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RESEARCH PAPER

# Utilization of durian peels (*Durio zibethinus*) and lubricant treatment sludge as raw materials of Refuse-Derived Fuel

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**Abstract.** Fossil energy is among the most widely utilized energy sources in Indonesian industry, but its continuous use is leading to its depleted. Refuse-derived fuel (RDF) offers an alternative made from organic and inorganic waste. Durian peel is identified as a promising raw material for RDF due to its high calorific value of 6,274 Kcal/kg. Additionally, Lubricant Treatment Sludge (LTS), which is collected from the oil treatment industry, is used to enhance RDF's calorific value, as it contains residual oil rich in hydrocarbons. To bind the RDF components, tapioca starch, durian seeds, and rejected papaya were selected as adhesives. The mixture ratios of durian skin, LTS, and adhesive were tested at compositions (90:0:10), (85:5:10), (80:10:10), (75:15:10), and (70:20:10). Subsequent RDF characteristics analyses included tests for moisture content, ash content, volatile matter, fixed carbon, and calorific value. Based on these evaluations, the most optimal composition was determined to be 90% durian peel, 0% LTS, and 10% tapioca starch adhesive. This composition exhibited a moisture content of 1.6%, volatile matter of 74.6%, ash content of 8.4%, fixed carbon of 15.2%, and a calorific value of 3,516 Kcal/kg. Tapioca starch emerged as preferred adhesive due to its favorable properties and characteristics.

**Keywords:** adhesive; durian peel; refuse derived fuel; waste to energy; sludge

## 1. Introduction

Most industries in Indonesia have a high demand for fossil fuels like coal, petroleum, and natural gas. The limitation of fossil fuels is a major challenge in Indonesia, given that 90% of the country's primary energy source in derived from fossil fuels (Anggono et al., 2020). Refuse-derived fuel (RDF) emerges as a potential alternative energy source to replace fossil fuels. RDF can be produced from biomass and sludge (García et al., 2021). According to the American Society for Testing and Materials (ASTM), RDF is classified into seven categories (from RDF-1 to RDF-7) based on raw materials used and the resulting products. RDF-5, for example, is derived from combustible waste and is produced in granular, slag, or pellet forms. The advantages of RDF include its ability to be stored for extend periods, its practically in transportation, and its high calorific value ranging from 3,000-7,000 Kcal/Kg (Putri & Sukandar, 2013; Suryani et al., 2019).

Indonesia has established quality standards for RDF must met before it can be used as a fuel. These standards are outlined in the technical specification guidebook for RDF as an alternative

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fuel in the cement industry, prepared by the Ministry of Industry of the Republic of Indonesia in 2017. The RDF quality standards applicable in Indonesia are detailed in Table 1.

**Table 1.** RDF Quality Standards in Indonesia

| Parameter | RDF Standard of Indonesia |
|---|---|
| Moisture content (%) | ≤ 20 |
| Volatile matter (%) | 50-80 |
| Ash content (%) | ≤ 10 |
| Chlorine (%) | ≤ 0,75 |
| Calorific value (Kcal/kg) | >3,000 |

* Ministry of Industry, 2017

The quality of RDF can be analyzed based on characteristics such as moisture content, ash content, volatile matter, fixed carbon, and calorific value. Durian peel is a promising biomass used as raw material for RDF due to its favorable characteristics. Based on previous studies, durian peel can yield a calorific value of 6,274 Kcal/Kg and has a moisture content of 0.01%, surpassing the Indonesian RDF standard (Nuriana et al., 2013).

In 2021, Indonesia produced 1.35 million tons of durian fruit (*durio zibethinus*). Durian fruit typically consists of 60-75% peel, 25-30% flesh, and 5-15% seed (Nurrohmah et al., 2021). This high production volume of durian fruit presents an advantage for utilizing durian peel as a raw material for RDF.

