Production and characterization refuse derived fuel (RDF) from high organic and moisture contents of municipal solid waste (MSW)

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Abstract. Many cities in developing countries are facing a serious problems to dealing with huge municipal solid waste (MSW) generated. The main approach to manage MSW is causes environmental impact associated with the leachate and landfill gas emissions. On the other hand, the energy available also limited by rapid growth of population and economic development due to shortage of the natural resource. In this study, the potential utilized of MSW to produce refuse derived fuel (RDF) was investigate. The RDF was produced with various organic waste content. Then, the RDF was subjected to laboratory analysis to determine its characteristic including the calorific value. The results show the moisture content was increased by increasing organic waste content, while the calorific value was found 17-36 MJ/kg. The highest calorific value was about 36 MJ/kg obtained at RDF with 40% organic waste content. This results indicated that the RDF can be use to substitute coal in main burning process and calcinations of cement industry.

1. Introduction
Indonesia and other developing countries are facing serious problem to handle the huge amount municipal solid Waste (MSW). The MSW generated increase with the population growth and economic development. The State Ministry of Environment (MoE), the Republic of Indonesia was estimated the total MSW generated in 2006 approximately 38.5 million ton [1]. This amount is predicted increase to five times by 2020 [2]. Thus this condition lead Indonesia to the serious environmental problems. There are many method can be used to dealing with the MSW, for instant thermo chemical treatment by using incineration, combination mechanical and biological treatment, and bio–gasification, and landfilling. All of these methods has its advantages and disadvantages [3]. For instant, although incineration has been widely used to destroy the MSW due to its capability to reduce the volume of MSW up to 90% of original volume and the energy resulted from the MSW burning can be recovered to generate an electricity or district heating [4, 5]. However, this method is potentially to harmful the environment through the concentration heavy metals content in the bottom ash, as well as the dioxins and furans in flue gas [6, 7].

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Unlike to the incineration, the capability of mechanical and biological treatment to reduce volume of MSW relative small as the recyclable fraction in MSW much low compare to the organic fraction. However, during the biological treatment the organic carbon content of MSW can be reduced, which will be reduce the greenhouse gas emission from the next process (i.e. landfilling). Bio–gasification is biochemical process to convert an organic fraction of MSW to produce biogas, which include anaerobic digestion and fermentation. This method only suitable for homogenous wastes having high percentage of organic biodegradable matter and high moisture content. Whilst the landfilling of MSW is associated with the environmental problems mainly with the leachate and biogas emissions [8].

Although all above method have been successful widely used to treat the MSW, such as technologies are applicable in high GDP countries. In city at the emerging countries such as Banda Aceh, Indonesia, the landfilling still the main method for waste management. Moreover, the landfilling of waste was carried out without any pre–treatment, since the waste management alternatives mentioned above are associated with costs that are beyond economic capacities [9]. In addition, Banda Aceh also faced with a problem of available the energy due to lack of natural resource for energy production. Therefore, the refuse derive fuel (RDF) is a potential MSW treatment options which is can solve both, the waste management problem and energy shortage. Thus the objective of this study is to produce RDF from high organic and moisture contents of MSW, characterize its properties, and to investigate composition of organic waste is suitable for RDF production. Finding of this study is very important for waste management development, particularly in developing countries.

2. Material and Method

2.1. Study area description

Banda Aceh or Banda Aceh is the capital and largest city in the province of Aceh, Indonesia. Banda Aceh city is located in northwestern tip of Sumatra Island coverage an area 61.36 square kilometer which divided into nine sub–districts (shown in Fig. 1) including Baiturrahman, Banda Raya, Jaya Baru, Kuta Alam, Kuta Raja, Lueng Bata, Meuraksa, Syiah Kuala and Ulee Kareng. According to the Statistic Bureau report, the total of populations of Banda Aceh city in 2014 is 249,499 inhabitant spread across these sub–district as shows in Table 1 . Banda Aceh was not frequently the subject of discussion before December 26, 2004, when the earthquake at magnitude 9.3 in Indian Ocean was triggered tsunami waves and hit the western coast of Sumatra island. Banda Aceh was the closest city to the earthquake's epicenter, and severely affected after tsunami wave sweep this city. Based on the central government report, approximately 126,602 people have been killed, 93,638 people was missing, and another 514,150 people was displacement [10].

