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Case Report

Comparative analysis of HHV and LHV values of biocoke fuel from palm oil mill solid waste

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ABSTRACT

This research aims to investigate and compare the energy value of different biocoke and raw palm oil-biomass. Applying pressure and heating simultaneously during biocoke production is a direct method used in this research. The results of the proximate analysis showed that the water content in each sample tested was below 10%. The water content can be reduced to 5% for all samples except oil palm-midrib. The highest raw biomass heating value was recorded from palm-kernel-shell at 16.83 MJ/kg; the lowest oil palm-midrib was 14.60%. Meanwhile, the highest lower heating value was recorded from biocoke at 19.08 MJ/kg, and the weakest empty-fruit-bunches 17.01 MJ/kg.

1. Introduction

The ever-growing global demand for sustainable and environmentally responsible energy sources has driven the exploration of alternative fuels derived from renewable resources. Among these resources, biomass waste presents a compelling prospect due to its abundance and potential to reduce the environmental impact of conventional energy production. Biomass waste encompasses a wide range of organic materials, including agricultural residues, forestry byproducts, and municipal solid waste, all of which can be converted into valuable energy sources. One such conversion method is the production of biocoke, a carbon-rich fuel obtained through pyrolysis and carbonization processes applied to biomass waste. Renewable energy sources, especially in Indonesia, are relatively abundant, as reported in previous publications [1–7]. One of the great energy sources currently is biomass waste left over from processing palm oil mills [8–13]. All solid waste left over from palm oil mill processing can be converted into energy. Biomass waste conversion technology into energy has been widely introduced and reported in several publications [14–18]. Solid waste left over from palm oil mill production has a high energy value and is almost equivalent to the calorific value of coal. Proximate, ultimate, and lignocellulosic analyses of corncob agricultural residue biomass waste have also been investigated [19]. The research results reported that the carbon value of corncob-based biocoke fuel reached 45.56%. The heating and pressure processes applied during biocoke production can reduce the water content significantly. This biocoke fuel based on biomass waste has a high calorific value.

A solid-liquid separation method for wastewater to detect adsorption and Pb-II ions in highly porous composites (PCM) has been reported by Ref. [20]. Mesoporous conjugate materials embedded with functional ligands allowed for the development a colourimetry approach that was both sensitive and selective in detecting and removing copper Cu-II ions from polluted water samples [21]. Selective and sensitive detection in removing Hg-II mercury from contaminated solutions using mesoporous

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silica-based optical nanocomposite materials has also been reported [22]. An evaluation system has been studied through the removal and detection of Ni-II ions regarding the initial Ni-II concentration, solution pH, detection limit, reaction time, and metal ions simultaneously [23]. Extraction by determining traces of palladium II in wastewater using a silica-based mesoporous adsorbent can be processed using a simple, sensitive method [24]. Sensitive detection of Pb-II ions can be carried out using a one-step method without using sophisticated instruments, as reported by Ref. [25]. Selectively, arsenic (V) (As(V)) in contaminated water can be removed with ligand-retaining inorganics, especially for composite materials with high surface area [26]. Increasing levels of Cd-II ions in natural water harm human health, ecosystems and the environment, as reported by Ref. [27]. Co-II ions can be removed quickly via the composite adsorbent (CpAD) method as newly designed in research [28].

A fuel's calorific value, or energy content, is a fundamental parameter determining its usefulness in various applications, from power generation to industrial processes and residential heating. Understanding the calorific value of biocoke and comparing it with other biomass waste materials is essential to evaluate its potential as an efficient energy source. This comparison can provide information in decision-making regarding selecting appropriate biomass feedstock materials and processing techniques for specific energy needs. Investigation of the calorific value of oil palm empty fruit bunches (EFB) through hydrothermal carbonization (HTC) with initial absolute pressures of 0.1 MPa, 1.3 MPa, and 3.1 MPa has been carried out by Ref. [29]. Where the maximum heating value from several experiments reached 23.6 MJ/kg. Production of pellet fuel based on EFB biomass waste produces the highest calorific value of 17.393 MJ/kg with a water content of 9.581% and a durability index of 99.93% [30]. The calorific value of palm oil shells (PKS) has been investigated using gasification techniques [31]. The results of the investigations showed that the highest calorific value reached 22.22 MJ/kg. Different studies report that the calorific value of PKS-based briquette fuel surpasses 18.72 MJ/kg, which is higher than the calorific value of other biomass [32].