LTS is utilized as raw material to enhance the calorific value of RDF. LTS is sourced from the oil treatment industry and typically consists a combustible oil portion ranging from 20 to 40% (Mukhtar et al., 2015). The high oil content obtained from the oil treatment process makes LTS a high viable material for RDF production. The creation of an RDF mixture requires the use of an adhesive to achieve the necessary structural strength and ease of shaping. The types of adhesive use can affect the calorific value, moisture content, and ash content of the RDF mixture (Hasanah & Tjahjani, 2020). Tapioca starch is the most commonly used adhesive for binding the raw materials together. Tapioca starch typically contains of 70 to 81% starch content, providing strong adhesion properties (Hardwianti et al., 2014). Two potential biomass materials used as adhesives are durian seed and rejected papaya. Durian seed was chosen due to its high starch content of 42.1%, a resulting in an adhesive that can contribute to a calorific value of 5,486 Kcal/kg (Djeni & Saptadi, 2000). Rejected papaya is also considered a viable adhesive option, offering a calorific value of 4,822.06 Kcal/kg (Maharani, 2022).

Carbonization is a process in which raw materials are heated without oxygen at a temperature ranging from 300 to 900˚C to transform them into black carbon. During carbonization, organic compounds undergo decomposition to produce acid vapor, acetate, tar, hydrocarbons, and methanol (Alwathan & Patmawati, 2019). This process involves multiple simultaneous reaction including dehydrogenation, condensation, hydrogen transfer, and isomerization. Hydrogen is separated from hydrocarbons such as methane during carbonization, leaving behind carbon (Breulmann et al., 2017). The objective of this research is to explore the utilization of durian peel and LTS as raw materials for RDF using various types of adhesives.

## 2. Material and methods

### 2.1. Preparation of raw materials for RDF

#### 2.1.1 Durian peels charcoal

Durian peels were collected as waste from traditional markets in Samarinda. Initially, the durian peel was cleaned and cut into small pieces to facilitate drying. These small pieces were then placed in an oven to 105°C for 24 hours to dry. Subsequently, the dried durian peel underwent carbonization in a furnace at 400°C for 1 hour (Yilmaz et al., 2017). After carbonization, the durian peel carbon was cooled down in a desiccator and then sieved into 100 mesh particle sizes. The process of preparing sun-dried and carbonized durian peel is illustrated in Figure 1.

(a) (b)

**Figure 1.** The portrait of (a) sun-dried durian peel and (b) carbonized durian peel

### 2.1.2 Lubricant Treatment Sludge (LTS) charcoal

LTS was collected from an oil treatment industry in Balikpapan and subsequently underwent several treatments before being utilized as a raw material for RDF. Initially, the LTS was dried in an oven at 105°C for 24 hours. Following this, the dried LTS was subjected to furnace at 400°C for 1 hour (Yilmaz et al., 2017). The carbonized LTS was then sieved to achieve particle sizes of 100 mesh. The process of preparing sun-dried and carbonized LTS is illustrated in Figure 2.

(a) (b)

**Figure 2.** The portrait of (a) sun-dried LTS and (b) carbonized LTS

### 2.1.3 Preparation of adhesive

#### a. Durian Seed

Durian seed were cleaned and then dried in an oven at 105°C for 24 hours. The dried seeds were subsequently sieved into powder with 100-mesh particle sizes. To create an adhesive, water was added to the powder and thoroughly mixed (Dewi et al., 2016).

#### b. Tapioca starch

Tapioca starch serves as another adhesive option when mixed with boiling water. For the right consistency, combine tapioca starch and waster in a 1:10 ratio, then cook the mixture on the stove until it thickens to the desired adhesive texture (Maharani, 2022).

**c. Rejected papaya**

Papaya deemed unsuitable for sale gathered from a traditional market in Balikpapan. The collection rejected papayas were squeezed to separate their water and solid components, with the solid content intended for use as an adhesive.

## 2.2 Production of RDF

The production of RDF began with the preparation of raw materials including durian peel charcoal, LTS charcoal, and adhesive. Each type of adhesive was mixed with various compositions of durian peel charcoal and LTS charcoal. Table 2 presents the different compositions of durian peel charcoal, LTS charcoal, and adhesive used in the study.

