Physicochemical properties and porosity of coconut shell waste (CSW) biomass

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Abstract. Utilizing waste biomass as a reserve energy source can play an essential role in reducing expanding fossil fuel's environmental impact. This paper presented an analysis of physical, chemical, morphological, calorific values and porosity of biomass from coconut shell waste (CSW) as an alternative for biofuel feedstock. The physical properties of CSW biomass were dominated by volatile matter and fixed carbon content of 73.8 and 22.7 (wt.%, DB), respectively. The calorific value is 20.39 MJ/kg, giving a significant energy effect when the biomass is burned. The chemical properties of CSW biomass were dominated by C and O content of 41.04 and 57.47 (wt.%), respectively, contributing most of the oxygen to the thermal process. However, most elements of chemical properties contributed to the formation of ash in the combustor, including minor and major elements (S, K, Si, Al, P, Cl, Ca, Mg, and Fe). Besides, they had a negative effect in the form of slagging in the combustion residue. The porosity analysis of CSW biomass was 67.30 – 72.92%, which was able to increase the size of char particles during the thermal process. The analysis of physicochemical properties and porosity of CSW biomass confirmed that this material could be beneficial as an alternative energy reserve in the future.

1. Introduction
The world's energy demand is increasing gradually to meet the needs of industrial and commercial fields. Meanwhile, it is projected that fossil fuel sources face dwindling reserve sources [1]. The use of renewable energy becomes an alternative way to substitute fossil fuels by converting them into bioenergy. This solution is a promising alternative, can be renewed continuously, is environmentally friendly, and is estimated to contribute >10% of world energy needs; from biomass origin, the agricultural sector contributes a vast biomass resource [2,3].

Indonesia is one of the largest coconut producers in the world. It has a total annual production of up to 3 million tons and is estimated to produce 360 thousand tons CSW. The production of CSW in large quantities certainly requires proper management to maintain the quality of biomass [4]. As primary raw material requirements for biofuel feedstock, it is necessary to pay attention to material quality and characteristics, such as calorific value. However, other factors determine the biomass conversion process between the two extremes of dry and wet. High humidity in the Indonesian environment greatly affects biomass quality related to the absorbed water in the material feedstock [3,5]. The amount of water
content in the biomass affects the energy level required for evaporating. It also significantly determine its combustion behavior in the combustor [6,7].

In order to ensure the thermal process continuity in the reactor, it is critical to know the fundamental characteristics of biomass [8]. Therefore, it is crucial to characterize the biomass material content to find out the various aspects involved in it. Identifying the physical properties content makes it possible to predict feedstock's quality and give the essential data to determine the proper handling mode during thermal processes [9]. Likewise, the chemical properties of biomass become one of the parameters which need to be considered since they determine the amount of energy contained in the biomass, and their inorganic components would affect the formation of ash and slag deposits in the boiler components [10]. Studies that hitherto discuss the thermal characteristics of CSW pyrolysis, such as those of Ali et al. [11], have been reported. However, it is also necessary to know in-depth the characteristics of CSW’s physical, chemical, morphological properties. Moreover, the fundamental research correlated the material porosity with its potential as a fuel feedstock has not been found in the literature.

In this study, the essential characteristics in terms of physical, chemical, morphological, calorific value, and porosity in coconut shell waste (CSW) were analyzed to understand their potential as future and long-term energy reserves.

2. Material and Method

2.1. Material

CSW biomass was obtained from Kalipare traditional market, Malang Regency, Indonesia. It was separated from the outer coconut fiber and then air-dried; after that, it was mashed by means of ground. The powder was then filtered with a standard size of 60 mesh. The powder material was preserved and stored in an airtight bottle and then characterized.

2.2. Proximate and Gross Calorie Value

The composition of the CSW sample’s physical properties was analyzed with ASTM D 3173-17, ASTM D 3174-12, ASTM D 3175-17, ASTM D 3172-13, ASTM D 4239-14e1, and ASTM D 5865-13 test methods, respectively to evaluate contents of moisture, ash, volatile matter, fixed carbon, sulphuric and gross calorific values.

2.3. Chemical composition

Evaluating the chemical composition of CSW samples was determined by Energy-dispersive X-ray (EDX) spectrometry. In order to obtain the image, an FEI Inspect S50 (AMETEX EDAXTSL) x-ray micro-analysis was used through a scanning electron microscope at three magnifications. Based on the scanned image of each magnification, the material porosity could then be determined.

3. Result and Discussion

3.1. Physical properties of CSW

Table 1 showed the physical properties of CSW biomass, including contents of moisture, ash, volatile matter, fixed carbon, sulphuric, and gross calorific value (GCV) in the air-dried analysis or as received (ar) condition and dry basis (db). It was clearly observed that the CSW biomass was dominated by volatile matter 73.8 (wt%, db), followed by fixed carbon 22.7 (wt%, db), moisture content 4.0 (wt%, ar), ash 3.5 (wt%, db), and sulfur 0.10 (wt%, db).

The large percentage of the volatile matter showed the ease level of biomass material for combustion at low temperatures, which impacted high levels of reactivity [6]. It made it easier for the biomass to be more inflammable and reactive for combustion during the thermal process [12]. Volatile matter is the main constituent of biomass matter, including carbon monoxide, hydrogen, methane, oxygen, and other hydrocarbons formed chemically and generated during thermal processes [13].

The second-largest content of CSW biomass was fixed carbon of 22.7 (wt%, db). A high percentage of fixed carbon indicated a large amount of rest material which could be decomposed after the release of volatile matter through gas-phase oxidation so that the large VM/FC ratio affected the reactivity level
of solid fuels [13,14]. It is known that the fixed carbon content of CSW biomass is lower than that of volatile matter, indicating that CSW biomass is more reactive and easier to ignite in the combustion system.

