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Tapping Indonesia's bioenergy potential: Solid biofuel production from banana leaves by employing hydrothermal treatment

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Abstract

Agricultural and agro-industrial wastes are increasingly being used for the generation of fuel products. Banana residues has a potential to be used as biomass energy sources in tropical country due to its availability, fast growing characteristic of banana plant, carbon neutrality and the fact that each banana plant bears only one stem of fruit. Thermal conversion of biomass to higher energy density fuels is gaining a growing interest as it is sustainable and has a potential to reduce greenhouse gasses. However, many forms of biomass in the waste stream, including banana residues, have very high moisture content, which makes them both inefficient to store, transport, and process using conventional technology. The hydrothermal treatment (HT) is known for converting high moisture content solid wastes into dried, uniform, pulverized, coal-like solid fuel. In the present study, banana leaves was characterized and subjected to HT in a batch process to evaluate the suitability of these biomass sources for solid fuel production. Banana leaves was treated via HT at the temperatures of 180 and 200°C with the holding time of 30 min. The results showed that HT can increase the carbon and energy content of banana leaves, while the ash content decreased with the increased of temperature. The calculated value for theoretical potential power generation from treated banana leaves is 3.8 GW. These results showed that the production of solid fuel from banana leaves by employing hydrothermal treatment can contribute to the development of renewable energy, especially in Indonesia.

Keywords: banana leaves, solid fuel, hydrothermal treatment

1. Introduction

The global energy demand is rapidly increasing with increasing population and economic growth. Fossil fuel which remains as the dominant energy resource are closely linked to environmental degradation and predicted unable to cope with future energy requirements. As a response to the environmental concerns and fossil fuel depletion issue, renewable energy is increasingly gaining a growth interest. Biomass has become one of the most commonly used renewable sources of energy in the last two decades, second only to hydropower in the generation of electricity. Among the various sources of renewable energy, biomass is highly considered as it is carbon neutral, more evenly distributed than finite fossil-fuel energy, and may be developed using more environmentally friendly technologies.

Banana, one of the most ubiquitous fruits, is widely grown across the world. About 120–150 million tonnes of bananas are grown annually in the world, and it is the fourth most important food product in the world [1]. Indonesia, which is an agro-based country, has a tropical climate suitable for growing various horticultural crops including tropical fruits such as banana. Out of many kinds of Indonesia fruits banana gives the highest production.

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Banana occupies one-third of the national fruit production of which 80% of the total banana produced comes mainly from Java and Sumatera. In 2008, banana produced was more than 6,000,000 t and is targeted to reach 11,000,000 t in 2025 as indicated in the presidential statement in 2005 [2].

Banana production in Indonesia was mainly backyard, mixed cropping system, and some monoculture in small farms [2]. During the harvesting, the banana fruit only represents about 12 % of the weight of the plant and the stem, leaves, and other parts are not edible. For every ton of bananas harvested, approximately four tons of lignocellulosic waste are generated (three tons of pseudostem, 160 kg of stems, 480 kg of leaves and 440 kg of banana peels), and approximately 100 kg of fruit are rejected [3]. Therefore, efforts have been made to use banana leaves and stems for various nonfood applications.

In Indonesia, banana leaves are mostly utilized for wrapping food. However, this will eventually turn into waste after it has served its purpose. It is also used for composting, animal feed or handicraft material, but only in small amount. Production of fuel from banana residues could give an added value, contribute to the energy production, as well as deal with the environmental impact generally caused by its disposal. Banana plant has a potential to be used as biomass energy sources in tropical country due to its availability, fast growing characteristic, carbon neutrality and the fact that each banana plant bears only one stem of fruit [4]. Some researchers have demonstrated the potential of banana residues for energy generation and these studies are based on the production of biogas from the digestion process [5, 6], briquettes [7] and generation of ethanol from banana residues [8].