**Table 2.** Composition of raw material of RDF

| Types of adhesives | Composition<br>Durian peel charcoal: LTS Charcoal: Adhesive | | | | |
|---|---|---|---|---|---|
| | **90:0:10** | **85:5:10** | **80:10:10** | **75:15:10** | **70:20:10** |
| Tapioca Starch | 90:0:10 TS | 85:5:10 TS | 80:10:10 TS | 75:15:10 TS | 70:20:10 TS |
| Durian Seed | 90:0:10 DS | 85:5:10 DS | 80:10:10 DS | 75:15:10 DS | 70:20:10 DS |
| Rejected Papaya | 90:0:10 RP | 85:5:10 RP | 80:10:10 RP | 75:15:10 RP | 70:20:10 RP |

All composition variations undergo the same treatment: raw materials are mixed with adhesive. Once thoroughly combine, the mixture is molded using a small tube-shaped mold with diameter of 1.2 cm in diameter and 2.5 cm in length. The resulting RDF is then dried in the sun for 1-2 days to reduce its water content. Figure 3 illustrates RDF produced using different combination of durian peels, LTS, and adhesive.

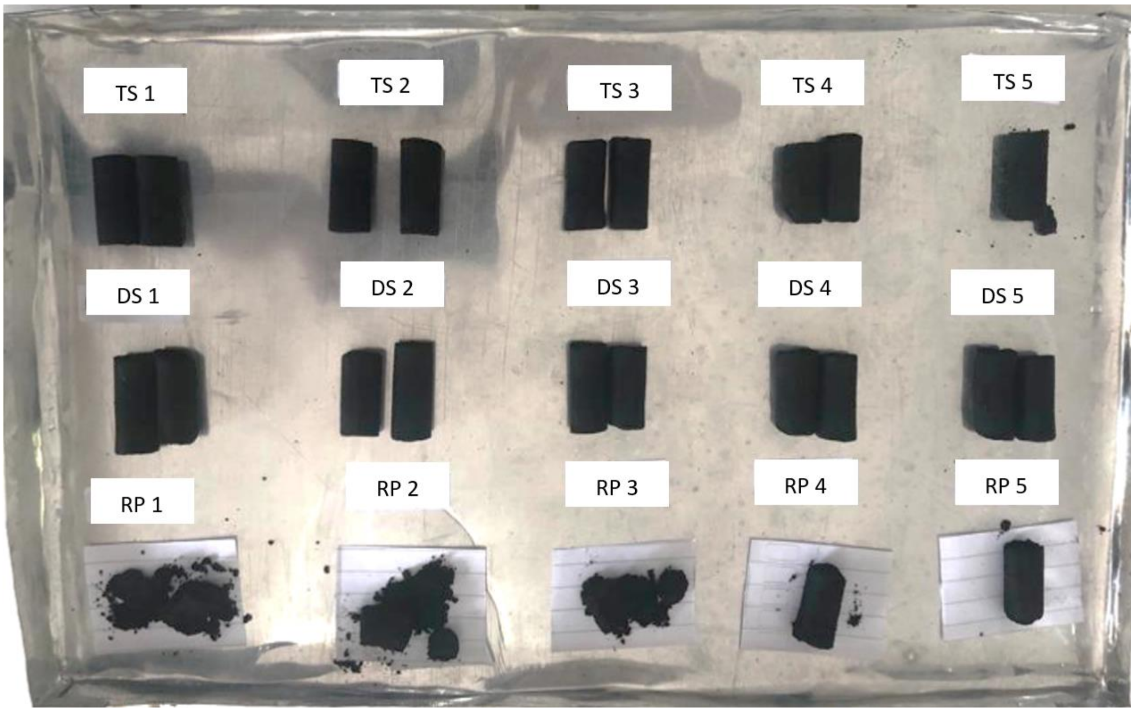


**Figure 3**. RDF with the variation of adhesive

### 2.3. Characterization of RDF

#### 2.3.1 Proximate analysis

**a. Moisture content**

Moisture content refers to the amount of water present in a material, typically expressed as a percentage (Deglas & Fransiska, 2020). The standard requirement for producing high-quality RDF is that water content should below 30% (Putri & Sukandar, 2013). The moisture content of RDF can be determined using the ASTM D-3173-17 standard with the formula in Equation 1.

$$Moisture\ content\ (\%) = \frac{A - B}{A} \times 100\% \tag{1}$$

where $A$ is the initial sample mass before drying, and $B$ is the sample mass after drying.

