tea dregs as the base biomass found that the addition of crude glycerol up to 10 percent substantially improved pellet durability, reaching values as high as 98 percent. At this level of addition, the pellets achieved a calorific value of 16.38 MJ/kg, with moisture content maintained at 8.1 percent and ash content recorded at 6.08 percent. These values comply with the Indonesian National Standard (SNI 8675:2018) for biomass pellets, which confirms their suitability for practical applications in renewable energy systems [23]. Furthermore, pyrolysis experiments conducted on pellets with glycerol contents ranging from 20 to 40 percent revealed interesting energy dynamics. While pellets with higher glycerol levels produced less liquid phase and more gaseous products, the heating value of the gas remained stable at around 14 MJ/kg regardless of glycerol content. This consistency suggests that glycerol-containing pellets can be effectively converted into gaseous fuels through pyrolysis, thereby broadening their applicability beyond direct combustion [24].

When comparing the three additives, certain distinctions become clear. Waste cooking oil and sunflower oil both function primarily by increasing the calorific value of biomass and decreasing ash levels, thereby enhancing combustion efficiency and reducing maintenance requirements for energy systems. Their effect on carbon and hydrogen enrichment within the pellet composition is particularly significant for boosting the energy content of the fuel. In contrast, crude glycerol exerts its strongest impact on the mechanical and durability aspects of pellets, while contributing only modestly to calorific value improvements. Nevertheless, crude glycerol offers an additional dimension of utility through its compatibility with thermochemical conversion processes such as pyrolysis, enabling the generation of gaseous fuels with reliable energy content. Taken together, these findings demonstrate that while the three additives operate through different mechanisms, they collectively expand the potential for optimizing biomass fuels both in terms of energy performance and sustainability.

Beyond their direct influence on pellet properties, the integration of waste cooking oil, sunflower oil, and crude glycerol into biomass fuel systems also carries broader implications for sustainability and circular economy practices. Each additive represents a waste stream that would otherwise pose environmental disposal challenges, such as the pollution risks of discarded cooking oil or the surplus accumulation of crude glycerol in biodiesel industries. By redirecting these residues into bioenergy applications, not only is the value of biomass enhanced, but waste management burdens are simultaneously reduced. This dual advantage illustrates the potential of additive assisted biomass utilization as a form of industrial symbiosis, where one sector's by product becomes another's resource. Furthermore, the choice of additive can be strategically matched to local availability, with waste cooking oil and sunflower oil being more prevalent in food-producing regions, while crude glycerol aligns with biodiesel producing areas. Such adaptability strengthens the feasibility of large scale adoption. From a policy and economic perspective, incorporating these additives could reduce reliance on imported fuels, lower greenhouse gas emissions, and promote compliance with renewable energy targets. Future studies should therefore investigate the techno-economic performance of additive enriched pellets at pilot and industrial scales, including combustion trials in existing co-firing systems. A comprehensive understanding of long-term ash behavior, emission profiles, and lifecycle impacts will be essential for establishing the role of additive enhanced biomass as a reliable contributor to the clean energy transition.

CONCLUSION

Indonesia's continued dependence on coal has driven rapid growth in greenhouse gas emissions, highlighting the urgent need for alternative energy sources. Biomass co-firing offers a viable option, particularly with rice husk, which is abundantly available and has a relatively good calorific value. However, its energy performance remains lower than coal, requiring treatments to enhance fuel quality. Torrefaction offers technical and environmental advantages by improving heating value and reducing moisture under moderate conditions, while additives such as crude glycerol, sunflower oil, and waste cooking oil have been proven to further improve calorific value and combustion efficiency. However, neither approach alone has delivered significant improvements. By combining torrefaction with carefully selected additives, it is possible to optimize biomass properties and increase its competitiveness as a substitute for coal in co-firing applications. This integrated strategy not only supports the reduction of coal dependency in Indonesia but also contributes to sustainable waste utilization and the advancement of renewable energy development.

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