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Production of bio-coal based on empty fruit bunches by torrefaction method with fixed bed and tubular continuous reactors

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Abstract
Excessive use of fossil energy has negative impacts, which can cause climate change and environmental degradation. Thus, there is a need to find alternative, more sustainable energy sources. Biomass derived from Empty Fruit Bunch (EFB) waste is a newfound renewable energy source. However, its utilization is not optimal due to its low heating value and high chlorine (Cl) and potassium (K) content, which can interfere with combustion. EFB is washed with peat water to reduce potassium and chlorine content, and the torefaction process is used for combustion. This research aims to develop bio-coal production from empty fruit bunches using the torefaction method using fixed beds and continuous tubular reactors. The production process development also aims to obtain a larger production capacity than previous studies. This study uses varying weights of EFB produced into bio-coal, namely 250, 500 and 1000 grams, with a torefaction process temperature of 200°C for 30 minutes. As a result, the peat water flow rate decreased K, Cl and K_2O content to the lowest content reduction value, which amounted to 8.31%, 0.42% and 3.96%, respectively. The heating value of bio-coal produced in a fixed bed reactor is 26,166 kJ/kg, while in a continuous tubular reactor, it is 21,720 kJ/kg. Based on these results, the fixed bed reactor shows a higher heating value than the continuous tubular reactor. The heating value obtained from these two types of reactors is comparable to sub-bituminous coal, which is usually used in steam power plants.

Keywords:
Bio-coal;
Empty Fruit Bunches;
Heating Value;
New renewable energy;
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INTRODUCTION

Fossil energy, which consists of coal, oil, and natural gas, has been a key driver of industrial progress and economic growth for centuries. However, the overuse of fossil energy has led to severe environmental and resource problems. Fossil energy utilization is currently heavily dependent on the industrial, transportation and domestic sectors worldwide [1]. Population increase and rapid economic growth have resulted in increased energy demand, further accelerating the exploitation of fossil resources [2]. However, the utilization of fossil energy leads to the emission of greenhouse gases, such as carbon dioxide (CO_2), which is caused by the increasing concentration of CO_2 in the atmosphere due to increased combustion of oil, gas, and coal, thus leading to global warming. To overcome humanity's dependence on fossil fuels, the search for energy sources other than fossil fuels, commonly known as alternative or renewable energy, must continue [3].

Renewable energy comes from constantly available sources and will never run out, as it can be replenished relatively quickly. Examples include hydro, geothermal, solar power, wind power, marine energy and biomass [4].

Biomass is a renewable energy source that can produce environmentally friendly energy without causing adverse impacts on the environment. It refers to organic materials derived from living organisms or creatures, such as plants, animals, and microorganisms. Biomass includes non-fossil organic matter from plants, animals, microorganisms, and waste [5].

Indonesia's biomass potential is abundant and spread across the country. Biomass, as a new renewable energy source with unique characteristics, is expected to reduce dependence on fossil energy. The potential of biomass in Indonesia is shown in Table 1. The largest potential biomass resource in Indonesia is palm oil, with a capacity of 12,794 MW and empty fruit bunches (EFB), one waste product of the palm oil industry. The Bioenergy Directorate reports that the biomass potential of EFB is 828 MW [6]. EFB is solid waste from processing palm oil, which produces 21% CPO (crude palm oil) and 22.5% EFB from processing 1 ton of EFB [7].

Based on this data, many empty fruit bunches produced from palm oil mills become biomass waste. During this time, EFB is either left to rot or directly used as fuel. Empty fruit bunches have been used as fuel in boilers. Still, their utilization has not been optimized due to their low heating value and high chlorine (Cl) and potassium contents (K), which can interfere with the combustion process [8]. During combustion in furnaces and superheaters, potassium converts into potassium oxide (K_2O). The remaining potassium oxide ash from combustion can adhere to the walls, reducing the boiler's efficiency [9]. The use of various types of biomass as boiler fuel poses risks of contamination and damage to boiler heating equipment, including slagging, fouling, corrosion, agglomeration, and sintering [10].

The chlorine present in EFB-based bio-coal can induce corrosion in the boiler during combustion [11].