**b. Ash content**

Ash content is the inorganic residue remaining after material combustion, comprising substances such as silica, calcium, magnesium, phosphorus. Lower ash signifies higher RDF quality (Deglas & Fransiska, 2020). The ash content of RDF can be calculated using the ASTM D-3174-12 standard with the formula in Equation 2.

$$Ash\ Content\ (\%) = \frac{A}{B} \times 100\% \tag{2}$$

where $A$ is the ash residue post carbonization, and B is the initial sample mass before carbonization.

**c. Volatile matter**

Volatile matter refers to substances that vaporize (other than water) due to material decomposition. The presence of hydrocarbons in RDF contributes to higher levels of volatile substances, rendering RDF more flammable (Deglas & Fransiska, 2020). The percentage of volatile matter in RDF can be calculated using the ASTM D-3175-20 standard. The calculation formula is presented in Equation 3.

$$Volatile\ matter\ (\%) = \left(\frac{B}{A} \times 100\%\right) - MC(\%) \tag{3}$$

where A is the initial sample mass before carbonization, B is the sample mass after carbonization, and MC is the moisture content percentage.

**d. Fixed carbon**

Fixed carbon denotes the carbon content remaining after volatile matter removal. The fixed carbon content in RDF can be calculated using the ASTM D-3172-07 standard with the formula in Equation 4.

$$Fixed\ Carbon\ (\%) = 100\% - (MC + AC + VM) \tag{4}$$

where MC, AC, and VM are the percentages of moisture content, ash content, and volatile matter, respectively.

#### 2.3.2 Calorific value

The calorific value represents the amount of heat produced by a gram of fuel (Almu et al., 2014). This value is determined using a combustion test called a calorimeter, where the sample was burned in a closed container filled with oxygen. Measurements are taken once the sample's volume stabilizes. The calorific value significantly influences the quality of RDF. Higher calorific values indicate better RDF quality. Adhesives negatively impact RDF by retaining water, which lower the calorific value. The calorific value (Hg) can be calculated by using Equation 5.

$$Hg = \frac{t.w - I_1 - I_2 - I_3}{M} \tag{5}$$

where $Hg$ determines the calorific value in Kcal/Kg, $M$ is the mass of the sample, $t$ is the temperature difference in Celsius degree, $w$ determines 2426/°C, $I_1$ is the amount of sodium used for titration, $I_2$ presents the value of 13.7 x 10.2 x $M$, $I_3$ is the length of wire used.

## 3. Result and discussion

### 3.1. Durian peel carbon and LTS carbon characteristics

The characteristics of raw materials were analyzed based on parameters including moisture content, volatile matter, ash content, fixed carbon, and calorific value. Table 3 presents the specific characteristics of durian peel carbon and LTS carbon.

**Table 3.** Characteristics of carbonized Durian Peel and LTS

| Parameter | Charcoal characteristic | |
|---|---|---|
| | Durian peel | LTS |
| Moisture Content (%) | 0.26 | 0.07 |
| Volatile matter (%) | 61.73 | 32.85 |
| Ash Content (%) | 7.60 | 64.94 |
| Fixed carbon (%) | 30.66 | 2.14 |
| Calorific Value (Kcal/kg) | 5,217 | 4,779 |

Based on the test results, the moisture content of durian peel was found to be 0.07%, while LTS had a moisture content of 0.26%. Low water content contributes to a higher calorific value, whereas higher moisture levels can make shaping RDF difficult and promote biological activities, thereby reducing RDF durability and calorific value (Yilmaz et al., 2017). Durian peel exhibited a significantly higher volatile matter content at 61.73% compared to LTS at 32.85%. This high volatile matter in durian peel is attributed to its rich organic composition that vaporizes readily at high temperatures. The ash content of LTS was 64.94%, significantly higher than the 7.60% found in durian peel. The elevated ash content in LTS is attributed to various sludge components such as silica, magnesium, and aluminum, which are resistant to combustion and remain as residual matter (Srisanga et al., 2017). In terms of fixed carbon, durian peel contained 30.66% while LTS had 2.14%. The lower fixed carbon content in LTS is due to its high ash composition. However, LTS exhibited a notably high calorific value of 4,779 Kcal/kg due to the presence of hydrocarbon from the oil treatment process (Djeni & Saptadi, 2000). Comparatively, the calorific value of durian peel was measured at 5,217 Kcal/kg, indicating a higher quality of RDF due to its greater calorific output.