Meanwhile, the calorific value of PKS pellets carried out via torrefaction was the highest at 20.68 MJ/kg [33]. Several previous research results show that the calorific value of palm oil mill waste is almost equivalent to coal, making it very suitable to be used as raw material for solid fuel production. Apart from that, the availability of palm oil mill waste is very promising and sustainable.

This work aims to investigate the calorific value of biocoke fuel on different palm oil mill solid wastes. The results of this analysis can be used as an illustration and reference as well as to determine the amount of energy contained in each sample so that the availability of biocoke fuel production is more guaranteed. Biomass waste from palm oil mill processing has a relatively high energy value if produced into biocoke. In addition, making biocoke fuel from palm oil mill processing has a high potential to reduce greenhouse gas emissions and environmental pollution. The production of biocoke fuel from palm oil mill biomass waste carried out in research can replace conventional fuel because its energy content is equivalent to coal. Apart from that, it can increase the economic value of society through involvement in both the sample-making process and during production. The results of biocoke production can be applied in small, large and household-scale industries, especially for heating.

2. Methods and materials

2.1. Sample collection and preparation

Biomass samples for biocoke fuel production in this work were collected directly from palm oil mills in Aceh Province. Collection of samples such as empty palm fruit bunches (EFB) and palm kernel shells (PKS) obtained from processing waste from palm oil mills. Meanwhile, oil palm fronds (OPM) and palm fibre (OPF) are accepted at harvest time. Meanwhile, oil palm stems (OPT) are produced during rejuvenation or cutting. The complete process of collecting, drying, chopping, and grinding samples is presented in Fig. 1. The collected samples are dried first to reduce the water content. Next, the EFB, OPM, and OPT samples were cut, shrunk, and dried again, making it easier for further processing. After all samples have dried, they are ground using a flouring machine to reach a size of <500 μm.

2.2. Process production of biocoke

Production of biocoke based on palm oil waste can be carried out after the sample is ready to be ground to a size of <500 μm. The ground samples were weighed at 2 g for each sample. Then, the sample is inserted into a mould prepared previously. After the sample is inserted into the mould, it is pressed to 22 MPa and heated to 190 °C for ±4.5 minutes. Next, the sample is cooled before being released from the mould and stored for analysis. Illustration of biocoke production from the start until the biocoke sample is obtained, as shown in the schematic diagram in Fig. 2.

The process of inputting the sample into the mould for each used is done using the same process. First, the sample is inserted and pressed until it reaches a pressure of 22 MPa. Next, heating is provided up to 190 °C, read digitally via a thermocouple. The heater wrapped in the mould is first set to a constant temperature. If the heater has reached 190 °C, it will automatically stay on and not exceed the predetermined temperature. After arriving at 190 °C, wait for ±4.5 minutes, remove the heater, and cool it to room temperature. The biocoke production procedure using palm oil biomass as raw material is presented in Fig. 3.

2.3. Laboratory analyses

Proximate analysis was carried out to determine the water content, volatile matter, fixed carbon, and ash content of biomass waste materials and biocoke samples using ASTM D5142 Standard. The final analysis involves determining the elemental composition of the sample, including carbon (C), hydrogen (H), nitrogen (N), sulfur (S), and oxygen (O) contents. Each sample's gross heating value (GCV) was determined using bomb calorimetry. Calorific value analysis was carried out using a TGA701 Thermogravimetric Analyzer for each sample used in this research.

3. Results and discussion

The experiments carried out in this work specifically investigated the comparison of the higher heating value (HHV) of five types of biomass waste from palm oil mill processing and post-harvest waste. This HHV investigation aims to determine the potential energy produced from each waste. Utilizing residual waste from processing palm oil mills into energy has automatically reduced waste that has the potential to become air pollution and damage human health. Using waste for energy is one of the proper steps to reduce greenhouse gas emissions and help the government reduce dependence on conventional fuels. The availability of biomass waste that can be processed into energy is currently quite promising for a long time. The availability of energy sources from biomass has been widely reported in several previous publications [34–36]. This research first carried out a proximate and ultimate analysis to see the chemical properties contained in raw biomass. Proximate and ultimate analysis results recorded from raw biomass are stored to compare values during biocoke analysis.