Table 1. Potential of Biomass in Indonesia [6]

No.	General Potential of Biomass	Unit	Total
1	Palm oil	MW	12,794
2	Sugarcane	MW	1,286
3	Rubber	MW	2,771
4	Coconut	MW	180
5	Paddy	MW	9,808
6	Corn	MW	1,735
7	Cassava	MW	269
8	Wood	MW	1,330
9	Cows and Buffalo (Manure)	MW	537
10	Municipal Waste (Organic)	MW	2,065
	Total Potential	MW	32,773

EFB is promising as an alternative fuel, but it has several constraints for use as a fuel. Therefore, with the obstacles and challenges outlined above, there is a need for a method to improve the quality of EFB as an environmentally friendly fuel alternative. Also, the prevention of boiler tube material degradation is necessary to minimize economic losses [12].

The washing process can reduce the potassium and chlorine content of EFBs, and it is relatively simpler and cheaper. Peat water is utilized to reduce the potassium and chlorine contents in EFB through washing. Peat water is acidic due to the presence of humic acid and fulvic acid [13]. As a result, peat water is effective in dissolving potassium and chlorine because humic acid has the ability to adsorb minerals [14], making it more efficient in dissolving these elements compared to regular water. Several studies have been carried out previously to reduce the potassium and chlorine content in EFB. The washing process with running water has been proven to reduce the potassium content in EFB by up to 50% [15]. The use of peat water in the washing process has been proven to reduce potassium (K) and potassium dioxide (K_2O) content in EFB with reduction results of up to 5% and 3.7%, respectively [16].

The torefaction method is used in the pretreatment of biomass to improve its quality and make it usable for a long time [17]. Torrefaction is a mild pyrolysis that usually the imposition temperature is around 200-300ºC. Temperature in the torrefaction process is important in increasing the energy content of the EFB. In this process, the carbon content remains high, while the volatile matter is lost, increasing the quality of the biomass [18]. The process produces a uniform solid product with reduced moisture content and higher energy content compared to raw biomass.

Bio-coal is a natural fuel processed through the combustion of dry waste materials. Bio-coal is a carbon-neutral fuel that can replace fossil coal in industrial processes. Several studies have been conducted previously to improve biomass quality by using the torrefaction method. Research is undertaken on optimizing palm shell torrefaction to produce solid bio-coal energy from palm kernel shells produced in a reactor. The bio-coal produced with a heating value of 24,500 kJ/kg was achieved at an optimum temperature of 300°C with a residence time of 20 minutes and a nitrogen gas flow rate of 300 mL/minute [19]. Another study used a continuous tubular-type reactor with torrefaction results of empty palm fruit bunches ranging from 16357.23 to 21083.98 kJ/kg. The highest heating value is at a temperature torrefaction of 275°C with a time of 30 minutes of

21083.98 kJ/kg [20]. Research related to bio-coal has also been carried out previously on empty oil palm fruit bunches weighing 100 grams, the torrefaction process using a fixed bed reactor at a temperature of 300°C for 30 minutes resulted in a heating value of 28742.17 kJ/kg [16], the highest heating value obtained was 31,256.95 kJ/kg in the torrefaction process for 60 minutes at a temperature of 300°C, with a residual mass of 31 grams [21]. Similar research was also carried out with a sample weight of 1000 grams at a torrefaction temperature of 200°C for 30 minutes, resulting in a heating value of 26162.55 kJ/kg [22].

This research aims to reduce the potassium and chlorine content in EFB using peat water and improve bio-coal production from empty fruit bunches using the torrefaction method with fixed beds and tubular continuous reactors. The development of the production process also aims to obtain a greater production capacity compared to the research that has been carried out previously.

MATERIAL AND METHODS

This research uses empty oil palm fruit bunches as the basic material for bio-coal production. Bio-coal production using the torefaction method uses a fixed bed type reactor and a tubular continuous type. EFB is washed with peat water to reduce potassium (K) and chlorine (Cl) content in EFB. EFB is then oven dried before entering the torefaction process. This study divided EFB's weight into bio-coal, namely 250, 500 and 1000 grams.

Washing Method

The washing process is carried out for 60 minutes by adjusting the water flow rate using a flowmeter. The peat water flow rate was varied by 10, 20, 30, and 40 liters per minute (lpm). During washing, the EFB is placed in a filter container so that the water can flow down. A schematic diagram of the EFB washing process is shown in Figure 1.