### 3.2. Characteristics of adhesive

The adhesive was used to adhere the raw material and facilitate the shaping of RDF, thereby impacting RDF quality. The characteristic of the adhesive plays a significant role in this process, as outlined in Table 4.

The moisture content in the adhesive directly influences the moisture content of RDF. Among the raw materials, rejected papaya exhibited the lowest moisture content (2.46%), compared to durian peel (9.52%) and tapioca starch (9.57%). The low moisture content in rejected papaya is attributed to water extraction through squeezing, whereas water was intentionally added to durian peel and tapioca starch during preparation (Anggono et al., 2020). All adhesives displayed a high volatile matter content ranging from 96 to 99%, as they were not carbonized, retaining a significant amount of organic content. The calorific values of tapioca starch and durian peel were measured at 3,557 Kcal/kg and 3,743 Kcal/kg, respectively, while rejected papaya exhibited a lower calorific value of 2,178 Kcal/kg.

**Table 4.** Adhesive characteristic

| Parameter | Adhesive characteristic | | |
|---|---|---|---|
| | Tapioca starch | Durian seed | Rejected papaya |
| Moisture content (%) | 9.57 | 9.52 | 2.46 |
| Volatile matter (%) | 99.77 | 96.62 | 96.4 |
| Ash content (%) | 0.22 | 2.96 | 2.91 |
| Fixed carbon (%) | -9.18 | -8.94 | -2.01 |
| Calorific value (Kcal/kg) | 3,557 | 3,743 | 2,178 |

### 3.3 Effect variation biomass and adhesives on RDF characteristics

#### 3.3.1 Moisture Content

Moisture content is a critical parameter affecting the quality of RDF. Lower moisture content generally indicates higher RDF quality. High moisture content can lead to the consumption of heat energy for water evaporation within the RDF before effective combustion can occur (Junaidi et al., 2017). The results of the RDF moisture content test are illustrated in Figure 4.

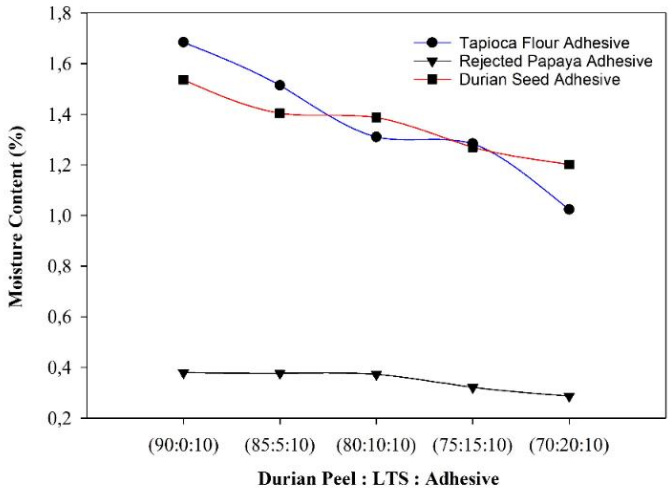


**Figure 4.** Effect of adhesive and RDF composition on moisture content

Figure 4 illustrates the impact of durian peel, LTS, and adhesive on the moisture content of RDF. RDF incorporating rejected papaya adhesive exhibit lower moisture content compared to those containing tapioca starch and durian seed. This reduction in moisture content can attributed to factors such as the inherently low moisture level of rejected papaya adhesive and the LTS composition in RDF. Notably, all RDF composition tested have met the quality standard of less than 20% moisture content.