Table 1. Population, area and population density of nine administrative sub–districts within the Banda Aceh city.

| No. | Sub–district      | Population (persons) | Area (km²) | Population density (person/km²) |
|-----|-------------------|----------------------|------------|---------------------------------|
| 1   | Baiturrahman      | 35,249               | 4.54       | 77.64                           |
| 2   | Banda Raya        | 22,961               | 4.79       | 47.94                           |
| 3   | Jaya Baru         | 24,481               | 3.78       | 64.76                           |
| 4   | Kuta Alam         | 49,545               | 10.05      | 49.30                           |
| 5   | Kuta Raja         | 12,831               | 5.21       | 24.63                           |
| 6   | Lueng Bata        | 24,581               | 5.34       | 46.03                           |
| 7   | Meuraksa          | 18,979               | 7.26       | 26.14                           |
| 8   | Syiah Kuala       | 35,702               | 14.24      | 25.07                           |
| 9   | Ulee Kareng       | 25,170               | 6.15       | 40.93                           |

Banda Aceh 249,499 61.36 40.66

Source: [11]
Approximately 130.7 ton of a MSW is collected within the Banda Aceh city and transported to the landfill site daily. The MSW collection and transportation is undertaken by the Sanitation and Park Department (DKP) of Banda Aceh municipality. The collection was carried out by two methods, first door-to-door collection of waste from various sources in within the city area by using 26 ordinary trucks, 4 compactor trucks and 10 pick-ups. The frequency of waste collection is 1–4 trips per day depend on the population density and volume of waste generated. Second, MSW was collected from temporary disposal station. There is 85 temporary disposal stations across of Banda Aceh area made of container or brick-box located close to the residential and commercial area, hence the community can be disposed their waste into it any time. The DKP will be transported the waste to the landfill site by using arm-roll truck or ordinary trucks 1–7 times per week. At the landfill site, the waste was directly disposed onto the landfill without any preliminary treatment.

3. Results and Discussion

3.1. Composition and volume MSW generated

Result of waste sampling and measuring found that each Banda Aceh people was generated approximately 0.52 kg/capita/day. This amount is small compare to MSW generated in other city such as Kuala Lumpur for about 1.62 kg/capita/day [12, 13], Beijing 0.85 kg/capita/day [14], in Macao 1.52 kg/capita/day [15]. It is can be understood since the waste generation rate was influenced by numerous factors, such as gross domestic product (GDP), norm and culture, waste management policies, consumption habits and lifestyle. In this case, the GDP of Banda Aceh also lower compare to other cities mentioned. In term source of waste, the residential was the larger source of MSW in Banda Aceh. The residential area was contribute for 71.23% of 130.7 ton/day was MSW generated from

Figure 1. Map of Banda Aceh city administrative area.
Banda Aceh. The second large contributor was shop (e.g. copying and printing shop, restaurant, etc.) which is contribute for about 23.54%, while the schools, markets, and offices were contribute for about 4.38%, 0.53%, 0.24% (see Fig. 2(a)), respectively.

![Figure 2. MSW Generated of Banda Aceh (a) by source, and (b) by composition.](image)

As in other developing country, the organic wastes was the major content of MSW generate in Banda Aceh. The composition of organic waste was comprising to 62.74% of total MSW collected. This figure a bit small compare to other study was conducted by Meidiana and Gamse [16], where the composition of organic wastes generated from three classified as big to small cities in java for about 64.5% to 78.1%. On the national level, an average organic waste fraction was about 65% [17]. However, the composition of organic waste found in this study was typical waste in developing countries which is around ±70% organic content [18]. The composition of plastic, paper and cardboard, metals, and glass were 9.45%, 14.57%, 0.85%, and 1.85%, respectively. Whilst, around 10.54% of waste was classifie
d as unidentified waste. Fig. 2(b) is present the composition of Banda Aceh MSW based on wet weight of waste.

### 3.2. Characteristic of RDF

The characteristic of RDF is greatly influence by the proximate (e.g. moisture, ash and volatile contents) and ultimate (e.g. C, H, O, N and S contents, as well as HHV) analysis. These information is very useful to represent the RDF quality. Therefore, the RDF was analyzed proximately and ultimately as presented in Table 2 and compared to the low rank coals from Nagan Raya district, Aceh and the charcoal made of its as reported by Khairil, Irwansyah [19].

**Table 2. Proximate and ultimate analysis of RDF and other fuel.**

| Fuel type | Proximate Analysis (%wt) | Ultimate Analysis (% wt) | Calorific value (MJ/kg) |
|-----------|--------------------------|--------------------------|-------------------------|
|           | Moisture content | Volatile content | Fixed carbon | Ash content | C | H | N | O | S |               |
| Coal 1)   | 11.82     | 46.61     | 38.03        | 3.54       | 58.02 | 5.5 | 1.26 | 35.01 | 0.21 | 22.38 |
| Charcoal 1) | 6.8 | 48.13 | 41.16 | 3.91 | 64.55 | 5.23 | 1.41 | 28.59 | 0.22 | 23.91 |
| RDF 2)    | 6.4       | 8.82      | 75.58       | 9.2        | 49.75 | 9.04 | 10.77 | 28.55 | 1.69 | 24.96 |

Source: [19] and this study.

Table 2 shows that the moisture and volatile contents of RDF is lower than coals and its derived charcoal. In contrary, the ash content of RDF is higher than that fuels. The high content of ash may come from dust of street waste, whilst in the coals and charcoals the ash content is mostly impurities contained in the pore of surface coals. The impurities of coals should be smaller than in MSW, since the coals is quite homogeneous compare to the MSW. The low moisture and volatile contents in RDF probably due to low moisture and volatile contents in its origin wastes, thus apart of them have been
released during the drying process. Whereas in the coals and charcoal the moisture and volatile matters were trapped in the pore space.

