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The Effect of Lignin and Cellulose on Combustion Characteristics of Biocoke

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ABSTRACT

This study investigates the effect of two significant components of biomass, lignin, and cellulose, on the combustion characteristics of biocoke. Lignin, a complex polymer, and cellulose, a polysaccharide, are widely present in biomass and contribute to its structural integrity. The method used to produce biocoke fuel uses a heating and pressing process. Biomass samples include empty fruit bunches, oil palm fibre, rice husks, mangroves, and sugarcane bagasse. The proximate analysis results showed that the highest water content was recorded in palm oil shells. The ash content recorded from rice husks was 15.21% higher than another biomass. The highest energy value was obtained from palm oil shells at 23.53%. Meanwhile, the empty oil palm fruit bunch biomass sample produced the highest lignin content of 59.43%. However, the cellulose content of empty fruit bunches is lower than that of oil palm fibre (37.34% compared to 42.62%). Overall, the heating and pressing methods used for biocoke production can increase the energy content in biocoke. Thus, biocoke fuel has the potential to be an alternative energy source to replace fossil fuels.

1. Introduction

The global search for sustainable and environmentally friendly energy sources has increased interest in biomass-derived fuels. Among these alternatives, solid biocoke fuel produced via a direct method without carbonation has emerged as a promising candidate due to its renewable nature and potential reduction in environmental impact. Biocoke has the potential to replace conventional fossil fuels in various applications, from industrial processes to power generation, thereby contributing to a more sustainable and environmentally friendly energy landscape. Renewable energy sources that

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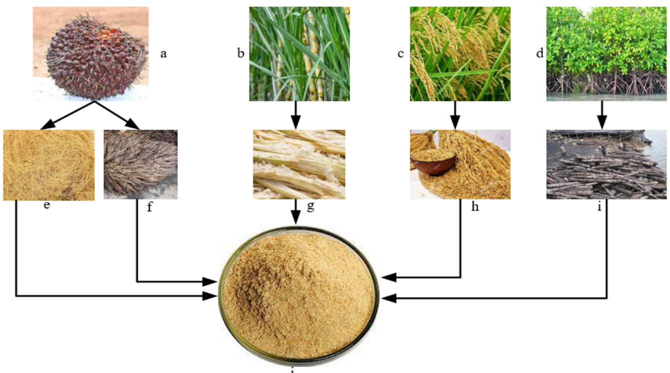
can be converted into energy have been widely reported in several previous publications [1-7]. In recent years, the Indonesian government has also promoted the use of renewable energy through several policies [8-12]. Technology for renewable energy applications has also begun to be considered in line with the demand for renewable energy sources as a substitute for fossil fuels [13-18]. Energy efficiency plays a vital role so that the environmental impact can be minimized.

The combustion characteristics of solid fuels play an important role in determining their efficiency, energy yield and impact on the environment [19-22]. In this context, understanding how specific components of biomass feedstocks, such as lignin and cellulose, influence the combustion behaviour of biocoke is of critical importance [23-28]. Lignin and cellulose are two essential elements of biomass materials, each having different chemical properties and roles in the carbonization process. Lignin, a complex aromatic polymer, provides structural integrity to plants and has been linked to the ignition performance of solid fuels. On the other hand, cellulose is a polysaccharide responsible for storing energy in plants and is known to influence the rate of combustion and heat release during combustion [29-33]. Investigations into biomass-based biocoke fuel have become a concern among researchers currently.

Despite the growing interest in biocoke as an alternative fuel source, there remains a substantial gap in our understanding of how the relative proportions of lignin and cellulose in biomass feedstock affect the combustion characteristics of the resulting biocoke. While previous studies have investigated the combustion behaviour of biocoke, few have delved into the nuanced influence of lignin and cellulose content. This research seeks to bridge this gap by systematically examining the effect of lignin and cellulose on the combustion properties of biocoke. The primary objective of this study is to elucidate the relationship between the lignin-to-cellulose ratio in biomass feedstock and critical combustion characteristics of biocoke, including ignition temperature, burn rate, and calorific value. By comprehensively analysing these properties, we aim to provide valuable insights that can inform the production and utilization of biocoke as a sustainable energy source.

2. Methodology

The samples used for lignin and cellulose analysis in this research were empty oil palm fruit bunches (EFB), oil palm fibre (OPF), rice husks, sugar cane bagasse and mangrove biomass waste. EFB and OPF biomass waste is collected directly from palm oil mills in North Aceh, Aceh Province. Meanwhile, bagasse waste is collected from rubbish dumps. Rice husk waste is obtained from rice mills, and mangroves are collected from dry riverbanks. The type of biomass waste that has been collected is then dried and ground before being processed and analysed. The process and steps for sample collection through to drying and grinding are presented in Figure 1.



