Preliminary study of pellets Refuse Derived Fuel (RDF-5) based on Durian waste for feedstock in fast pyrolysis

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Abstract. The abundance of durian waste in Indonesia encourages the energy potential analysis of waste as a renewable source of energy. Fast pyrolysis had employed to convert the durian waste into gas and bio-oil. Peel and seed of durian (durian waste) was processed into pellets RDF-5 with the natural adhesive material. The RDF-5 in this study was cylindrical with 15 mm diameter and 50 mm length. The analysis of the energy potential of RDF-5 based on durian waste was conducted in different variations of the composition by using bomb calorimeter. Meanwhile, to explore the optimum parameters that affected on the fast pyrolysis process had conducted experiments in different variations of temperature 400°C-600°C. The results showed that the composition ratio between durian waste and natural adhesive material affected to the caloric value of RDF-5. Similarly, the quality and quantity of bio-oil and gas were affected by the temperature. When the temperature increases, the quality and quantity of bio-oil and gas also increases. This paper will be discussed the pyrolysis parameters on the fast pyrolysis process of RDF-5 based on durian waste in detail.

1. Introduction
Durian (Durio zibethinus Murray) only produced in Asia which has tropical climate, such as Indonesia, Malaysia, Thailand, etc. Production of durian fruit in abundance every year certainly abundant durian shell leaving anyway [1]. Only 20% -30% of durian fruit that can be used (eaten), while the seeds and shell removed. It causes environmental problems if the disposal is not handled appropriately. Durian shell is difficult to dispose of and it causes environmental issues including respiratory diseases, pungent smell and water contamination [2]. Durian shell contains the main components of biomass like cellulose, hemicellulose, and lignin. Recently, the utilization of lignocellulosic biomass as a renewable source for fuels and chemicals has been addressed by many researchers because of its favorable property of potential energy [3].

Thermal treatment methods such as combustion, pyrolysis, and gasification are the significant processes where the wastes can be utilized as fuel [4]. The pyrolysis process is the best technology for processing biomass than direct combustion and gasification. Pyrolysis can produce three kind of products at once using fairly low temperatures. During pyrolysis, the biomass components are turned into light gases (volatiles), liquids (bio-oil), and solid char [3]. There are 3 types of pyrolysis process is
the most developed that is slow pyrolysis, fast pyrolysis, and flash pyrolysis. Slow pyrolysis tends to produce chars with temperatures of 3000C - 4000C, fast pyrolysis tends to produce liquid smoke at temperatures of 4000C - 6000C, and flash pyrolysis tends to produce gas with temperatures above 6000C.

Processing durian waste by pyrolysis process cannot continuously be done because durian only exist in certain season and easy to decompose, for that reason durian waste need to be made Refuse Derived Fuels (RDF) to maintain chemical composition in biomass. Refuse Derived Fuel (RDF) from municipal solid waste can be an alternative form of energy to replace fossil fuels [5]. According to American Society for Testing and Materials (ASTM), RDF-5 is combustible waste fraction densified (compressed) into the form of pellets, slugs, cube, or briquettes [6]. Making RDF-5 from waste has the same heat value with coal and oil, also get a lower cost.

Durian waste as a feedstock pyrolysis raises problems that can be solved by making RDF-5, but whether by making RDF-5 will affect the product of the pyrolysis process? The problem will be investigated further by looking at liquid smoke production results in fast pyrolysis process from feedstock ratio using durian non-RDF and RDF-5.

2. Materials and methods

2.1. Durian waste sample for feedstock

Durian waste (shell and seed) is collected randomly to be cut into small pieces and cleaned up the dirt and then dried in order to lose the water content, then chopped using a machine up to the size 1 - 2 mm. The result of the cut is partially used for non-RDF feedstock, the rest will be dried again for processing to make RDF. Durian waste that has been dried will be chopped again to form powder and filtered using mesh 100 to take the powder (will be made RDF). Preparation of RDF using durian seeds smoothed with a ratio of 1 mL of water: 3 grams of seed to be an adhesive slurry. The sole of durian powder and durian seed adhesive slurry is made into three RDF types with the following comparison:

- Type 1 uses 300gr of powder with 700gr of adhesive
- Type 2 uses 300gr of powder with 800gr adhesive
- Type 3 uses 300gr powder with 900gr adhesive

The RDF is compressed with a compression pressure of 60 psi at a diameter dimension of 15 mm and a length of 50 mm, then dried. Dry RDF will be tested approximate to know the volatile content, moisture content, ash content, and fixed carbon and calorific value. RDF type that has high calorific value will be compared with non-RDF and used as feedstock pyrolysis to know its quality and quantity.