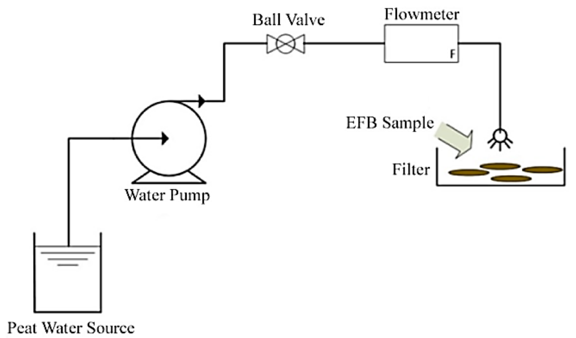

Figure 1. Schematic of the EFB Washing Process

Drying Method

The process of drying empty fruit bunches uses an electric oven at a temperature of 105°C and this procedure adheres to the ASTM D 2974-87 standards. This drying process aims to dry the EFB thoroughly. The oven should be checked for hot spots to avoid possible ignition of the sample [23]. The process of drying EFB in an oven is shown in Figure 2.

Torrefaction Method

The torrefaction process was carried out at a temperature of 200°C for 30 minutes. In the fixed type reactor, the EFB is inserted into the reactor which is heated using a band heater ceramic with a power of 1000 watts. The torrefaction scheme with a fixed bed reactor is shown in Figure 3.

The continuous tubular type reactor follows the same method as the fixed-bed reactor but with a higher power of 2500 watts. In a continuous tubular reactor, a sprocket mounted on a chain is driven by a motor and a screw conveyor connected to the sprocket. A reducer gear is used with a speed of 0.7 rpm during the torrefaction process to regulate the rotation speed. The torrefaction scheme with a continuous tubular reactor is shown in Figure 4.

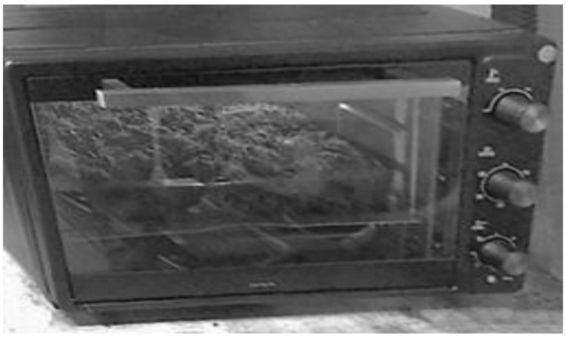

Figure 2. EFB Drying Process with an Oven

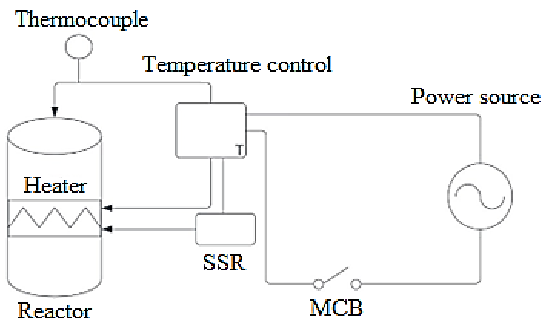

Figure 3. Schematic of Torrefaction with a Fixed Bed Reactor

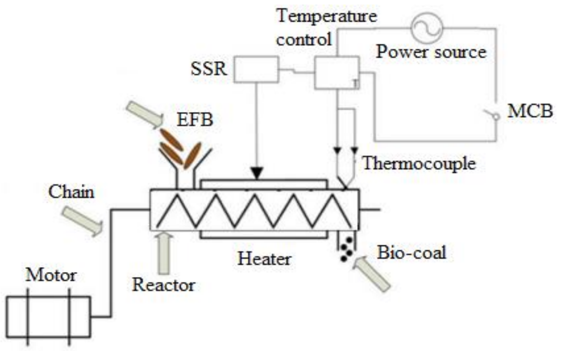

Figure 4. Schematic of Torrefaction with a Tubular Continuous Reactor

RESULTS AND DISCUSSION

In this study, peat water was utilized to lower the potassium, chlorine, and potassium oxide levels in EFB. The flow of peat water assists in dissolving the potassium and chlorine present in EFB. The reduction in potassium can result in a decrease in the potassium oxide concentrations in EFB bio-coal. To determine the levels of potassium, chlorine, and potassium oxide in bio-coal samples, X-ray fluorescence (XRF) testing was conducted. The XRF technique has proven to be efficient in detecting various chemical elements [24].

As shown in Figure 5, the contents of potassium (K), chlorine (Cl), and potassium oxide (K_2O) continued to decrease as the peat water flow rate increased from 10 to 40 lpm. The graph shown is an EFB sample weighing 250 grams, with results obtained with the smallest K, Cl and K_2O contents at a peat water flow rate of 40 lpm, namely 8.31%, 0.42% and 3.96%, respectively.