Based on the results of the analysis, it can be reported that the water content in raw biomass shows a significant decrease when the temperature increases. The largest decrease in water content was recorded in OPT and EFB biomass, namely 22.51% and 22.71%, respectively, from 100% water content before heating, when the heater reached 907 °C. The decrease in water recorded from OPM biomass reached 25.29% and PKS 25.65%. Meanwhile, the highest reduction in water content was

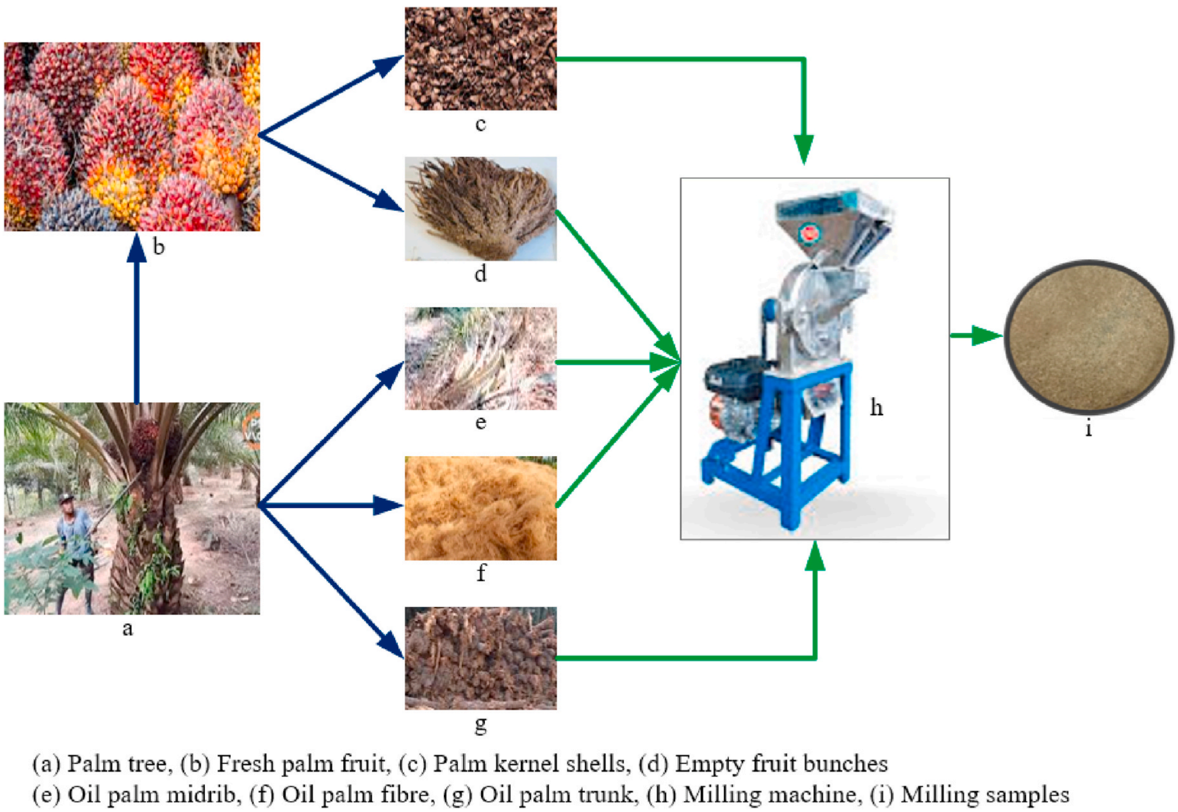

Fig. 1. Sample for biomass palm oil.

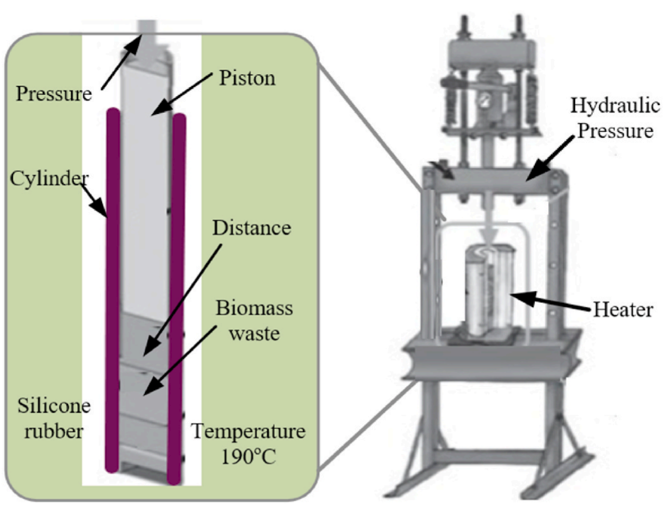

Fig. 2. Schematic diagram to process biocoke.