2.2. Pyrolysis

The pyrolysis process uses a reactor shell in fixed bed type with a capacity of 38.5 liters and a liquid smoke cooling process using a condenser vertical with cross-flow cooling flow direction. The reactor material uses carbon steel with tube as a heat-resistant sand container to retain heat to the reactor. Temperature readings are carried out using a digital thermocouple K type with two temperature data retrieval points, the temperature setting is carried out for 15-20 minutes from the initial installation before obtaining a constant temperature. The cooling process uses a condenser with a length of 150 mm and a regular water cooling fluid at 2000 L / hr. The pyrolysis process will be carried out using non-RDF feedstock and RDF which has the highest heating value by combustion process using variation of temperature range 4000C, 5000C, and 6000C. The speed of the pyrolysis process in generating liquid smoke will be calculated every 5 minutes with a holding time of 90 minutes (1.5 hours).

2.3. Filtering

Liquid smoke produced from the process of pyrolysis is divided into three grades:

- The raw liquid smoke belonging to grade 3, still contains many tar which is usually used for wood preservative.
- Class 2 liquid smoke, liquid smoke that has been filtered treatment but still has a hazardous material content which is used as formalin.
- Class 1 liquid smoke, is a safe liquid smoke consumed and free from the content of harmful substances that are usually used as food preservatives.

Liquid smoke from pyrolysis will be processed by 1. sedimentation, 2. filtration using active zeolite, and 3. filtration using activated carbon to get grade 2 or grade 1. Sedimentation done minimum 24 hours after smoke extraction, while filtration process using active zeolite and activated carbon is diluted by using a weight of 8 gr filter and will compute the weight difference before and after filtration as the weight of the filtrate filtered with the filtrate.

3. Result and Discussion

3.1. Feedstock pyrolysis

RDF drying process is done by using sunlight for 2 hours per day for a week and obtained data as follows:

![Drying with sunlight](image)

**Figure 1.** Drying RDF for feedstock.

From the graph it can be seen that drying only occurs for 3 days, because afterwards the weight of RDF has not decreased. The RDF is then tested approximate, with the following data:

| Moisture (%) | RDF type 1 | RDF type 2 | RDF type 3 | non-RDF |
|--------------|------------|------------|------------|---------|
| Ash (%)      | 4.1        | 4.8        | 4.4        | 3.7     |
| Volatile (%) | 62.1       | 62.3       | 63.2       | 60.3    |
| Fixed Carbon (%) | 21.5 | 21 | 20.1 | 22.8 |
| Caloric Value (Cal/gr) | 3808.4 | 3718.1 | 3555.8 | 3486.9 |

**Table 1.** Analysis result for feedstock.

| Moisture (%) | Jerman | Eropa | Finlandia | Itali |
|--------------|--------|-------|-----------|-------|
| Ash (%)      | <20    | <25   | 25-35     | 25    |
| Volatile (%) | 8-12   |       |           |       |
| Caloric Value (Cal/gr) | 3585 | 3107-3824 | 3585    |

**Table 2.** International standard of RDF.

If viewed from a test data RDF-5 compared to a standard international, all type RDF RDF-5 already belonging to the specifications of the standardization of RDF. High water content causes the resulting smoke much more but according to the international standardization of RDF it lowers the quality of the RDF because at the combustion time, the first process is evaporation of water. So that, more water will be needs more energy required for the combustion process. According to Germany standard, the increasingly volatile levels would make the RDF is increasingly combustible and the lower levels of...
ash, the quality of the RDF will be increasingly good. Of test data, RDF-5 type 3 has a high volatile levels and RDF-5 type 1 have the lowest levels of ash than RDF-5 other. Non-RDF have the lowest levels of volatile and the lowest levels of grey. Fixed carbon is the rest of the parsing, a substance that does not evaporate from the combustion process. So, fixed carbon high levels results more bio char and the test data, the biomass of non-RDF has a highest levels of fixed carbon. From the test results, RDF type 1 has the highest heating value compared to others. Increasing the heating value from waste created the RDF will produce heat energy is higher, so that this RDF will be used for comparison with non-RDF in the pyrolysis process.

