International Journal of Advances in Applied Sciences (IJAAS)
Vol. 12, No. 3, September 2023, pp. 250~256
ISSN: 2252-8814, DOI: 10.11591/ijaas.v12.i3.pp250-256

Experimental study of RDF-5 performance based on natural waste on fast pyrolysis process on the quality of the liquid smoke

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Article Info

Article history:

Received Nov 3, 2022
Revised Mar 4, 2023
Accepted Apr 12, 2023

Keywords:

Durian waste
Fast pyrolysis
Liquid smoke
Palm fiber waste
Refuse derived fuel-5

ABSTRACT

Energy problems are one of the cases faced by almost all countries in the world. No longer found oil reserves in significant quantities causing problems in the energy sector. The world's energy needs continue to increase and become a global problem in the use of energy in various sectors resulting in an energy crisis. The use of waste-to-energy (WtE) technology is appropriate, considering that energy needs continue to increase along with the increasing amount of waste that is not managed and hurts the ecosystem. Refuse-derived fuel (RDF) is a waste management technique that converts waste into bio-solid fuel. RDF is produced from the mechanical separation of combustible and non-combustible fractions from waste. Utilizing RDF biomass from durian peel and sugar palm is one of the efforts to maximize the pyrolysis process in organic waste, increasing the combustion potential. Processing durian skin and sugar palm waste into RDF will maximize the potential of the combustion results, which can later facilitate testing. This study also aims to utilize sugar palm waste and durian peel to have a use value as an alternative fuel. This research was an experimental study, fast pyrolysis was employed by using 300 grams both in durian and sugar palm, and the temperature was varied from 400, 500, and 600 °C. The results showed that the test of liquid smoke RDF-5 sugar palm at a temperature of 400 °C at 112 mL and RDF-5 durian at 600 °C at 137 mL.

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1. INTRODUCTION

Energy problems are one of the cases faced by almost all countries in the world. No longer found oil reserves in significant quantities causing problems in the energy sector. The world's energy needs continue to increase and become a global problem in the use of energy in various sectors resulting in an energy crisis [1]. Reduced non-renewable energy reserves can be seen from the growth in non-renewable energy consumption, which has increased yearly. Besides that, world oil consumption has increased by an average of 1.8% or 1.7 million barrels per day, natural gas by 3% or 96% billion $m^{3,}$ and coal by 1% or 25 million tons [2]. Non-renewable resources, such as oil and coal, still dominate energy needs in Indonesia. Oil reserves in Indonesia decreased by 0.74% in 2016, and natural gas by 5.04%. Oil reserves are estimated to run out in 9 years, and natural gas will run out in 42 years [3]. These days, the energy source of petroleum is still the primary energy source in its use, especially in the fields of electricity, industry, and transportation, even though fossil energy has several negative impacts, one of which is environmental pollution.

Alternative energy sources have been found in various research. Awasthi *et al*. [4] state that bioenergy from waste processing through waste-to-energy (WtE) technology can become a renewable energy base in the future that is economical and environmentally appropriate. The use of WtE technology is appropriate, considering that energy needs continue to increase along with the increasing amount of waste that is not managed and hurts the ecosystem. Solid waste dumps constitute a significant source of methane which is categorized as a greenhouse gas in the short term [5]. Waste management using WtE technology can help overcome the energy crisis and pollution caused by waste. Garbage left without processing can trigger various types of pollution, including water, soil, and air pollution. The waste of the transportation industry and household waste causes this pollution. In addition to waste, the decomposition process that occurs also emits odors that can be aesthetically disturbing. The biomass potential as a renewable energy source in Indonesia was 49.81 gigawatts (GW) [6]. Biomass can be used as new renewable energy by converting it into solid, liquid, and gas [7]–[13]. Processing of biomass into bio-oil is one of the processes of processing biomass into fuel through the pyrolysis process. Bio-oil is a liquid condensate resulting from the thermal conversion process, which is dark brown in color, thick, and resembles crude oil [14]. Pyrolysis is the best technology for processing biomass rather than direct combustion and gasification. Pyrolysis can produce three products at once at a fairly low temperature. During pyrolysis, biomass components are converted into light gas (volatile), liquid (bio-oil), and solid charcoal [11]. In the pyrolysis process, the biomass is fed into the reactor and then heated at a certain temperature and time without the addition of air. The yield and composition of the pyrolysis oil depend on the biomass composition and operating process parameters. However, pyrolysis using biomass directly produces less than optimal results, so it is necessary to make refused-derived fuel (RDF).