recorded from OPF biomass of 32.45% with the same heating level, namely 907 °C. When the maximum temperature reaches 951 °C, the water content in EFB biomass is only 19.46%, OPT 20.57%, OPM 23.16%, and PKS 24.08%. Simultaneous heating with pressure applied to produce biocoke fuel can reduce the water content, thereby increasing the calorific value.

Meanwhile, the working method for producing biocoke fuel is explained in Figs. 2 and 3. The biocoke fuel production in this research does not require additional materials and only requires appropriate heating and pressure. A simple method with a low detection rate of 0.26 μg/L has also been carried out [37]. However, the technique was used to investigate the effect of a pH solution on Hg-II adsorption via conjugate

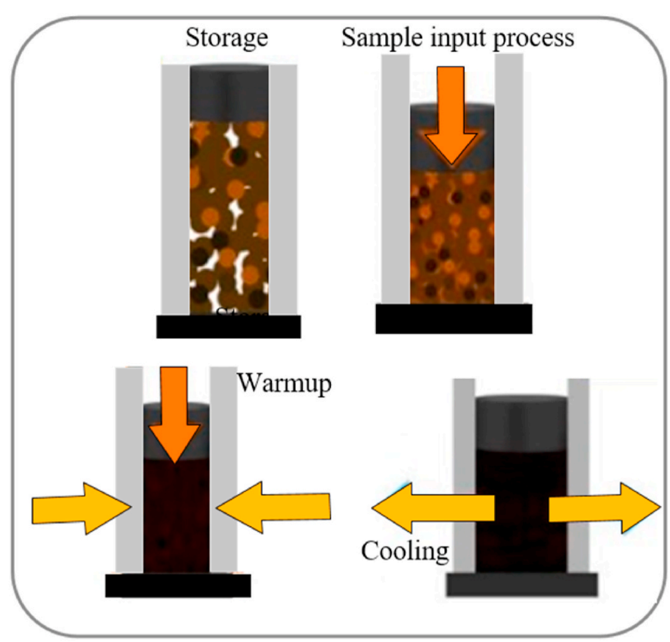

Fig. 3. Procedure of production biocoke.

nanomaterial (CNM). At the same time, a lower detection of 0.21 μg/L was allowed only for Pb-II ions in water bodies [38,39].

Meanwhile, when the temperature reaches 951 °C, the water content in OPF biomass leaves a water content of 29.75%. The decrease in water content in each biomass tested continued to decrease until the end of the experiment. The biomass's water content had reached below 10% at the experiment's back, as presented in Fig. 4.

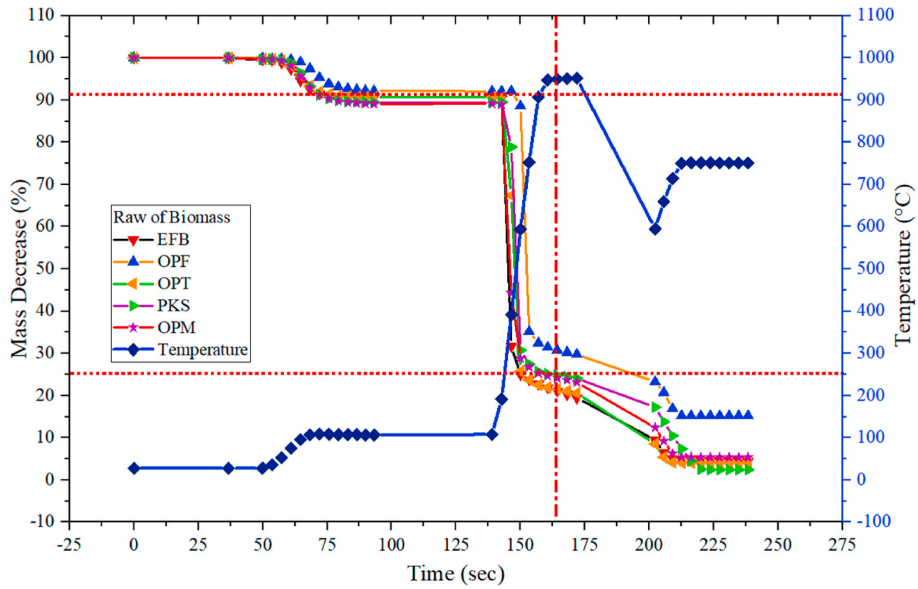

Fig. 4. Comparison of mass decrease for different biomass types.