![Figure 2. Pellet RDF or RDF-5.](image)

### 3.2. Pyrolysis process

The pyrolysis process uses 300 gr feedstock, used for RDF type 1 and non-RDF and obtained pyrolysis process data with temperature variation as follows:

![Figure 3. Volume liquid smoke of non-RDF in different temperature.](image)

![Figure 4. Volume liquid smoke of RDF in different temperature.](image)
From the experimental graph, can be seen that burning biomass with a temperature of 4000°C would produce a stable liquid smoke rises, in contrast to a temperature of 5000°C and 6000°C that will instantly produce liquid smoke with a lot of volume and then very little or almost nothing an increase in the volume of liquid smoke. The results of smoke-liquid for non-RDF produce smoke liquid at most at 6000°C, as well as the RDF. The results of the liquid smoke with low volume in temperature 4000°C, either RDF or non-RDF. It proves that the higher the temperature of combustion can produce liquid smoke much more and the speed to produce liquid smoke also varies in the type of biomass and temperature variations. Can be seen from two diagram, the biomass of non-RDF with temperature 4000°C can directly produce liquid smoke and temperature 5000°C, 6000°C require a waiting time of approximately 10 minutes to produce liquid smoke. The feedstock of RDF for the temperature 5000°C, 6000°C require a waiting time of approximately 10 minutes to produce liquid smoke and temperature 4000°C to require a longer waiting time.

3.3. Liquid smoke processing

Liquid smoke processing is done in three stages, this treatment to find out the actual volume produced from the results of the process of pyrolysis without any mix of char or the other. One of the most effective ways to improve the quality of liquid smoke is reducing the oxygen level e.g. by the application of catalysts [7]. Therefore, the treatment to raise the grade and quality of liquid smoke that is generated also.

3.3.1. Sedimentation

| Table 3. Decrease volume of sedimentation non-RDF. |
|-----------------------------------------------|
| Temperature | Initial Volume | Final volume | Reduction |
| 400 °C      | 86 mL          | 81 mL        | 5 mL      |
| 500 °C      | 87 mL          | 81 mL        | 6 mL      |
| 600 °C      | 90 mL          | 85 mL        | 5 mL      |

| Table 4. Decrease volume of sedimentation RDF. |
|-----------------------------------------------|
| Temperature | Initial Volume | Final volume | Reduction |
| 400 °C      | 78 mL          | 76 mL        | 2 mL      |
| 500 °C      | 84 mL          | 81 mL        | 3 mL      |
| 600 °C      | 137 mL         | 133 mL       | 4 mL      |
Sedimentation of the 6 samples obtained indicate the shrinking volume for liquid smoke from biomass in non-RDF feed contains char more which could be precipitated by filtration with sedimentation only.

3.3.2. Filtration of active zeolite

Table 5. Decrease volume of filtration active zeolite non-RDF.

| Temperature | Initial Volume | Final volume | Reduction |
|-------------|----------------|--------------|-----------|
| 400 °C      | 81 mL          | 69 mL        | 12 mL     |
| 500 °C      | 81 mL          | 77 mL        | 4 mL      |
| 600 °C      | 85 mL          | 80 mL        | 5 mL      |

Table 6. Decrease volume of filtration active zeolite RDF.

| Temperature | Initial Volume | Final volume | Reduction |
|-------------|----------------|--------------|-----------|
| 400 °C      | 76 mL          | 71 mL        | 5 mL      |
| 500 °C      | 81 mL          | 76 mL        | 5 mL      |
| 600 °C      | 133 mL         | 122 mL       | 11 mL     |

Active zeolite is used as a main filter, ion exchanger, absorbent, and catalyst for liquid smoke. Filtering by zeolite is intended to get the active substances are completely safe from hazardous materials in order to be safe to use. See data from the filtration of active zeolite, to feedstock of non-RDF most reduction volume of liquid smoke from combustion with low temperatures but for feedstock of RDF conversely, i.e. the highest temperatures can produce highly reduction of liquid smoke after the filtration using active zeolite.