Sugar palm is one of the palm tribes. Palms are sugar palm plants that function, among other things, economic functions, and functions. Almost all parts of plants, from roots, stems, leaves, and fruits, have economic functions for various human purposes. Durian (*Durio zibethinus Murray*) is a tropical fruit native to Southeast Asia with many variations. Durian produced ±700 tons per year with uneven production throughout the year. Durian contains a lot of antioxidants and polyphenols, which have a higher ability than antioxidants in the form of vitamins. In contrast, durian has both types of antioxidants in the form of vitamin C and non-vitamins. In Thailand, durian cultivation is carried out intensively in the form of gardens, while in Indonesia, it is in the form of yards. The distribution of durian also extends to various countries, such as Myanmar, India, and Pakistan [15]. However, only 15-30% of durian fruit is edible. The rest is disposed of as waste which causes environmental problems if not disposed of properly, even though durian skin contains high volatile and carbon [16].

RDF is a waste management technique that converts waste into bio-solid fuel. RDF is produced from the mechanical separation of combustible and non-combustible fractions from waste. RDF is a material that is easy to burn and has a high calorific value from municipal solid waste (MSW) [11], [17]–[19]. Pyrolysis has several advantages over gasification and direct combustion, for example, lower reaction temperature, and combustion without oxygen, allowing not only the production of energy but also high-value-added products, such as char, biofuels, and gases [20]. The use of RDF-5 from durian waste and sugar palm waste as feed in the fast pyrolysis process requires the proper ratio. RDF-5 will be tested with a bomb calorimeter to determine its calorific value. Tests of moisture content, ash content, volatile content, fixed carbon, and calorific value will be tested at the integrated research and testing (LPPT) laboratory. The RDF-5, with the highest heating value, will be used in the pyrolysis process to compare the quality of its liquid smoke with non-RDF biomass. The results of the liquid smoke from the two samples were then tested for their chemical composition with gas chromatography-mass spectrometry (GCMS). In our previous experiment, we used durian as the biomass, compared the biomass as RDF and non-RDF [11], [12], and investigated biomass pyrolysis on connecting tube performance for liquid smoke production [18].

Utilizing RDF biomass from durian peel and sugar palm is one of the efforts to maximize the pyrolysis process in organic waste, increasing the combustion potential. In addition, processing durian skin and sugar palm waste into RDF will maximize the potential of the combustion results, which can later facilitate testing. This study also aims to utilize sugar palm waste and durian peel to have a use value as an alternative fuel.

2. EXPERIMENTAL APPARATUS

In this experiment, we used a fixed bed reactor with a pyrolysis furnace volume of 38.5 liters. This reactor also had a condenser with a finned pipe type with the opposite fluid direction. The pyrolysis reactor is shown in Figure 1. The temperature was measured using MAX 6675 with a K-type thermocouple connected with micro-controller Arduino Mega 2560 (Arduino, Turin, Italy) with two reference measurement points. In this experiment, we used 300 grams of waste, with variations in pyrolysis temperature, 400, 500, and 600 °C. After reaching the working temperature in each experiment, the temperature was held for 90 minutes. After reaching 90 minutes, the liquid smoke will come out of the outlet hole from the condenser. The liquid smoke product that comes out is then collected in a glass bottle, then the liquid smoke that has been collected is subjected to a distillation process at 90 °C to get pyrolysis oil. After obtaining pyrolysis oil in each variation, the pyrolysis oil was tested with GCMS (Trace 1310, Thermofiscer, Massachusetts, United States) in the integrated research and testing at Universitas Gadjah Mada (UGM) Yogyakarta. The natural waste for RDF production is shown in Figure 2 when Figure 2(a) shows durian skin waste and Figure 2(b) shows palm sugar waste. Furthermore, Figure 3 shows the RDF product made from durian skin as shown in Figure 3(a), and palm fiber waste as shown in Figure 3(b).

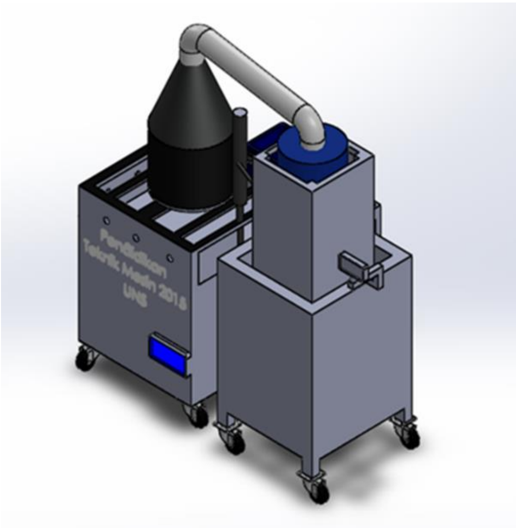

Figure 1. Fixed bed pyrolysis reactor

(a) (b)