#### 3.3.2 Volatile matter

Volatile matter in RDF refers to organic substances that evaporate due to the decomposition of compounds within the material (Hestiyantini et al., 2022). High volatile matter is important parameter as it indicates the time required for RDF to begin burning. A higher volatile matter content corresponds to faster burning rate of the RDF, indicating greater reactivity (Merry Mitan et al., 2018). The results of the RDF water content test based on composition and type of adhesive are depicted in Figure 5.

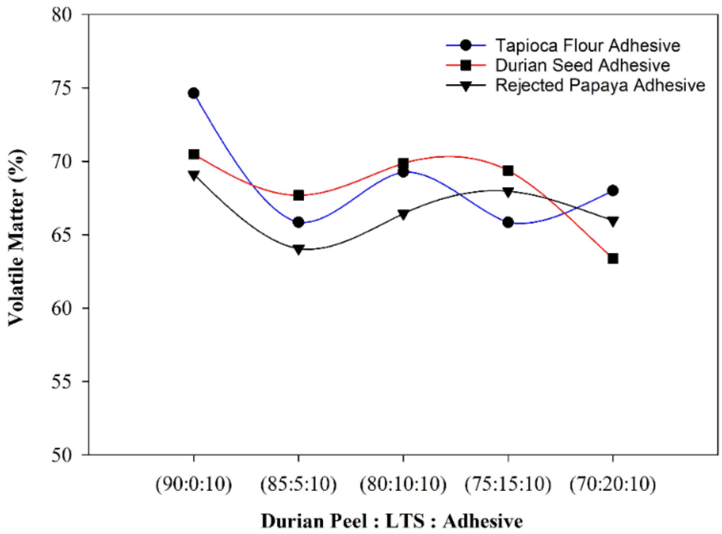


**Figure 5.** Effect of adhesive and RDF composition on volatile matter

Based on the results of characteristic analysis, the volatile matter content of RDF falls within the range of 65%-75%. The type of adhesives used significantly influences the volatile content of RDF. Among the adhesive tested, tapioca starch exhibited the highest volatile matter at 74.6%, while durian seen adhesive showed the lowest at 63.38%. Tapioca starch high volatile matter can be attributed to its rich organic content and low ash content, allowing for complete evaporation (Hardwianti et al., 2014). The composition of raw materials in RDF also impacts volatile matter levels. For instance, a composition of 90% durian peel charcoal, 0% LTS charcoal, and 10% adhesive yields a volatile matter content of 74-69%. Conversely, a composition of 70% durian skin charcoal, 20% LTS charcoal, and 10% adhesive results in decreased volatile matter content at 63-67%. This decreases is attributed to the higher proportion of LTS charcoal, which contains inorganic materials unable to burn at temperature below 950°C (Srisanga et al., 2017).

### 3.3.3 Ash content

It is understood that high ash content diminishes the calorific value of RDF. Therefore, lower ash content indicates higher quality RDF (Deglas & Fransiska, 2020). High ash content can notably impede heat transfer to the RDF surface and oxygen diffusion during combustion (Staničić et al., 2022). The results of the ash content test for each composition and type of adhesive are presented in Figure 6.

From the graph in Figure 6, it can be observed that the type of adhesives does not significantly affect the ash content. Adhesives such as tapioca starch, durian seeds, and rejected papaya relatively minor differences in ash content, ranging from 0.2 to 2.9%. This further evidenced by the composition of 85% durian skin charcoal and 5% LTS charcoal using 10% adhesive (tapioca starch, durian seeds, and rejected papaya), resulting in ash content values of 14.2%, 13.8%, and 13.6%, respectively.

Unlike the type of adhesive, the composition of raw material significantly affects to the ash content of produced RDF. For example, a composition of 90% durian peel charcoal, 0% LTS charcoal, and 10% adhesive yields an ash content of 8.4-10.4%. Conversely, a composition of 70%

durian peel charcoal, 20% LTS charcoal, and 10% adhesive results in higher ash content ranging from 19.4 to 21.2%. These findings demonstrate that the presence of LTS charcoal contributes to increased ash content. As more LTS charcoal is added, the ash content rises. LTS charcoal tends to have high as content due to the presence of inorganic minerals such as silica, calcium oxide, and alumina (Guangyin & Youcai, 2017).