Banana residues, such as other biomass, have low bulk density caused difficulties in handling and logistics. The residues usually have high moisture content (around 80%) which leads to various problems during direct combustion process. Hard to ignite, unsteady and unstable combustion, incomplete combustion, and huge amount of gaseous pollutants are due to high moisture content [9]. High chlorine contents in biomass would cause corrosion problems whereas high alkaline metal, such as potassium (K), is responsible for slagging fouling problem in the heat transfer equipment. For several thermal conversion technologies, such as pyrolysis and gasification, a pre-drying process is necessary to improve the thermal efficiency, which would therefore significantly increase the operating cost [8]. Therefore, a suitable pretreatment is required to improve the fuel characteristics of the biomass.

The hydrothermal treatment (HT), a process to treat biomass in water/steam media at relatively lower temperature, is known for converting high moisture content solid wastes into dried, uniform, pulverized, coal-like solid fuel. HT offers significant advantages for biomass conversion, such as avoiding an energy-extensive drying process, high conversion efficiency and relatively low operation temperature among thermal methods [9]. Additionally, HT also can remove inorganics such as Ca, S, P, Mg, K Fe, and Mn from biomass [10]. Some works focusing on specific issue have been done to investigate the feasibility of solid fuel production from biomass waste by employing the HT. Investigation on the production fuels from various agriculture residues should be given a consideration as to not over depend on a single source. To date the research on HT of banana residues has not been conducting yet. Most studies focus on biological conversion (anaerobic digestion) instead. The aim of this work is to characterize banana plantation wastes through chemical, proximate, elemental, and caloric value. However, in this study the investigation was limited to banana leaves as a preliminary. Banana leaves was characterized and subjected to HT in a batch process to evaluate the suitability and the potential of this biomass source for solid fuel production, especially in tropical countries like Indonesia.

2. Experimental

The banana leaf samples (*Musa cavendish*) which were collected from a banana plantation in Philippine were received in dried milled condition from MSU-Iligan Institute of Technology (MSU-IIT), Phillipine.

HT was carried out in a lab scale facility, a 3L batch type autoclave reactor, at two temperatures of 180°C and 200°C. The temperature of the reactor was controlled using a PID controller. The reactor pressure was not controlled but indicated by the pressure gauge. For each run, the reactor was loaded with 25 g of the sample and distilled water in 1:10 biomass-water ratio under the atmospheric pressure. Air in the reactor was purged with nitrogen gas to give an inert atmosphere inside the reactor. The reactor was then heated by an electrical heater to achieve the target temperature and kept for the holding time of 30 min. After completed, the product was discharged from the reactor. The solid part was separated from the liquid by using the vacuum filtration, then oven dried at 105°C for 24 hr, and stored in a sealed bag before further experiment and analysis.

The determination of the CHN and ash of samples was performed using Vario Micro Cube Elemental Analyzer (Elementar, Germany). The ultimate correlation by Demirbas [11] was used to estimate the higher heating value (HHV) of the raw and treated samples. The correlation is given below:

$$\text{HHV} = 0.335 \text{ C} + 1.423 \text{ H} - 0.154 \text{ O} - 0.145 \text{ N} \quad 1)$$

(C, H, O, N in dry ash free basis)

The proximate analysis of the raw and the hydrochars was performed by SHIMADZU D50 simultaneous TGA/DTA analyzer based on ASTM D 3172.

3. Results and discussion

3.1. Effect of hydrothermal treatment on fuel properties

Results of ultimate analysis, proximate analysis and high heating value (HHV) are presented in Table 1. HT denotes for the hydrothermally treated sample followed by the treatment temperature. During hydrothermal treatment, some chemical reactions, such as dehydration, hydrolysis, and decarboxylation occurs which cause loss of some carbon, hydrogen and oxygen. The HT process increased the carbon content as the reaction temperature increased which is aligned with results reported by the previous researchers. Biomass losses relatively more oxygen and hydrogen compared to carbon during HT. Subsequently, the calorific value of the product increases with the increase of the HT temperature. The HT-200 solid product has a heating value which almost equal to low-grade sub-bituminous coal (approximately 20 MJ/kg). It indicates the possibility of using hydrothermally treated products as co-firing fuel with coal.