3.3.3. Filtration of active carbon

Table 7. Decrease volume of filtration active carbon non-RDF.

| Temperature | Initial Volume | Final volume | Reduction |
|-------------|----------------|--------------|-----------|
| 400 °C      | 69 mL          | 62 mL        | 7 mL      |
| 500 °C      | 76 mL          | 70 mL        | 6 mL      |
| 600 °C      | 80 mL          | 76 mL        | 4 mL      |

Table 8. Decrease volume of filtration active carbon RDF.

| Temperature | Initial Volume | Final volume | Reduction |
|-------------|----------------|--------------|-----------|
| 400 °C      | 71 mL          | 66 mL        | 5 mL      |
| 500 °C      | 76 mL          | 71 mL        | 5 mL      |
| 600 °C      | 122 mL         | 115 mL       | 7 mL      |

Activated carbon is used to support the filtrate, aims to clear up and absorb odors so obtained liquid smoke that smells of light and doesn’t sting. It also helps to clear up the resulting liquid smoke. Active Carbon filtration results are almost the same reduction conclusion with filtering using zeolite. From the filtration data can be concluded that in each type of filtrate can filter smoke with different capabilities, so the data obtained as follows:
Table 9. Analysis result of treatment liquid smoke for non-RDF.

| Temperature | Final Reduction | Weight | Specific Gravity |
|-------------|-----------------|--------|------------------|
| 400 °C      | 24 mL           | 58 gr  | 920.6 kg/m³      |
| 500 °C      | 16 mL           | 68 gr  | 971.4 kg/m³      |
| 600 °C      | 14 mL           | 73 gr  | 960 kg/m³        |

Table 10. Analysis result of treatment liquid smoke for RDF.

| Temperature | Final Reduction | Weight | Specific Gravity |
|-------------|-----------------|--------|------------------|
| 400 °C      | 12 mL           | 63 gr  | 954.5 kg/m³      |
| 500 °C      | 13 mL           | 68 gr  | 957.7 kg/m³      |
| 600 °C      | 22 mL           | 110 gr | 956.5 kg/m³      |

The data above show the end of reduction from treatment is feedstock with non-RDF results most reduction on the temperature of combustion is 4000°C is inversely proportional to feedstock with RDF i.e. most reduction of liquid smoke on the temperature of combustion is 6000°C. Can be seem from the treatment, can be summed up that best quality of liquid smoke for RDF feedstock with temperature of combustion in 4000°C and non-RDF at a temperature of combustion in 6000°C. While to density, the highest density for RDF and non-RDF in liquid smoke at temperature 5000°C. To know the difference in the quality of liquid smoke in depth like the difference in chemical composition, nature of the liquid smoke, etc. of each liquid smoke, more needs to be a deeper research and testing of liquid smoke.

4. Conclusions
The use of durian waste to be treated with pyrolysis using feedstock from RDF and non-RDF biomass affects the results of pyrolysis processes and products. This can be seen from the process of making a feedstock that has the highest heating value is RDF type 1 in the pyrolysis process, the speed of biomass to generate smoke liquid occurs faster in biomass RDF with a temperature of 6000°C. The higher temperature of the combustion can produce the higher result of liquid smoke, either RDF or non-RDF. On the results of filtration of liquid smoke found that the most shrinkage is the type of biomass non-RDF with the temperature 4000°C and for RDF in the temperature of 6000°C. The highest specific gravity is the type of biomass non-RDF with the temperature 5000°C. It can be seen also the quality and quantity of liquid smoke after receiving treatment, the type of biomass used (RDF and non-RDF) greatly affected. So, with RDF for feedstock in fast pyrolysis can provide benefits both in terms of feedstock before pyrolysis and after pyrolysis. However, the overall treatment including research that has been done above, only able to produce liquid smoke up to grade 2 either use feedstock with non-RDF or RDF-5. So that, the liquid smoke hasn't been able to be applied for consumption as a food preservative.

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