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Original Research Article

The Potential of Landfill Waste in Rembang City as Raw Material for Refuse Derived Fuel (RDF)

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Abstract
The Landoh landfillwas expired in 2022 due to the increasing amount of waste generated. The solution is to extend the service life of the landfill using the landfill mining method. The waste in the landfill is used as raw material for refuse derived fuel (RDF). The aim of the research is to find out the potential of landfill mining at Landoh landfillwhether it can be used as raw material for RDF. Primary data was taken from Landoh landfill in February 2022 with a depth of 1-2 meters and 3-4 meters from the surface of the waste generation and interviews with landfill officials. The waste samples were analyzed for waste composition, moisture content, volatile content, ash content and heating content. The waste composition is dominated by organic waste which has a large moisture content but a small caloric content. From the results of the research that the waste needs to be pre-treated (chopping and drying) for 21 days in order to fulfil the standard values of moisture content, volatile content, ash content and calorific content according to RDF raw material requirements. This method is a solution to overcoming expired landfills, reducing the volume of waste and landfill area requairements.

Keywords: Calorific value; refuse derived fuel; landoh landfill

1. Introduction

The increase in population and economic level as well as consumption patterns of the community each year has resulted in an increase in the volume, variety of types and characteristics of existing waste. All existing components, including households, commerce, health, business, industry, hospitals and schools produce waste every day. The largest proportion of waste currently in the form of food waste contains high moisture content (Zhang et al., 2008). This increase in waste generation will be a challenge in itself in the use of landfill as waste disposal infrastructure (F.R Mujaddidah et al., 2017). The segregation process that is not optimal yet causes accumulation of waste in the landfill which has an impact on reducing the age of the landfill (Najmi, 2018).

Rembang Regency in 2020 has a population of 647,776 people with a total waste generation of 1,762.32 m^3/day. The level of waste handling that has been carried out is 40.52 tons/day. The only landfill available in Rembang Regency is Landoh landfill which will expire in 2022. The landfill has a daily capacity of 232.4 m^3/day or the equivalent of 13.18% of the total waste generation. Landoh landfill's existing condition is 6.24 hectares with a landfill area of 2.1 hectares. So far, the waste that has been accommodated in Landoh landfillcomes from 7 sub-districts out of a total of 14 existing sub-districts, namely Rembang, Sulang, Pamotan, Lasem, Sluke, Kragan and Sarang sub-districts with waste coming from settlements, markets, shops and industry. The management method that has been carried out so far is open dumping where the conditions indicate a moderate level of danger with a risk index value of 592.35 (Dinda, 2018). Piles of waste in landfills have experienced five fires and the last one was in 2019.

A waste management program to reduce the amount of waste generation has been carried out starting from the establishment of a waste bank at the RT level, waste management at the integrated waste management site, assistance for strengthening the capacity of waste managers to both the Regional Government and community groups but the results are still not optimal. The need for innovation to reduce the amount of generation as well as to have the benefit of extending the life of the landfill is by utilizing old waste (mining landfill waste) as an energy source in the form of Refused Derived Fuel (RDF). The purpose of landfill mining is to reduce waste in the available zone, recover waste material so that it can be reused with economic value to obtain new land to accommodate the final residue of waste. This step can be a solution for waste management whose volume continues to increase along with rapid industrialization, population growth and economic improvement (Lei Zhao, 2016). The advantage of RDF as a fuel with a source of waste material is that it has a higher calorific value, is quite constant, homogeneity of the physical-chemical composition, ease of storage, handling and transportation, lower pollutant emissions and reduced excess air requirement during combustion (A Caputo et al., 2002). RDF has a high and constant calorific value, uniform chemical and physical composition, ease of storage, easy handling and transportation and low pollutant emissions. Gendebien (2003) states that the typical composition of RDF is waste in the form of plastic, paper, wood, textiles,

The purpose of this study was to measure the potential of old waste (mining landfill waste) at Landoh landfillas a source of energy in the form of solid material fuel parameters standard. The results of this study can be a solution and reference for other regions in reducing the volume of waste in the landfill while reducing the area of landfill to extend the life of the landfill. The Indonesian government has issued SNI 8966: 2021 to accelerate the use of biomass waste as a raw material for making solid material fuel parameters standard or RDF in power plants (BSN, 2021). RDF is a technique for handling waste by turning waste into something useful, namely fuel.