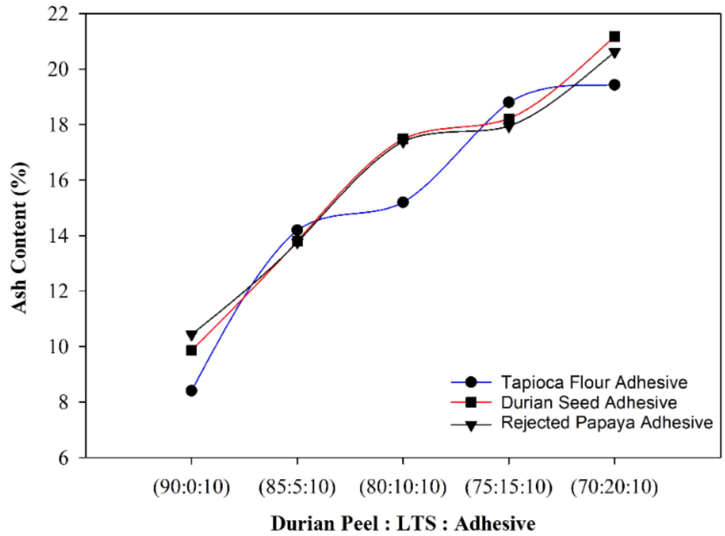


**Figure 6.** Effect of adhesive and RDF composition on ash content

### 3.3.4 Fixed carbon

Fixed carbon in RDF serves as the primary heat producer during combustion (Kongprasert et al., 2019). Thus, a higher fixed carbon value indicates better quality RDF. The results of the fixed carbon test on RDF illustrated in Figure 7.

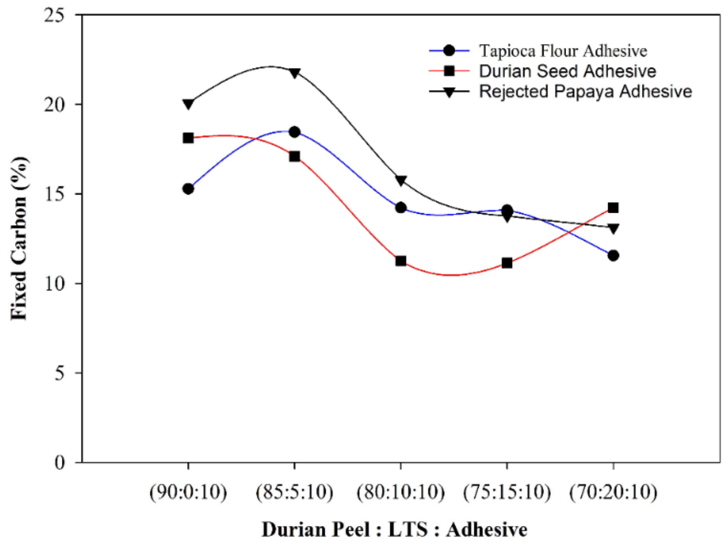


**Figure 7.** Effect of adhesive and RDF composition on fixed carbon

The test results indicate that the types of adhesives used does not significantly affect the fixed carbon value. The fixed carbon value of tapioca starch adhesive ranges from 11 to 19%, durian seed adhesive from 11 to 18%, and rejected papaya adhesive is 13 to 22%. However, variations in

RDF raw material composition have notable impact on fixed carbon content. For instance, a composition of 90% durian peel and 10 LTS with rejected papaya adhesive yields a fixed carbon value of 20%, whereas a composition of 70% durian peel and 20 LTS with rejected papaya adhesive results in a fixed carbon value of 13%. This variation can be attributed to differences in chemical composition of durian peels and LTS. Carbonization of durian peel during heating increases lignin content, thereby enhancing fixed carbon levels (Tambaria & Serli, 2019).