The decrease in water content in biomass is due to the heating provided so that the water content evaporates and increases the amount of energy. The reduction in water content is followed by an increase in volatile matter for each biomass waste. The tool used in the research for analyzing water content is the Thermogravimetric Analyzer (TGA). Other chemical properties besides the water content analyzed include volatile matter (VM), fixed carbon (FC), and Ash. Meanwhile, the results of carbon, hydrogen, nitrogen, and oxygen are analyzed using the ASTM D5373 method, known as ultimate analysis.

Furthermore, this research analyzed the chemical properties of biocoke samples produced from palm oil biomass waste. The biocoke production process uses a direct method: constant heating and pressure. The biocoke production time requires ±10 minutes with detailed heating time during the production process of 4.5 minutes and 5.5 minutes to lower the temperature to room temperature. After reaching room temperature, the biocoke is removed from the mould and cooled further before being analyzed through proximate and ultimate. The treatment of all samples used remains the same to make the analysis more measurable. Next, the TGA analysis is carried out like when analyzing raw biocoke. It can be said that the water content in biocoke is still visible, but it is no longer as much as when it was raw. The highest reduction in biocoke water when the temperature reached 907 °C was recorded from biocoke-OPT at 24.33% from 100% when initially added. Meanwhile, the decrease in water content obtained from biocoke-PKS was 27.93%, biocoke-EFB 28.26%, and biocoke OPM 28.98%. Meanwhile, the highest remaining water content was recorded from biocoke-OPF at 36.03%.

When the temperature reached a maximum of 952 °C, the overall water content in the biocoke decreased but was not significant. The respective decrease in water content is biocoke-OPT 22.38%, biocoke-EFB 22.62%, biocoke-PKS 26.05%, biocoke-OPM 26.90%, and biocoke-OPF 34.01% as shown in Fig. 5. The low decrease in water content in biocoke is due to It has evaporated first during biocoke production. Hence, the water content in biocoke is not the same as raw biomass.

The results of the proximate and ultimate analysis tested in this study

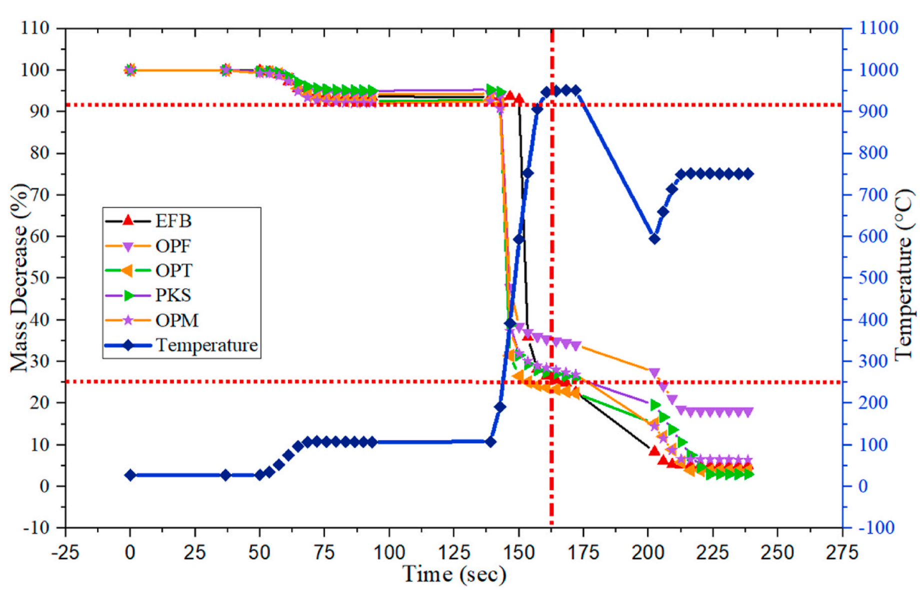

Fig. 5. Comparison of mass decrease for different biocoke.

using samples of palm oil mill biomass waste show that the ash content is lower than several biomass wastes reported in research [40]. The highest ash content in this study was recorded from OPM at 5.39%, and the lowest at 2.46% was recorded at PKS. However, the ash content obtained from White pine (WP) and Pinus sylvestris (PS) biomass [40] is lower than that recorded in this study. Meanwhile, the volatile matter (VM) content obtained from this study was also higher overall than the VM reported in the study [40]. The highest VM content was recorded from EFB at 71.20% and the lowest from PKS at 65.42%, as shown in Table 1.