2. Methodology

RDF is one of the products produced from landfill mining in the form of an alternative fuel that has a calorific value equivalent to coal. According to Nithikul (2007), RDF is a flammable material derived from urban solid waste. RDF is an alternative fuel derived from a mechanical process with mixed municipal waste raw materials where non-combustible waste is set aside to produce a homogeneous mixture. In general, the RDF system has two functions, namely production and combustion. In the production process, recyclable waste such as glass and iron is set aside first so it does not enter the RDF production stage. While other types of waste such as organic waste, paper and plastic can be used as raw materials and chopped to reduce size which is then processed to produce RDF products such as fluff or pellets.

The manufacture of RDF takes advantage of the presence of both domestic and industrial waste which has a high calorific value in very large quantity and quality (TTT Dong & BK Lee, 2009). The main characteristic that must be known when treating waste with a thermal process is the calorific value (Tri Andrianingsih et al., 2018). To find out the potential of RDF raw materials from landfill mining, it is necessary to do composition analysis using SNI 19-3964-1994, characteristic analysis using proximate analysis and calorific value analysis. Proximate analysis was carried out by testing the water content (SNI 03-1971-1990), ash content (ASTM E 830-87), volatile content (ASTM E897-88) carried out in the laboratory of the Department of Environmental Engineering, Diponegoro University.

Analysis was carried out to determine of waste composition analysis, proximate analysis and calorific analysis. Proximate analysis consisting of water content, volatile content and ash content (Gidarakos et al., 2005). All analysis results will be compared with Standard Parameters of Material Fuel from (SNI 8966: 2021) concerning solid material fuel for power plants (BSN, 2021) consist K1, K2 or K3 also standard criteria in various countries such as Europe, England, Germany, Finland and Italy and countries in Asia such as Turkey, Indonesia and Thailand presented in **Tabel 1**.

Table 1. Standard parameters of solid material fuel (SNI) and standard criteria in several countries

Parameter	Standard Parameters of Material Fuel (SNI 8966: 2021)			RDF Standards in Various Countries							
	K1	K2	K3	Turkey	Europe	English	German	Finland	Italy	Indonesia	Thailand
Organic Material Content	≥95	87.5≤x<95	80≤x<87.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Water Content	<15	<20	<25	25	<25	7-28	<20	25-35	<25	<20	<30
Volatile Content	65	70	75	92.3	-	-	50-80	-	-	65-75	-
Ash Content	<15	<20	<25	7.7	<5	12	8-12	5-10	20	N/A	N/A
Calorific Value (Kcal/kg)	≥20 (MJ/kg)	≥15	≥10	3,500	3,585	4,469	-	3,105-3,821.5	3,582.68	3,000	N/A

Source: Gendebien et al, (2003), Nithikul (2007), Kara et al, (2009)

Primary data collection at Landoh landfillby taking waste samples at sample points, interviews with landfill managers and other related agencies conducted in January - February 2022. Sampling was carried out with an excavator and a shovel, put into a plastic sample, coded and each sample was weighed according to its composition followed by testing at the UNDIP environmental engineering laboratory. Each sampling point is taken at a depth of 1 meter and 4 meters from the surface of the pile of waste weighing 2-4 kg. The locations are at point A (-6.760058° and 111.380025°) and point B (-6.760098° and 111.380179°). **Figure 1.** shows sampling points in zone 1 of Landoh Landfill. Sample data to obtain information on waste composition, waste characteristics, moisture content values, ash content values, calorific value and volatile value of existing waste generation. Test results on waste composition, water content, volatile content, ash content and calorific value to find out how big the potential of landfill mining is as RDF raw material

Figure 1. Sampling points in zone 1 of landoh landfill

3. Result and Discussion

3.1 Waste Composition Analysis

The purpose of waste composition analysis is to show how much flammable waste and non-combustible waste is. The composition of the waste is divided into 4 categories, namely flammable waste, non-combustible waste, soil and rock. Combustible waste consists of plastic, organic, wood, cloth and paper. Meanwhile, non-combustible waste consists of glass, metal, stereoform, rubber and ceramics (Izaty, Fatimah Nurul, 2018).