### 3.3.5 Calorific value

The heating value represents the amount of heat released per unit mass of RDF (Zubairu & Gana, 2014). Higher heating values indicate better quality of RDF (Putri & Andasuryani, 2017). A high calorific value is achieved when RDF has low water content, low ash content, and high fixed carbon (Senanayake et al., 2015). In Indonesia, the RDF quality standard for calorific value parameters is ≥ 3,000 Kcal/kg. The results of the calorific value test for RDF are presented in Figure 8.

The Figure 8 depicts RDF composed a mixture with a ratio of 90:0:10 (durian peel: LTS: adhesive) using tapioca starch adhesive, durian peel, and rejected papaya. The respective calorific values of these component are 3,516 Kcal/kg for durian peel, 3,250 Kcal/kg for LTS, and 4,807 Kcal/kg for adhesive, derived from rejected papaya. When 10% adhesive is added to the RDF composition, it impacts calorific value. Prior studies have shown that adding 10% adhesive to coconut shell charcoal, which originally had a calorific value of 6,527 Kcal/kg, resulted in a decrease to 5,587 Kcal/kg (Deglas & Fransiska, 2020). The highest heating value observed was RDF with adhesive derived from rejected papaya, with calorific value range of 4,807-3,837 Kcal/kg. This high calorific value of the rejected papaya adhesive is attributed to its low moisture content.

The composition of RDF significantly affects to its calorific value. The inclusion of LTS charcoal tend to decrease the calorific value. For instance, RDF containing 20% LTS charcoal exhibits a calorific value ranging from 3,837 to 3,054 Kcal/kg, whereas RDF without LTS composition ranges from 4,807 to 3,250 Kcal/kg. According to previous studies, RDF with 30% sludge composition has calorific value of 2,259 Kcal/kg, while RDF with 20% sludge composition yields 2,830 Kcal/kg (Yilmaz et al., 2017). The diminished calorific value of RDF is attributed to the high ash content of LTS (Zhang et al., 2020).

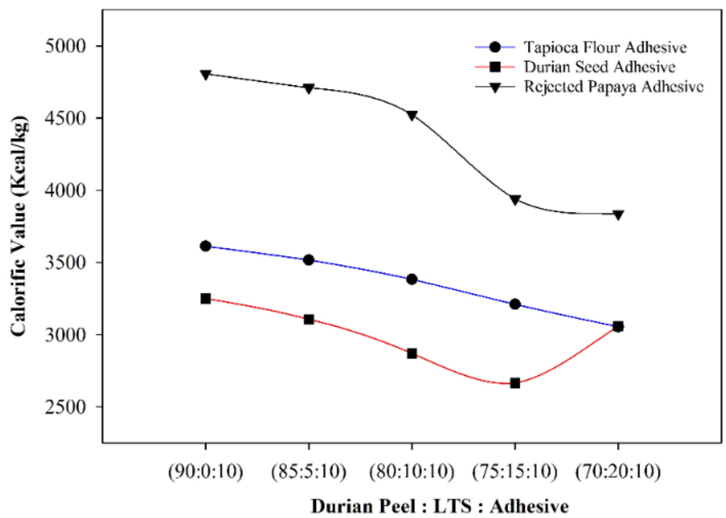


**Figure 8**. Effect of adhesive and RDF composition on calorific value

### 3.4 Statistical analysis

The heating value of the statistical test aimed to determine the significance value of the effect of adhesive type and composition on RDF characteristics. The test employed either parametric analysis using the one-way ANOVA method or non-parametric analysis using the Kruskal-Wallis method. Based on the one-way ANOVA and Kruskal Wallis test, it can be concluded that, the effect of adhesive types on the volatile matter, ash content, and fixed carbon was not statistically significant. Similarly, variations in composition of moisture content, volatile matter, ash content, and calorific value was not statistically significant.

## 4. Conclusion

Based on conducted research, it was found that most effective RDF composition consists of 90% durian peel, 0% LTS, and 10% tapioca starch adhesive. This RDF composition exhibits water content of 1.6%, volatile matter of 74.6%, ash content of 8.4%, fixed carbon of 15.2%, and a calorific value of 3,516 Kcal/kg. Additionally, it was observed that tapioca starch adhesive shares similar characteristics with durian seeds. Therefore, durian seeds can be considered as an alternative adhesive.

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