Meanwhile, the highest VM content recorded in research [40] was 24.24%. Meanwhile, this study's fixed carbon content (FC) is much lower than the results obtained from Ref. [40]. Meanwhile, the results of the analysis of the adsorption properties of nanomaterials have excellent properties, especially for sensitivity and selectivity [41]. This is due to the presence of O and N atoms on the surface to create more intensive interactions. In different studies, it is clear that detection for adsorption and recovery of ytterbium Yb-III can provide significantly better colour [42]. Investigations regarding the adsorption of Cs ions onto mesoporous adsorbents from solution were carried out through experiments [43]. The experimental results showed that the mesoporous adsorbent was 107.16 mg/g higher than the crown ether-anchored adsorbent. However, the several references described above generally investigate heavy metals. Meanwhile, our research specifically investigated the calorific value of biocoke fuel from different biomass waste products from palm oil mill processing.

The results of the ultimate analysis carried out in this research show that the biomass of PKS is slightly higher than the others. A higher carbon content indicates more energy that can be utilized. However, overall, the samples tested have exceeded 40%, higher than several other biomass wastes such as firewood and corn cobs. The nitrogen content obtained from palm biomass waste is also minimal, below 1%, meaning it has met the required standard of 3% [44]. Meanwhile, the oxygen content in biomass waste is higher overall than in the research results [40]. The lowest oxygen content was obtained from OPM 45.51% and the highest OPT 48.78%, as shown in Table 1. Meanwhile, the highest increase in oxygen recorded in research [40] was recorded from Ginkgo biloba (GB) biomass at 15.87%.

The proximate analysis using raw biomass showed that PKS produced a higher HHV of 16.83 MJ/kg and LHV of 16.14 MJ/kg. Meanwhile, the LHV of biocoke-PKS reached 19.08, increasing significantly compared to the LHV in raw biomass. The overall energy value contained in biocoke has increased significantly compared to raw biomass. This means that biocoke has a high energy potential and is almost the same as coal. LHV biocoke-EFB reached 17.70 MJ/kg compared to raw biomass of 15.29 MJ/kg, as presented in Table 2.

The results of lignin and cellulose analysis can also determine the energy value contained in biomass. The results of the analysis carried out in the study showed that the cellulose and lignin content was also high compared to the study reported by Ref. [45]. A higher cellulose content indicates that the biomass is slightly more flammable. However, on the other hand, if the lignin content is higher than cellulose, it will burn a little longer. Based on the results of the analysis, OPT and OPM biomass produced 61.93% and 51.57% cellulose, respectively. Meanwhile, the lignin content of OPT and OPM is 30.90% and 36.57%, respectively, as shown in Table 3. Based on the analysis carried out in this research, it can be concluded that palm oil biomass-based biocoke has promising energy potential in the future and can be considered as one of the alternative energies to replace fossils.

Table 2
HHV analysis for raw biomass and biocoke production.

Sample	HHV		LHV			LHV Biocoke	HHV Biocoke
	MJ/kg	Kcal/kg	KJ/kg	MJ/kg	Kcal/kg	MJ/kg	MJ/kg
OPF	15.97	3.817	15.292	15.29	3.655	17.70	23.85
EFB	15.38	3.676	14.675	14.68	3.508	17.01	26.57
PKS	16.83	4.023	16.138	16.14	3.857	19.08	25.71
OPT	14.60	3.490	13.925	13.93	3.328	17.56	24.50
OPM	16.44	3.929	15.703	15.70	3.753	17.50	22.65

4. Prospects for biocoke fuel in the future

Palm oil biomass-based biocoke fuel has the potential to be a promising renewable energy source in the future. Here are some of the prospects and considerations.

✓ The palm oil industry produces large amounts of biomass waste, including empty fruit bunches, palm kernel shells, palm fibre, palm midrib, and palm trunks. These materials can be used as raw materials for biocoke production, making them a readily available resource.
✓Palm oil biomass is renewable and can be produced sustainably when managed responsibly. Utilizing it for biocoke production can reduce the environmental impact of palm oil production.