(a) Fresh palm fruit, (b) Sugar cane, (c) Rice plants, (d) Mangrove, (e) Oil palm fibre, (f) Empty fruit bunches, (g) Bagasse, (h) Rice fruit, (i) Dried mangroves, and (j) Sample after grinding.

Fig. 1. Type of biomass waste

The collected biomass waste is cut into small pieces to facilitate drying. Next, the dried samples were ground through a milling machine until they reached <500 microns. Then, each sample was weighed 5-10 grams for proximate and ultimate analysis. Next, the samples were weighed at 2 grams for each example of biocoke fuel production. Biocoke production in the research used a hydraulic press and moulds using iron pipes with a diameter of 12 mm x 12 mm. The sample that has been weighed weighing 2 grams is put into a mould and pressed to 22 MPa. When the pressure reaches 22 MPa, a heater is provided and controlled with a thermocouple. Heating during production is carried out for ± 4.5 minutes with a cooling time before being removed from the mould of around 5-10 minutes so that the biocoke produced is thoroughly cooked. The hydraulic press machine and mould for biocoke fuel production are shown in Figure 2.

(a) hydraulic press, (b) pipes and heaters, (c) thermocouple

Fig. 2. Hydraulic press and biocoke mould

3. Results

The high lignin in biocoke fuel can increase the calorific value of the fuel. This is because the amount of lignin in the fuel will produce a high calorific value. Thus, biocoke fuel with a high lignin content can produce more energy per unit mass. Apart from that, high lignin can also increase the thermal stability of biocoke fuel. This means the fuel will be more resistant to extreme temperature changes and could remain intact in high-speed combustion. Biocoke fuel with high lignin can produce more gas during the combustion process, affecting combustion efficiency and exhaust emissions. The high lignin in biocoke fuel can increase the dimensional stability of the fuel. This can make it more resistant to physical changes in shape during storage or transportation. The results of the analysis of lignin, cellulose, and hemicellulose from the different samples used in the study are presented in Table 1.

Table 1
Analysis of Lignin, Cellulose, and Hemicellulose of Biomass

Sample	Lignin (%)	Cellulose (%)	Hemicellulose (%)
EFB	53.18	37.34	9.49
OPF	43.62	42.62	13.76
Sugarcane	42.44	49.19	8.37
Rice Husk	28.49	47.14	24.37
Mangrove	33.01	47.14	24.37

The proximate analysis results showed that the highest water content was recorded in oil palm fibre (OPF) samples. Meanwhile, the water content in the rice husk samples showed results that were lower than the other samples, as presented in Table 2. The water content recorded in the study was lower than the coffee shell and hemp wood chip samples, as reported by [34,35]. The highest ash content recorded based on the proximate analysis results was recorded from rice husk samples at 15.21%. Meanwhile, the ash content recorded from other samples was much lower than rice husk. The ash content recorded in the samples used in the study was generally lower than the biomass waste results of coffee shells and hemp wood chips in the study [34], except for rice husks. The bound carbon content recorded from the OPF sample was the highest compared to other samples. Meanwhile, the volatile matter (VM) content for all samples analysed in the study showed that more than 60% of the compounds could burn into gas. The thermogravimetric analysis graph of the biomass waste tested in this study is shown in Figure 3.