At **Table 2.** the composition of waste at Landoh landfill and the percentage of flammable waste categories dominating all depth sampling points. It is mean that landfill in zone A is suitable for use as raw material for RDF because they contain large amounts of flammable waste. Based on the results of the calculations that have been carried out in **Table 2**, the depth that has the most combustible waste composition is 1-2 meters deep. Combustible waste at a depth of 1-2 meters has a greater percentage variation when compared to waste at a depth of 3-4 meters, starting from waste that is difficult to degrade such as plastic, diapers, maks to easily degradable waste such as organic waste. This is because the waste at a depth of 1-2 meters has not been fully degraded because the age of the waste is still new. The percentage of combustible waste that can be used as RDF fuel at a depth of 1-2 meters are 97,30%, while at a depth of 3-4 meter are 93,17%. From the calculation of the waste composition when compared with SNI standards which can be seen in **Tabel 1**, so the composition in zone A already fulfill the K1 classification standard value. Therefore if all combustible waste at zona A are used as raw material for RDF it can reduce 95.17% of the total volume of waste in zone A, that it means reducing the demand for landfills.

All sample have too many components of organic waste because some of waste sources come from settlements, markets, shops and industry without prior processing into compost. The amount of soil and rock materials is small because the landfill still uses the open dumping method, so there is not a large amount of soil and rock to cover the waste layer.

Table 2. Composition of landoh landfill waste samples based on depth and age of waste

Garbage Age	Sample	Depth(m)	organic	Plastic	Pampers & Masks	Wood	Glass	Rubber & Leather	Metal
3	**A1**	**1-2**	**58.72%**	**27,61%**	**5.76%**	**4.80%**	**0.36%**	**1.2%**	**0.24%**
4	A2	3-4	53.40%	31.54%	13.82%	3.25%	0%	3.9%	1.63%
3	**B1**	**1-2**	**44.96%**	**40.82%**	**2.72%**	**1.13%**	**0%**	**0.91%**	**0%**
4	B2	3-4	58.60%	30.85%	3.38%	0.00%	5.68%	0.54%	0%

Source: Landoh landfill waste sample, 2022

3.2. Proximate Analysis

Proximate analysis was performed to determine the percentage of water content, volatile content, and ash content (gidarakos et al., 2005). The method used refers to the Indonesian National Standard (SNI) and American Standard Testing and Materials (ASTM).

1. Water content analysis

Water content analysis using the gravimetric method. The working principle being that the waste is cut with a diameter of 5-10 cm and then dried in the sun so that all the water contained in the sample evaporates. Testing the water content serves to determine the percentage of water content in waste samples caused by rainwater that enters the waste pile such as plastic waste, cloth, paper and diapers. Measurement of water content is carried out in the laboratory. The test procedure is an empty watch glass heated in an oven at 105°C for 0.5 hours. After that, cool it in a desiccator for ± 10 minutes, then weigh the watch glass and record its mass. If the weight of the watch glass is not constant then put it back in the oven for 1 hour and do so until the weight of the watch glass is constant (a gram). Take each of the existing waste components (organic, inorganic or metal) ± 3 cm² and cut into thin pieces, then mix all the components. After that, put it into a watch glass whose mass is known and weigh again then record the mass (b grams). Heat in an oven at 105°C for two hours, then cool in a desiccator for ±10 minutes. Weigh the glass, watch and trash and record their mass (c grams).