### Table 1. Physical Properties of CSW

| Parameters          | Unit     | *ar | **db | Test Method     |
|---------------------|----------|-----|------|-----------------|
| Moisture content    | wt%      | 4.0 | ---  | ASTM D 3173-17 |
| Ash                 | wt%      | 3.4 | 3.5  | ASTM D 3174-12 |
| Volatile Matter     | wt%      | 70.8| 73.8 | ASTM D 3175-17 |
| Fixed Carbon        | wt%      | 21.8| 22.7 | ASTM D 3172-13 |
| Sulfur              | wt%      | 0.10| 0.10 | ASTM D 4239-14e1|
| Gross Calorific Value | kCal/kg | 4680 | 4875 | ASTM D 5865-13 |

*ar: as received; **db: dry basis

A moisture content level of 4.0 (wt%, ar) indicated relatively little water contained in CSW biomass. The importance of knowing the moisture content in biomass is that it affected the design of the combustor furnace, system efficiency, and combustion behavior. Lower water content was considered more profitable since it required less energy for the evaporation process during the thermal process, and in turn, it increases the combustion efficiency [15]. On the other hand, the higher water content in the biomass could increase the energy level of evaporation; a bigger size of the furnace is required due to a longer residence time of the material in the reactor and more greenhouse gas production release in the atmosphere [16].

Finally, ash and sulfur were present in small levels that are 3.4 and 0.1 (wt.%, ar), respectively. The amount of ash content was influenced by inorganic elements remaining after burning combustible substances [17]. A small percentage of ash content was desirable since it affected overall operating costs (transportation, storage, piping maintenance). The low ash content of CSW biomass was preferred because it was more efficient in disposal costs and the cleaning of slag deposits at the boiler’s bottom [16,18].

Table 1 showed the calorific value of CSW biomass by 4875 kCal/kg or the equivalent of 20.39 MJ/kg. This calorific value was equivalent to the coconut waste studied by Borel et al. [8] at 18.2 MJ/kg and corn silk at 19.50 MJ/kg [19], greater than *N. Oculata* at 16.80 MJ/kg [6], sewage sludge at 16.71 MJ/kg [20] and lower than bituminous coal at 25.44 MJ/kg [21]. The calorific value indicated the measure of the energy amount produced by burned biomass [13]. This calorific value resulted from this research confirms that CSW is strongly possible to be an alternative solid fuel for power generation.

### 3.2. Chemical properties of CSW

The chemical content of CSW biomass was analyzed with SEM and EDX spectrograms. Figure 1 showed the SEM photo of CSW biomass with three magnification variations at 200, 500, and 1000 times. Figure 2 showed the average value of three measurements in CSW biomass chemical elements, including carbon (C), oxygen (O), sulfur (S), potassium (K), silicon (Si), aluminum (Al), phosphorus (P), chlorine (Cl), calcium (Ca), magnesium (Mg) and iron (Fe).

The chemical content of both major elements with a composition >1% (S, K, Si, Al, P, Cl, Ca, and Fe) and minor ones with a composition of 1-0.1% (Mg) are relevant as ash fusing components. During combustion processes, these elements lead to generate adverse effects related to the formation of sediment, fly ash, aerosol emissions, and ash melting. The increase in the melting point behavior of ash is influenced by Mg and Ca elements, but the K element can decrease it [18]. Along with aerosol emissions, the elemental chlorine and sulfur biomass of CSW impacts corrosion in the combustor. However, chlorine (Cl) significantly reduces the melting point of ash. As the melting materials of the ash change due to the decreasing temperature, it causes slag in the combustor and the formation of hard deposits on the heat exchanger tube [6,18].

The concentrations of chemical elements C and O of CSW biomass were 41.04 and 57.47 (wt.%), respectively. The C element contributed to the generation of calorific value, and the O element served...
to supply the oxygen needed for thermal processes [6]. The ratio of C to O elements in the biomass contributed to the reactivity of the feedstock during thermal conversion.

![Figure 1. SEM Images of CSW with (a) 200x, (b) 500x and (c) 1000x magnifications](image)

![Figure 2. Chemical element composition of CSW biomass, where the error bar showed the error in the mean of three replications](image)

3.3. Porosity of CSW

Figure 3 showed CSW biomass porosity analysis results from the SEM photograph with magnifications of 200, 500, and 1000 times. The CSW biomass material at 200-time magnification showed the percentage ratio of porous volume and solid one is 67.30%. A 500-time magnification showed a pore percentage of 72.92%. The analysis of the 1000-time magnification showed that a pore percentage of 69.81%. This qualitative measurement confirmed that CSW biomass microstructure with a large pore percentage increased the char particles product during the conversion process when an endothermic reaction occurred.
4. Conclusion
The physical, chemical, and porosity properties of CSW biomass have been studied. According to the proximate analysis results, the physical properties of CSW biomass are dominated by volatile matter and fixed carbon, which are 73.8 and 22.7 (wt%, db), respectively, which shows that the biomass has high reactivity. The CSW calorific value is equivalent to coal. The analysis of chemical elements indicated that CSW is dominated by C and O, followed by a small portion of inorganics elements of ash formation. These investigative data show the potential of CSW biomass as an alternative fuel. In addition, this work analyzes the porosity percentage of the porous material with a value range of 67.30-72.92%, which supports the increase of char particles product during thermal processes.

Acknowledgments
The authors would like to thank for the financial support from Universitas Negeri Malang to this research.

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