Figure 2 The natural waste for RDF production (a) durian peel and (b) palm fiber waste

(a) (b)

Figure 3. The RDF product of natural waste (a) palm fiber and (b) durian peel waste RDF

3. RESULTS AND DISCUSSION

3.1. The comparison of performance RDF-5 durian waste and palm fiber waste

To get the incensement of liquid smoke product for each temperature variation, the liquid smoke was calculated every 5 minutes until the pyrolysis process was complete. Figures 4-6 show the quantity of liquid smoke product for each temperature variation. According to the result, the liquid smoke of durian waste continued to increase as the temperature increased from pyrolysis. However, the liquid smoke produced from palm fiber waste slightly decreased when the temperature of pyrolysis was increased. To analyze the volume increment of liquid smoke quantity as shown in Table 1, the volume can be calculated as (1).

$$\frac{\text{Final Volume}}{\text{Initial Volume}} \text{ x } 100\% = \qquad (1)$$

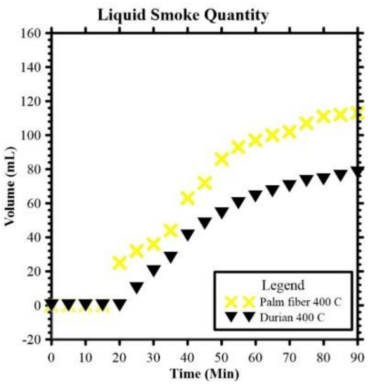

Figure 4. Liquid smoke quantity result for 400 °C

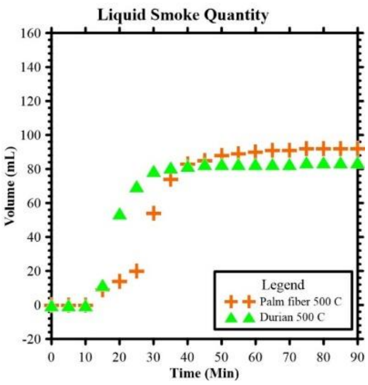

Figure 5. Liquid smoke quantity result for 500 °C

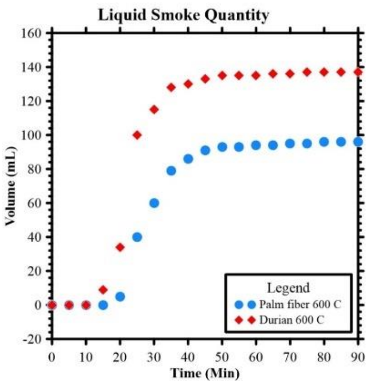

Figure 6. Liquid smoke quantity result for 600 °C

Table 1. Volume increment of the liquid smoke

Biomass	400-500 °C	500-600 °C	400-600 °C
Palm fiber waste	0.8141%	1.04%	0.849%
Durian waste	1.077%	1,63%	1.756%

3.2. Liquid smoke performance of pyrolysis product

To analyze the liquid smoke of pyrolysis, liquid smoke treatment is carried out in three stages i) Sedimentation process, sedimentation is carried out for a minimum of 24 hours. This treatment is carried out to reduce substances that are usually removed, especially tar. Tar in liquid form will turn into a solid so that it can be removed by precipitation at room temperature; ii) Filtration process, filtration using active zeolite weighing 8 grams for each liquid smoke is the primary filtrate that binds tar. The tar filtered in the active zeolite is the residual tar from the precipitation, which is still mixed with liquid smoke. Filtration using activated carbon weighing 8 grams for each liquid smoke is used as a support filtrate to reduce pungent odors and clear liquid smoke; and iii) Precipitation process, precipitation, and filtration will reduce the Benzo(a)pyrene levels in liquid smoke. These substances are included in polycyclic aromatic hydrocarbons (PAH) compounds which are carcinogenic and toxins that must be removed. Measuring the reduction of the initial volume by using the final volume of the treatment, the volume measurement is used as the shrinkage volume after the treatment. The comparison of post-pyrolysis process liquid smoke results is shown in Table 2. To analyze the shrinkage volume of liquid smoke as shown in Table 3, the volume can be calculated as (2).