The percentage value of water content at the beginning of the measurement is very high because the amount of water content is influenced by rainfall and rainwater that enters plastic, cloth and paper waste piles. If water content is too high, it will affect the quality of caloric value used as a RDF raw material. The difference in water content was less significant at the beginning, this was due to the recent age of the waste and difference in depth was not too far between sampel point 1 and sample point 2. The depth of waste sample which only ranges from 1-4 meters causes water content almost have the same value and time to start drying. Even though ther are still difference in each point which are affected by rainfall and rainwater trapped in waste such as organic, plastic, masks and cloth.

To get the expected water content value, pre-treatment was carried out. The results of the pre-treatment of the water content test showed at **Table 3**. There was a significant decrease in the water content from beginning to 5th day with a decrease rate between 34.22% - 64.5%, it was due to the chopping, drying and composition of the waste in it. Meanwhile the results of the decrease in water content were not much during the pre-treatment process from 5th until 21st day, namely an average of 0,68% - 12,94%.

The result comparison of the pre-treatment results of the waste sample test with standard SNI parameters for categories K1, K2 or K3 as well as the RDF raw material requirements in various countries as listed in table 1, all waste samples have fulfill the criteria. This proves that pre-treatment serves to reduce the water content.

Table 3. Results of water content of waste samples in landoh landfill

Sample	Depth	Testing Time	Sample Test Results
Sample A1	1-2 meter	Day 0	60.67%
		Day 5	**18.93%**
		Day 15	**13.72%**
		Day 21	**9,37%**
Sample A2	1-2 meter	Day 0	54,37%
		Day 5	**20,15**%
		Day 15	**8,05**%
		Day 21	**7,21**%
Sample B1	3-4 meter	Day 0	52,68%
		Day 5	**17,42%**
		Day 15	**10,48%**
		Day 21	**6,35%**
Sample B2	3-4 meter	Day 0	72,13%
		Day 5	**7,63%**
		Day 15	**7,37%**
		Day 21	**6,95%**

Source: Dept Laboratory. UNDIP Environmental Engineering, 2022

2. Volatile content analysis

Volatile content analysis which function is to find out percentage of volatile content. The volatile parameter depends on the water content, where exothermic phenomena will occur which can slow down biological processes (Rada et al., 2007). The value of volatile content is very important with the aim of reducing biodegradation to obtain the calorific value of waste (Huilinir & Villegas, 2014). Standard criteria for testing volatile content later can become RDF raw material based on America Standard Testing and Materials (ASTM) E 897-88 (2004).

Volatile content analysis using the gravimetric method. The working principle is the waste is heated, after that the volatile part of the waste will be ignited and evaporated. The test procedure is the dry waste sample as a result of determining the water content of the waste is crushed until smooth. After that, weigh the empty crucible which has been heated for 1 hour in a 600˚C furnace and then record the weight. Weigh ± 4 grams of dry and fine sample in a crucible cup and record the weight (a gram). Put the crucible into the 600°C furnace for 2 hours, and add ¼ hour to reach a temperature of 600˚C. Turn off the furnace and let the furnace temperature drop. Remove the cup and let it cool, then put it in the desiccator and weigh the cup (b grams). The results of volatile content of Landoh landfill are shown in **Table 4.**

Volatile content before pre-treatment has complied with SNI requirements (65-75%) are sample A1 of 72.30%; sample B1 of 66.30% and sample B2 of 72.40%. Meanwhile the A2 sample does not fulfill value because exceeds the standard. After pre-treatment, the value of the volatile content increased and did not meet the requirements as a solid material fuel. The volatile level of point A2 only met the requirements after pre-treatment was carried out on the 5th day. Comparison between pre-treatment results of Landoh landfill waste samples and the RDF criteria in Germany and Indonesia, only the pre-treatment results of waste samples A2 and B1 fulfil the requirements. When compared with the requirements of Turkey, all pre-treatment results fulfil the requirements. While the comparison of the results of the pre-treatment of Landoh landfill waste samples with the SNI solid material fuel parameter standards only fulfil the K3 requirements, namely the A2 and B1 waste samples.