Table 1. Proximate, ultimate, and HHV analysis of raw and hydrochars of banana leaves

Elemental Analysis	Mass fraction (%), daf ^a		
	Raw	HT-180	HT-200
C	47.28	50.37	53.32

H	6.02	5.83	6.00
N	1.75	1.92	2.03
O	44.95	41.88	38.65
Proximate analysis		Mass fraction (%)	
Volatile Matter	75.1	82.7	80.2
Fixed Carbon	17.3	10.3	18.1
Ash	7.6	7	6.1
HHV [MJ/kg]	17.23	18.44	20.15

^adaf: dry and ash free

From Table 1, it can be seen that banana leave has an ash content of 7.6%, while after HT at 200°C it decreased to 6.1%. The result showed that HT process can reduce ash content in banana leave feedstock. It is one of the other advantages of hydrothermal treatment using water/steam media. Inorganic material either as loose dirt or loosely bonded in a biomass matrix is removed during this process leading to the decrease of the ash content. The decreasing of ash content also showed that inorganic removal is more dominant than the relative increase of ash percentage because of organic volatiles losses during hydrothermal treatment. The result of this study is in contrast to the results of other steam explosion process which observed an increasing ash trend [12]. It might be because in this study, 1:10 solid/water ratio is used compared to other study using steam only that enable the solubilisation of inorganics. The removal of ash can reduce the possibility or the severity of the slagging and fouling problem that arise when burning high ash biomasses.

Banana leaves like other lignocellulosic biomass typically has high volatile matter content, which is significantly different from coal. Table 1 showed that volatile matter presents in the hydrochar decreased as HT temperature increased. High volatiles content indicates easy ignition fuels. It was reported that the co-firing of biomass with low-rank coal can enhance the ignition behavior due to high volatile matter content of biomass [13]. However, design of the boiler should ensure that the volatile content undergoes complete combustion to improve efficiency and reduce incomplete combustion related emissions.

3.2 Potential energy generation from banana leaves in Indonesia

Currently, there are still no biomass power plants in Indonesia that utilize banana residue as their biomass feedstock. The potential of banana residue to be directly combusted for energy generation strictly depends on its calorific value. However, the problem lies in that the moisture content of banana residue is very high and this will lead to low energy efficiency. Therefore, HT can be used as a potential technology to convert high moisture biomass like banana residues into energy more efficiently.

To calculate the potential power generation from direct combustion of hydrothermally treated banana leaves in Indonesia, the residue of the banana was determined. For every ton of bananas harvested, approximately 480 kg of leaves are produced [3]. During hydrothermal treatment at 200°C, about 30% of mass is loss. Using these bases and an average energy content of 18.9 MJ/kg (dry basis), the energy potential for the hydrochars from banana leaves can be calculated. The potential power was calculated according to the report of Mazlina Hashim [14], where 1 PJ can be converted into 46 MW of electrical energy with 21% electrical conversion efficiency. Based on the banana

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production for the year 2008 [2], the energy potential of banana leaves hydrochars is 397 PJ or total potential power is 3.8 GW (energy for hydrochars production has not been incorporated). These come only from banana leaves, so if all banana residues are combined, the energy potential will be higher.

Despite the considerable amount of energy potential which comes from banana leaves, several factors should be considered. One of the important issues is to determine the amount of residue that is available for energy use. The calculation presented here is not considering the amount of residues that are used for other purposes such as food packaging, animal feed or agricultural purposes. Another issue is the collection of banana leaves from the plantation. Banana production in Indonesia was mainly in small farms. Therefore, a good system needs to be implemented so that most of the banana residues can be collected centrally and sent to the HT plant.

4. Conclusion

This research preliminarily investigated the effect of hydrothermal process on banana leaves especially on its composition and heating value in order to evaluate the products as alternative solid fuel. The increase of carbon and energy content of hydrochars compared with the raw biomass were observed. The HHV of HT-200 product is 20.15 MJ/kg which is almost equal to low-grade sub-bituminous coal. The results also show that the reaction temperature affects the fuel properties positively both in energy density as well as ash reduction. Based on calculated estimation of electricity generation from banana leaves, about 3.8 GW could be generated in Indonesia. These results showed the potential to produce solid fuel from banana leaves by employing hydrothermal treatment.

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