Basic properties of the mangrove tree branches as a raw material of wood pellets and briquettes

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Abstract. In order to sustain mangrove forests, only branches part of the mangrove trees have been utilized. In this context, these parts have been used as the raw material of wood pellets and briquettes. These solid biofuels are produced by compressing pulverized woody biomass with or without additives in cubic-form or cylindrical units. In this study, five predominant mangrove trees, namely Avicennia marina, Bruguiera sexangula, Excoecaria agallocha, Rhizophora apiculata, and R. mucronata, have been harvested their branches. Wood with and without bark derived from branches has been investigated for their fundamental properties, namely percentage of bark, ash-content, and physical properties (moisture content, density, and specific gravity). These properties will determine the quality class of the resulted wood pellets and briquettes considering pre-treatment or the nature of the branches’ wood.

1. Introduction
After recovery of an extreme tsunami in 2004, mangrove forest, particularly along Sumatra, has been emphasized to intangible services such as barrier of winds, tides and hurricanes [1-2], habitat of endemics flora and fauna [2-4], and revenue-generating of ecotourism and recreational [5-7]. Recently, people living around mangroves have been familiar with tangible “processing” products through community empowerment activities, such as crackers made from mangrove leaves [8], syrup made of mangrove fruits [9], and natural dyes derived from mangrove biomass [10].

Biomass in mangrove forests is comprised of leaf, stem, and root components [11]. Mangrove leaves may contain nutrients elements [12], while stem and root may include woody biomass [13]. Utilization of the main stem of mangrove trees as a source of timber will promote negative impacts of mangrove forests. The forest will degrade because timber harvesting’s rate was usually faster than that of the growth [14]. Exploiting roots for wooden needs seems incorrect since the anatomical structure between stem and root is different [15].

Further, cost considerations during harvesting, i.e., digging, human or machine power, and environmental effect, look not sustainable [16]. In this context, utilization of branches and twigs derived from the top part of the mangrove trees was the best choice. Mangrove forests will keep their ecological function, conserve their natural services, and lower environmental impact, thus made them sustainable.

However, branches and twigs as aboveground biomass [17] are still less favourable to process and handle because of their drawbacks, such as the higher amount of bark, non-uniform shape and dimension, irregular shrinkage, and high moisture content. Only carpenters or artisans made them as woodcraft materials [18,19]. In addition, to get better strength of a composite board made of both
types of biomasses, the raw materials should consist of a combination of wood particles and flakes [20]. Fortunately, these types of biomasses appear to be attractive feedstock for bio-energy. Traditionally, firewood and charcoal are still widely used as an energy source by rural coastal communities in many islands of Indonesia for decades [12].

In this study, an attempt to produce advanced solid bio-energy in wood pellet and briquette made of mangrove wood branches was chosen because mangrove wood having high heating value [12] might optimize the value of branches wood [21]. The terminology of both wood pellet and briquette can be found elsewhere [22]. A recent publication [23] compared wood pellet and briquette from their dimensions, the first has had shorter diameter and vice versa. Both products have distinct characteristics of burning effects and different device applications from this definition, as presented in Table 1.

| Characteristics       | Wood pellet                        | Briquette                              |
|-----------------------|------------------------------------|----------------------------------------|
| Contact area with air | More extensive contact due to smaller dimension | Narrower contact due to larger size     |
| Ease to burn          | Easier to burn in well-ventilated condition | Need some time to burn, even in good ventilation |
| Velocity to transfer heat | Faster                                | Slower                                 |
| Combustion            | Burn more sufficiently              | Not too sufficient                      |
| Burning time          | Rapid                               | Superior                               |
| Application           | In a smaller device such as pellet stove, furnace, or cooking range | In large and middle scale boilers       |

In this contribution, the first report on an overview of the feedstock derived from branched wood of mangrove trees and then discusses the emerging of the two products solid biofuel (wood pellet and briquette) have been presented here. In this regard, further critical and evaluation focuses on fundamental properties of branch wood of mangrove trees mainly related to suitability for wood energy are required. Therefore, the present study aims to identify the fundamental properties of branch wood of five mangrove species relating to its properties and highlight its potential utilization as solid biofuel, namely wood pellet and briquette.