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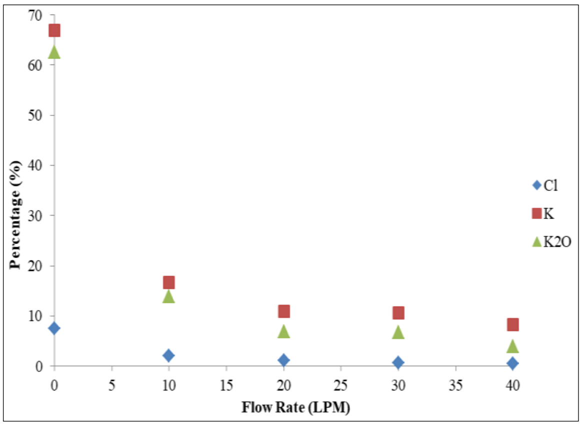

Figure 5. Potassium, Chlorine and Potassium Oxide Contents with Variation of Peat Water Flowrate

The graph shown is an EFB sample weighing 250 grams, with results obtained with the smallest K, Cl and K_2O contents at a peat water flow rate of 40 lpm, namely 8.31%, 0.42% and 3.96%, respectively.

The decrease in K, Cl, and K_2O content in EFB was caused by the increased flow rate of peat water, which dissolved most of the content and carried it away. In this study, the heating value of bio-coal from the torrefaction process is calculated using the equation from previous research [16]. The results of the heating value obtained from bio-coal production in a fixed bed reactor with varying peat water flow rates using a 250 gram EFB sample are shown in Table 2.

The increase in heating value with the torrefaction process is caused by the higher temperature of the torrefaction process, causing the carbon content to increase and the water content and content of volatile volatile substances to decrease. As shown in Table 2, the highest heating value of bio-coal was achieved at a flow rate of 40 lpm with an average value of 20.878 kJ/kg. The heating value of bio-coal also increases as the water flow rate increases, so it can be concluded that the washing process will remove the ash content in EFB, resulting in a high heating value of bio-coal [25].

A comparison of heating values in the torrefaction process between fixed bed type and continuous tubular type reactors is shown in Table 3. As in Table 3, bio-coal with a weight of 1,000 grams in a fixed bed reactor obtained the highest heating value of 26,166 kJ/kg.

Table 2. Heating Value of Bio-coal at a Mass of 250 g with a Fixed Bed Reactor

$\dot{V}$ (lpm)	Average Heating Value of *Bio-coal* (kJ/kg)
10	19,016
20	20,218
30	20,518
40	20,878

Table 3. Heating Value of Bio-coal with a Flowrate 20 lpm

Reactor Type	m_{raw} (g)	Average Heating Value of *Bio-coal* (kJ/kg)
Fixed Bed	250	20,218
	500	23,642
	1,000	26,166
Continuous Tubular	250	17,575
	500	21,480
	1,000	21,720

Previous research that has been done also uses a fixed bed reactor and torrefaction method, which obtained a heating value of 18,500 kJ/kg at 200°C [26], using corn cobs with a processing temperature of 280°C for 30 minutes.

The heating value obtained was 30,240 kJ/kg [27], and at a temperature of 300°C for 60 minutes, the heating value was 25,730 kJ/kg [8]. Furthermore, the continuous tubular reactor with a weight of 1,000 grams obtained an average heating value of 21,720 kJ/kg. Previous research using a continuous tubular-type reactor and the torrefaction method obtained a heating value of 20,760 kJ/kg at 275°C for 5 minutes and 24,115 kJ/kg at 300°C for 15 minutes [28].

Based on these results, the fixed bed reactor shows a higher heating value than the continuous tubular reactor. The heating value obtained from these two types of reactors is comparable to sub-bituminous coal which is commonly used in steam power plants, with heating values ranging from 19,300 to 26,700 kJ/kg.

CONCLUSION

Bio-coal produced by varying the peat water flow rate showed a decrease in K, Cl and K_2O content. Specifically, the 40 lpm water flow rate produced the lowest content reduction value compared to the other water flow rate variations, which amounted to 8.31%, 0.42% and 3.96%, respectively. The decrease in the K, Cl and K_2O content in bio-coal is caused by the ash content consisting of potassium and minerals that are dissolved and carried by the flowing water during the washing process. The decrease in potassium oxide (K_2O) content in EFB is also influenced by the reduction of potassium (K) content contained in EFB. The bio-coal produced using the fixed bed type reactor is superior to the continuous tubular type reactor in terms of heating value. The heating value produced using the fixed bed reactor is 26,166 kJ/kg, and for the continuous tubular reactor is 21,720 kJ/kg.

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