$$\frac{Final\ Volume}{Initial\ Volume}\ x\ 100\% = \qquad (2)$$

Table 2. Comparison of post pyrolysis process liquid smoke results

Name	RDF Palm fiber waste			RDF Durian		
	400 °C mL	500 °C mL	600 °C mL	400 °C mL	500 °C mL	600 °C mL
Sedimentation	-	-	-	-	-	-
Final volume	113	92	96	78	84	137
Initial volume	109	87	92	76	81	133
Shrinkage	4	5	4	2	3	4
Zeolite filtration	-	-	-	-	-	-
Final volume	109	87	92	76	81	133
Initial volume	99	83	88	71	76	122
Shrinkage	10	4	4	5	5	11
Carbon filtration	-	-	-	-	-	-
Final volume	99	83	88	71	76	122
Initial volume	88	79	84	66	71	115
Shrinkage	7	6	4	5	5	7
Total shrinkage	24	17	14	12	13	22

Table 3. The volume shrinkage of liquid smoke

Name	RDF Palm Sugar			RDF Durian		
	400 °C	500 °C	600 °C	400 °C	500 °C	600 °C
Initial volume	113	92	96	78	84	137
Final volume	88	79	84	66	71	115
Results	1.28%	1.16%	1.14%	1.18%	1.18%	1.19%

3.3. Gas chromatography-mass spectrometry of liquid smoke

The grouping of readable and identified compounds can be seen in Figure 7. Compounds read 94.86% at a temperature of 400 °C. There are 44 compounds classified into 5 groups as many as 34, and 1 compound is not yet known. While the compound is not read, 5.12% identified 3 compounds as much as 1.43% as an acid group and a carbonyl group, 5 compounds as much as 3.69% were not identified. Compounds read 95.75% at a temperature of 600 °C. There are 37 compounds classified into 6 groups as many as 26, and 1 compound whose group is not yet known, while from compounds that are not read 4.25%, 2 compounds are identified as much as 0.33% as an acid group and an alcohol group. 8 compounds, as much as 3.92%, were not identified.

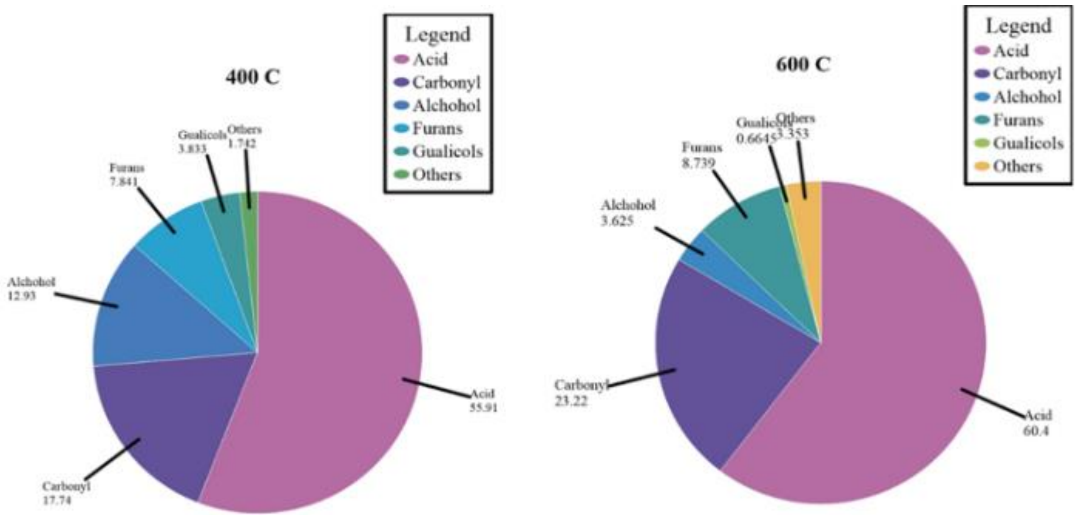

Figure 7. GCMS composition results on 400 dan 600 °C

4. CONCLUSION

The use of WtE technology is appropriate, considering that energy needs continue to increase along with the increasing amount of waste that is not managed and hurts the ecosystem. Biomass can be used as new renewable energy by converting it into solid, liquid, and gas energy. Pyrolysis has several advantages over gasification and direct combustion, for example, lower reaction temperature, and combustion without oxygen, allowing not only the production of energy but also high-value-added products, such as char, biofuels, and gases. This research was an experimental study, the fast pyrolysis was employed by using 300 grams both in durian and sugar palm. The temperature was varied from 400, 500, and 600 °C. The results of the test of liquid smoke RDF-5 sugar palm at a temperature of 400 °C at 112 mL and RDF-5 durian at a temperature of 600 °C at 137 mL. In this experiment, liquid smoke can be a potential alternative fuel because it contains alcohol, which can be used as an alternative fuel.

ACKNOWLEDGEMENTS

This research was funded by the Institute for Research and Community Service of Universitas Sebelas Maret Surakarta, also known as LPPM UNS (Lembaga Penelitian dan Pengabdian Masyarakat–Universitas Sebelas Maret Surakarta).

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