The value of the volatile content that has increased and decreased from the beginning to the end of the test reflects that the pre-treatment process which is carried out in a simple way has an effect on the value of the volatile content. The fluctuations in volatile levels in this experiment were due to the non-continuous drying time of the waste, the length of the drying range relying only on sunlight, the lack of frequency of waste turning, all of which affected the test results. The more volatile content in a material, the easier it is for the material to burn and ignite, so that the combustion rate is faster (Artati et al., 2013).

Table 4. Results of volatile content of waste samples in landoh landfill

Sample	Depth	Testing Time	Sample Test Results
Sample A1	1-2 meter	Day 0	**72,30%**
		Day 5	**67,21%**
		Day 15	89,67%
		Day 21	89,60%
Sample B1	1-2 meter	Day 0	82,61%
		Day 5	**66,30%**
		Day 15	**63,23%**
		Day 21	**71,02%**
Sample A2	3-4 meter	Day 0	**66,30%**
		Day 5	**67,44%**
		Day 15	**49,86%**
		Day 21	**74,43%**
Sample B2	3-4 meter	Day 0	**72,40%**
		Day 5	**69,13%**
		Day 15	81,19%
		Day 21	80,99%

Source: Dept Laboratory. UNDIP Environmental Engineering, 2022

3. Ash content analysis

Ash content analysis which function is determine the residue remaining after combustion at high temperatures. Ash plays a role in reducing the quality of solid fuels because it can reduce the calorific value (Fatimah Nurul, 2018). The things that affect the ash content are the composition of the waste, the age and depth of the pile. The higher the residue produced, the more difficult it is to store and transport the residue so that it requires large space and funds.

Ash content analysis using the gravimetric method. The working principle is the waste is heated and later on the volatile parts will ignite and evaporate. The test procedure is that the sample of dry waste as a result of determining the moisture content of the waste is then crushed until smooth. Weigh an empty crucible that has been heated for 1 hour in a 600°C furnace for two hours, preferably ¼ hour more to reach a temperature of 600°C. Then turn off the furnace and let the furnace temperature drop, remove the cup and let it cool down, then put it in the desiccator. Weigh the cup (b gram).

The value of sample ash content at the beginning of test shows that the deeper and longer the age of waste pile, make contained the lower ash content. It can be seen the beginning result ash content that the value of A2 (17.39%) is less than A1 (26.67%) and the ash content value of B2 (27.12%) is less than B1 (29.12%). The conclusion is that difference in the percentage of ash content is influenced by age of waste and dept of waste pile. While the test results after pre-treatment showed an increase and after that decreased. When compared with SNI standard, only A1 (10.33%) sample and B2 sample (18,81%) fulfill qualification. Sample A1 fulfill qualification with Italy, England and Jerman RDF criteria, while sample B2 fulfill qualification with Italy RDF criteria. The test results before and after pre-treatment can be seen in **Table 5**. If ash content exceeds SNI qualification standard, it need a large space to keep combustion residue.

Table 5. Results of ash content of waste samples in landoh landfill

Sample	Depth	Testing Time	Sample Test Results
Sample A1	1-2 meter	Day 0	26.67
		Day 5	32.79
		Day 15	**10.33**
		Day 21	**10.40**
Sample B1	1-2 meter	Day 0	29.12
		Day 5	32.56
		Day 15	50.14
		Day 21	25.57
Sample A2	3-4 meter	Day 0	17.39
		Day 5	33.70
		Day 15	33.67
		Day 21	28.98
Sample B2	3-4 meter	Day 0	27.12
		Day 5	30.87
		Day 15	**18.81**
		Day 21	**19.01**

Source: Dept Laboratory. UNDIP Environmental Engineering, 2022

3.3. Calorific Content Analysis

Calorific value affected by water content and volatile content. Both of these analyzes are influenced by depth of waste pile, where the deeper waste pile, water content decreases so that the volatile content increases. Because there is a relationship between these three things, it can be said that calorific value is also affected by the depth of the waste pile (Fatimah Nurul, 2018).