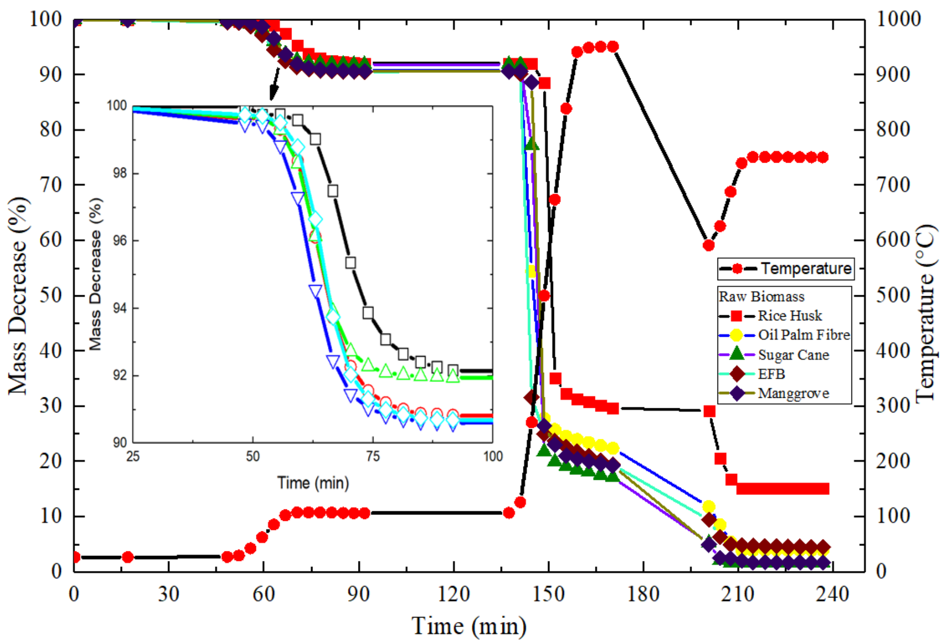


Fig. 3. Thermogravimetry Analysis from Different Biomass

Based on the results of the ultimate analysis carried out in this research, it can be reported that the highest carbon content was recorded in EFB at 53.18%, and the lowest was recorded in rice husks at 28.49%. However, when compared, the carbon content recorded in coffee husk shells and flax wood chips was higher recorded in this study for all samples. The carbon content in the fuel is due to the higher lignin and cellulose content, as presented in Table 2. The nitrogen content in the fuel used should not exceed 3%, as reported by [36]. The nitrogen content obtained from this study's samples was below 1%. Thus, the quality of the biomass samples used for biocoke production meets the energy quality required to produce low pollution.

Table 2
Proximate and ultimate analysis of different biomass wastes

Sample	Proximate Analysis (%)				Ultimate Analysis (%)			
	Moisture Content	Volatile Matter	Fixed Carbon	Ash	Carbon	Hydrogen	Nitrogen	Oxygen
EFB	9.34	71.20	14.76	4.70	43.70	6.37	0.06	47.69
OPF	10.50	65.42	21.62	2.46	47.90	6.13	0.55	45.55
Sugarcane Bagasse	8.01	74.83	15.43	1.73	45.28	6.41	0.00	49.19
Rice Husk	7.84	62.89	14.06	15.21	38.80	5.90	0.70	41.63
Mangrove	9.29	71.42	17.47	1.82	45.69	6.30	0.00	48.79
Coffee leather shell [34]	23.35	58.77	13.06	4.83	34.22	6.46	1.93	NA
Hemp wood chips [34]	11,49	42.22	13.06	37.73	23.64	4.20	1.80	NA

Calorific value is a critical indication in biomass samples as raw material for fuel production. The high calorific value of fuel will affect the quality of the energy produced. A comparison of energy values in raw samples and after fuel production is presented in Table 3. Production of biocoke fuel using heating and pressing methods can significantly increase the calorific value for all samples used. Biocoke fuel from OPF produces higher energy than other samples. However, overall, the energy produced increases compared to raw biomass. Based on the results of the analysis carried out in the research, biomass waste has a high potential to be used as a source of energy to replace fossils.

Table 3 is the result of a comparison of the calorific value of biomass raw materials with biocoke fuel. The results obtained from the analysis using the Bomb Calorimeter recorded energy from biocoke increased significantly compared to raw biomass. This shows that the method used in this research, namely heating, and pressing, is very appropriate for improving the energy content in biocoke. These results also show that biomass waste has the potential to be an alternative to fossil fuels and is sustainable.

Table 3
Comparison of HHV and LHV on different biomass

Sample	Raw Biomass		Biocoke	
	HHV (MJ/kg)	LHV (MJ/kg)	HHV (MJ/kg)	LHV (MJ/kg)
EFB	15.38	14.68	19.75	16.57
OPF	16.83	16.14	23.53	19.08
Sugarcane Bagasse	15.69	15.00	18.07	17.66
Rice Husk	14.13	13.49	17.53	15.74
Mangrove	15.75	15.05	20.05	17.87

4. Conclusions

This research aims explicitly to analyse biomass samples' physical and chemical properties as raw materials for biocoke production. The analysis results show that this biomass is worthy of being used as an alternative energy because it has a calorific value almost equivalent to coal. The results of the overall proximate and ultimate analysis of the samples used in the study were higher than coffee shell shells and hemp wood chips. The heating and pressing method for biocoke production applied in this study can significantly increase the calorific value for all samples. The highest calorific value was recorded in OPF biocoke fuel at 23.53%. The increased energy value produced is due to the high amount of lignin in the biomass sample. The lignin content in EFB was the highest at 53.18% compared to OPF. However, OPF has a higher cellulose content, so its energy value is higher.

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