2. Methods

2.1. Sample selection
The branch wood selected in this study was according to predominant mangrove trees found in Lubuk Kertang Village. This village has been a village partner of our university, and it is located in District of West Brandan, Langkat Regency, North Sumatra which is situated at 04° 02' 34.25" - 04° 05' 27.11" North latitudes, and between at 98° 14' 57.92" - 98° 18' 37.87" - East longitudes [25].

From 15 species found in Lubuk Kertang mangrove forest [25], the five predominant trees were selected to harvest their branch wood, namely api-api (Avicennia marina); mata buaya (Bruguiera sexangula); buta-buta (Excoecaria agallocha); bakau minyak (Rhizopora apiculata); and bakau hitam (R.mucronata). They were part of reforestation program conducted in 2015 [5-6, 25], thus their age was about 5-6 years. In order to confirm the specification as a standard branch wood, the diameter was determined at least 1 cm. For each sample tree, about 3-5 branches with 20-30 cm length were collected, and then the branches were kept in a plastics container. Therefore, there were about 30-50 branches in a plastics container for each species. After arrival in the laboratory, all the branches were seasoned until a constant air-dry weight was achieved. The constant air-dried branches then were kept in a plastics box with species labelling for further use.
2.2. Specimen preparation
The specimens testing from each species were chosen randomly from a plastics box with ten branches and then divided into two groups, bark (B) and without bark (WB). Group of WB was manually debarked using a knife. Before debarking, the specimen was weighed to get the initial weight ($W_0$). After debarking, both weights (wood and bark) were weighed to get wood weight ($W_W$) and bark weight ($W_B$), respectively. Percentage of wood and bark to the specimen (w/w) can be determined using equations (1) and (2), respectively:

\[ \frac{W_W}{W_0} \times 100\% \]  
\[ \frac{W_B}{W_0} \times 100\% \]  

The result of this calculation will then be used for the evaluation of ash content. Ash or mineral content would show their relative abrasiveness to equipment when there is high friction/shear during densification; the higher the ash content, the higher the abrasion [26].

Before placing the ceramic crucible into a furnace with a temperature of 600°C for 2 hours, sample powder of wood and bark with the composition according to the calculation in equations (1) and (2) was prepared. Both biomasses were ground, sieved, and weighed with a total weight of 1.000 grams. Ash content was determined after the biomass was thermally degraded according to National Standard of Indonesia.

2.3. Specimen testing
The physical properties comprised of moisture content (MC) of the wood were determined as described in ASTM D4442 [27]. Determination of density (D) and specific gravity (SG) did not follow ASTM D2395 [28] because dimensions measurements were conducted using vernier calliper even MC and D were calculated at air-dry condition, while SG was determined at oven-dry condition.

2.4. Data analysis
Statistical analysis was conducted using analysis of variance (Anova). Further, Duncan Multiple Range Test was carried out in order to evaluate the difference among the samples.

3. Results and Discussions
Selected specimens of branches mangrove wood have had an average diameter of 1.27+0.10 cm (B) and 1.18+0.14 cm (WB) with a range diameter of 1.05+1.48 cm (B) and 0.95+1.41 cm (WB). These measurements showed that wood branches in this study were relatively small compared to the dimension size of branches of other woody trees. Indeed, dbh (diameter at breast height) of mangrove trees were dominated in the range 10-19 cm. A study in Malaysia [17] showed that this class diameter occupied more than 54%. This class diameter also presumably yielded branches of wood with small size. When the branches were debarked, the percentage of barks showed differences among the species, as presented in Table 2.

| Species                  | Average diameter (cm) | Percentage (%) |
|--------------------------|-----------------------|----------------|
|                          | With bark (B)         | Without bark (WB) | of wood | bark |
| Api-api (A.marina)       | 1.41 ± 0.04           | 1.37 ± 0.05       | 92.42c  | 7.58c |
| Mata buaya (B. sexangula)| 1.19 ± 0.09           | 1.17 ± 0.08       | 89.48c  | 10.52bc |
| Buta-buta (E. agallocha)| 1.29 ± 0.05           | 1.15 ± 0.11       | 82.06b  | 17.94b |
| Bakau minyak (R. apiculata)| 1.20± 0.09           | 1.02± 0.09        | 79.37ab | 20.63a |
| Bakau hitam (R.mucronata)| 1.25± 0.07           | 1.18± 0.10        | 74.92a  | 25.08a |