Table 2 also present the comparison of ultimate analysis and HHV of RDF from Banda Aceh MSW to coals and charcoals prepared in laboratory furnace under temperature maintained at 250 °C [19]. The data in that table shows that the carbon content in RDF quite small compare to the coals and charcoals, however this figure a bit higher than the carbon content of RDF have been report by Nobusuke, Yoshinori [20]. Nobusuke was produced seven type of RDF from various wastes, including industrial waste, MSW, and synthetic waste. The carbon content of RDF prepare from MSW was ranged 42–44% dry weight. The carbon content of RDF from Banda Aceh MSW also slightly higher than the commercial RDF produced in Italia. The carbon content of RDF in Italia was around 49% with the moisture content for about 25–30% [21]. The similar comparison have been found for the other substances. In contrary to the carbon content, the calorific value of RDF from Banda Aceh MSW is higher to coals and charcoal from Nagan Raya district. Moreover, the calorific value RDF from Banda Aceh MSW about 25–42% high than the minimum calorific value of RDF in Finland, United Kingdom, and Italia. The minimum calorific value of RDF in these countries are about 3,107, 4,469, and 3,585 kcal/kg, respectively [22, 23]. The RDF from Banda Aceh MSW also already meet the minimum calorific value of RDF use as co–fuel for main burning process in cement industry which is required calorific value of 4,780 kcal/kg [24]. This finding indicated that the RDF from Banda Aceh MSW is potentially produce in commercial scale and use to substitute apart of coals consumption in cement industry was located next district. This effort will not only can reduce the green house gas emissions from waste management sector and cement industry, but also can solve the MSW management problem faced by cities in developing country, such as Banda Aceh as well.

3.3. Effect of organic waste content on the RDF properties

As the nature of MSW in developing contain high organic waste and moisture contents may be affect to the RDF quality. Thus, the effect of organic waste content to RDF properties was investigate. Fig. 4. presents the effect of organic waste content on proximate analysis and ultimate analysis of RDF.

Fig. 4 (a) shows the increase of organic content in RDF was not effect significantly to the proximate analysis (i.e. moisture, volatile, fixed carbon and ash contents). This is can be understand since the organic matter mostly comprising carbohydrate (e.g. cellulose, hemicelluloses and lignin) in some waste types (e.g. wood, branch of three), which is completely combustible. However, the moisture content was much increase by increasing the organic waste content. The moisture content of RDF was increase from 3% for RDF without organic waste to be around 10% at RDF containing organic waste for 80%.This was caused by high content of water in the organic waste.

In contrast, the carbon content and calorific value were increase by increasing organic waste content up to 40% of total weight of RDF. The carbon content and calorific value at this composition was about 62 % dry weight and 36 MJ/kg, respectively. This figure 48–59% higher than low rank coal from Nagan Raya district [19] and 90–145% higher than the minimum calorific value of RDF in Finland, UK and Italia [22, 23]. However, carbon content and calorific value was dropped for more organic waste content. The similar trend has been seen for hydrogen content, but it was in lower magnitude. The oxygen content was shows on the opposite response to the carbon content and calorific value, while the nitrogen content tend to increase by putting more organic waste. This may caused by the oxygen content in organic waste decrease during the drying process as the oxygen content tend to deplete by temperature increase. In contrast, the nitrogen content not effect by temperature. This phenomena also found when [19] increase the carbonizing temperature from 250 to 450 °C.
Figure 3. Effect of organic waste content on RDF properties, (a) proximate analysis and (b) proximate analysis.

4. Conclusion
The intention to alternative waste management in developing countries is getting higher due to the impact traditional waste management practice (e.g. landfilling) to the environment become more serious by rapid growth population and economic development. The landfilling of MSW associated with the leachate and landfill gas emissions. Although landfill gas emissions will become negligible within decades, while leachate emissions will be continue to polluted the environmental for hundreds of years. This paper present a study of production and characterization RDF from high organic waste and moisture content of MSW, which nature MSW in the developing countries. The use of MSW to produced RDF can be an option waste management problem and simultaneously the energy shortage due to lack of natural resource for energy. The aim this study is to produce RDF from high organic waste contents, characterization and exploring the best composition of organic waste use for RDF production.
The RDF was produced contain various percentage of organic waste and particle size. Although the organic waste much influenced to the RDF characteristic, the experimental data clearly show that MSW of cities in developing countries, such as Banda Aceh is can use for RDF production. Moreover, the calorific value of RDF was higher than the low rank coal from Nagan Raya district, Aceh provinces and comparatively to RDF produce from different sources and district in Ulsan city, Korea. The calorific value of RDF was resulted heating value ranged from 17 to 36 MJ/kg, which the highest heating value was obtained from RDF with organic waste content 40%. Furthermore, according to the minimum calorific value requirement, the RDF can be use to substitute apart of the coal utilized in cement industry, both in main burning process and calcinations. These can be provides by RDF with organic waste content 40%, which has the calorific value for about 36 MJ/kg.

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