✓ Biocoke produced from palm oil biomass can potentially reduce greenhouse gas emissions compared to traditional coke made from fossil fuels. This can contribute to climate change mitigation efforts.
✓Biocoke fuel can enhance energy independence for countries that rely on palm oil production. It reduces the need for imported fossil fuels and can be a valuable domestic energy source.

✓ Biocoke can be used in various applications, such as in the steel industry, where it can replace traditional coke made from coal. It can also be used in other industrial processes, including cement and power generation.

✓ Biomass conversion technologies, such as heating and pressure, have improved the efficiency and energy density of biomass-based fuels like biocoke, making them more economically viable.

Table 3
Lignin and cellulose analysis.

Sample	Lignin (%)	Cellulosa (%)	Hemicelulosa (%)
OPF	43.62	42.62	13.76
EFB	53.18	37.34	9.48
PKS	47.90	45.69	6.41
OPT	30.90	61.93	7.17
OPM	36.11	51.57	12.32

Table 1
Proximate and ultimate analysis.

Sample	Proximate Analisis				Ultimate			
	Moisture	Volatile	Fixed Carbon	Ash	Carbon	Hydrogen	Nitrogen	Oxygen
OPF	9.15	68.43	18.42	4.00	45.66	6.15	0.46	46.27
EFB	9.34	71.20	14.76	4.70	43.70	6.37	0.06	47.69
PKS	10.50	65.42	21.62	2.46	47.90	6.13	0.55	45.55
OPT	9.31	70.12	16.43	4.14	43.25	6.08	0.30	48.78
OPM	10.92	65.92	17.77	5.39	44.97	6.54	0.09	45.51

✓ The sustainable production of palm oil biomass for biocoke can receive certifications like RSPO (Roundtable on Sustainable Palm Oil) to ensure responsible and environmentally friendly sourcing.

However, there are also challenges and considerations to be aware of.

✓ Expanding palm oil plantations can have negative environmental and social consequences, including deforestation, habitat destruction, and displacement of indigenous communities. Careful management and land-use planning are essential to mitigate these issues.
✓ There may be competition between food production, biodiversity conservation, and bioenergy production from palm oil biomass. Balancing these competing interests is crucial.
✓ While advancements have been made, the energy efficiency of biomass conversion processes can still be a limiting factor, affecting the economic viability of biocoke.
✓ The success of palm oil biomass-based biocoke depends on the market demand for renewable alternatives to traditional coke. It also depends on the regulatory environment and incentives in place to promote sustainable bioenergy.
✓ Palm oil production has faced criticism for labour and social issues. Responsible and ethical practices must be implemented to address these concerns in the biocoke supply chain.

5. Conclusion

The experiments in this research are specifically for producing biocoke fuel using biomass waste left over from palm oil mill processing. Simultaneous heating and pressure are applied for biocoke production. The temperature and pressure for biocoke production for different samples are the same, namely 190 °C and 22 MPa. Overall, the samples tested showed increased calorific value compared to raw biomass. Biocoke fuel with OPT biomass waste offers the highest cellulose value of 61.93% compared to PKS 45.69%. The lowest LHV was recorded in the EFB biocoke sample of 17.01 MJ/kg, and the highest HHV was recorded in the EFB biocoke sample of 26.57 MJ/kg. This study's biocoke fuel sample produced for calorific value analysis was 12 mm. The simultaneous heating and pressure adopted in this study differs from briquette production because it does not use adhesives. The density of biocoke is also higher than charcoal briquettes.

CRediT authorship contribution statement

Asri Gani: Conceptualization, Funding acquisition, Methodology, Validation. **Erdiwansyah:** Data curation, Formal analysis, Investigation, Methodology, Resources, Writing – original draft, Data curation, Formal analysis, Investigation, Methodology, Resources, Writing – original draft. **Hera Desvita:** Data curation, Formal analysis, Software, Visualization. **Edi Munawar:** Conceptualization, Investigation, Validation. **Rizalman Mamat:** Validation, Visualization, Writing – review & editing. **Muhammad Nizar:** Data curation, Investigation, Validation. **Yeggi Darnas:** Conceptualization, Formal analysis, Validation. **Ratna Eko Sarjono:** Validation, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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