Api-api or A. marina exhibited the highest content of wood and the lowest content of bark by contrast to that of bakau hitam (R. mucronata) macroscopically and statistically. Anatomical study of
both species [29] showed distinct sub microscopic properties, but this kind of investigation was still required in the next study. Presumably, this condition affected the amount of wood percentage. However, it seemed no correlation with Table 3. Table 3 showed result testing of ash content biomass either woody part or mixed with bark. The data showed that ash or mineral are deposited mainly in the bark. Since the bark was removed from branch biomass, the mineral content decreased. The percentage of ash content was different for each species, indicating that type mineral deposit also differed qualitatively or quantitatively. The use of wood without bark and the absence of other wood treatments such as the addition of preservatives, paints, organic additives led to chemical parameters in produced products in line with virgin wood [30].

Table 3. Ash content of specimen mangrove branches in this study

| Species                  | Ash content (%) |
|--------------------------|-----------------|
|                          | With bark (B)   | Without bark (WB) |
| Api-api (A.marina)       | 3.9             | 2.3               |
| Mata buaya (B. sexangula)| 2.6             | 2.5               |
| Buta-buta (E. agallocha)| 7.3             | 1.7               |
| Bakau minyak (R. apiculata)| 7.3           | 1.5               |
| Bakau hitam (R.mucronata)| 4.8             | 2.7               |

The other essential properties that would influence the resulted wood pellet and briquette were physical properties, such as MC, D, and SG. Table 4 only exhibited original data of MC and SG. Since measurement, the specimen volume using a vernier caliper, result of the calculation was less precise. Therefore, the measured D data will be published in another publication as described in the reference [31]. D data presented here is elaborated data referred to in literature [32].

Table 4. Physical properties of mangrove branches in this study

| Species                  | MC (%)                  | D*) (g/cm³) | SG of | With bark (B)       | Without bark (WB) |
|--------------------------|-------------------------|-------------|-------|---------------------|--------------------|
| Api-api (A.marina)       | 52.48 ± 1.46            | 0.65        | 0.69±0.04 | 0.76±0.09          |
| Mata buaya (B. sexangula)| 44.22±2.01              | 0.74        | 0.77±0.06 | 0.70±0.07          |
| Buta-buta (E. agallocha)| 78.87±2.35              | 0.42        | 0.48±0.02 | 0.42±0.04          |
| Bakau minyak (R. apiculata)| 64.47±7.86          | 0.85        | 0.66±0.08 | 0.62±0.04          |
| Bakau hitam (R.mucronata)| 68.29±1.82              | 0.82        | 0.77±0.06 | 0.73±0.04          |

*) Remarks: this data originated and elaborated from literature [30]

As shown in Table 4, the MC of the branches' wood was high. Generally, MC branch woods with bark were higher compared to those without bark. Regular wood originated from the main stem usually has around 12-13% MC as studied by Manguriu et al. [33]. As aforementioned in the introduction section, typical branches wood has had some drawbacks: higher MC, thus making the shrinkage characteristics higher. Therefore, combination techniques among air drying, sunlight, and high-temperature chamber for treating branch wood as the raw material of wood pellet and briquette are required as work of Cubero-Abarca [34].

The density of wood in many species is largely determined by fibers (which are thick-walled cells composed of cellulose and lignin), the abundance of xylem vessels (which have lumen areas for water transport, decreases wood density), and wood density has also been linked to tree growth rates [35].
Therefore, even though the position was branch wood of mangrove trees, the density value might vary but tends to be high. In this regard, utilizing solid biofuel will be beneficial because it can raise high heating value.

4. Conclusion
Even though only three fundamental properties were presented, namely percentage of bark, ash or mineral content, and physical properties (MC, D, SG), these insights could maximize the value of branch wood derived from mangrove forest as solid biofuel material wood pellets and briquettes.

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