Calorific content analysis using calorimeter bomb. Materials used are benzoic acid, nickel chrome wire, cotton thread, nickel chrome cup, oxygen, nitrogen and par 6400 calorimeter. The working principle is sample weighed 1,0 gram into the cup, then the nickel chrome wire is connected to the electrode, the cotton thread is tied in two dead knots and placed in the middle of the wire, the oxygen regulator (450 psi) and nitrogen (80 psi) are opened, pressed the on button. Next, press Calorimeter operation on the Calorimeter menu, press heater and pump, wait for start to appear. The start pretest is carried out after the start appears, namely by inserting the electrodes into the calorimeter without threads and a cup, pressing the start pretest. The sample that has been weighed earlier is inserted into the Calorimeter, rotated to the left and closed. Then selected the operating method of determination for samples and standardization for standard benzoic acid. Pressed start sign, pressed sample ID and Enter, pressed ID Bomb, pressed enter, recorded sample weight by pressing enter. Wait until the process is complete, less than 15 minutes. View the data from the analysis results on the print out sheet.

The value of sample calorific content at the beginning of test shows at Table 6, that all samples cannot be used as raw material for RDF because not fulfill RDF criteria. Therefore all initial waste samples were pre-treated and then measured again on days at 5^{th}, 15^{th} and 21^{st}. At **Table 6**, shows an increase in calorific value at all sample points from before to after pre-treatment with an increase in calorific value of 2,815.03 – 5,318.97 Kcal/kg. The standard RDF value requirement in Indonesia is 3,000 Kcal/kg, thus all waste sample points have qualify the average standard value on 15^{th} day during the pre-treatment process. The results of pre-treatment of waste samples against RDF standard values (look at Table 1) in Turkey, Europe, Finland and Italy also qualify the RDF standard requirements. In contrast to the standard RDF value in England which has a value of 4,469 Kcal/kg, only the A2 sample point does not qualify this standard value. The difference calorific value at before and after pre-treatment is influenced by the composition of the waste and the depth of the waste.

Table 6. Results of calorific content of waste samples in landoh landfill

Sample	Depth	Testing Time	Sample Test Results
Sample A1	1-2 meter	Day 0	1.848,04
		Day 5	**3.487,95**
		Day 15	**4.098,02**
		Day 21	**4.663,07**
Sample B1	1-2 meter	Day 0	1.396,24
		Day 5	2.602,10
		Day 15	**4.370,84**
		Day 21	**4.570,50**
Sample A2	3-4 meter	Day 0	967,79
		Day 5	**3.288,97**
		Day 15	**3.860,61**
		Day 21	**4.039,96**
Sample B2	3-4 meter	Day 0	Missed firing
		Day 5	**4.371,02**
		Day 15	**4.393,05**
		Day 21	**5.318,97**

Source: Dept Laboratory. UNDIP Environmental Engineering, 2022

4. Conclusion

Based on the results of waste composition analysis, proximate analysis and calorific analysis, pre-treatment was carried out for 21 days with the expectations results would be in accordance with standard parameters as solid material fuel. Pre-treatment was carried out on day at 21st referring to the waste pre-treatment process using the biodrying method and pre-treatment test were carried out on days at 5th, 15 th and 21 st in the form of a moisture content test, volatile test, ash content test and callorific test.

Analysis composition of waste showed that Landoh landfillwaste sample had a fairly high combustible waste content at all waste sample points with a value between 92.84% - 98.07%. Analysis of water content and calorific content has fulfil the requirements both according to SNI standard material fuel parameters and various countries RDF standard.

Analysis volatile content waste samples need to be improved during the pre-treatment process, especially drying waste sample. Ash content of waste samples also not fulfill the requirements both according to SNI standard and various countries RDF standard, it affects the increase in storage space and residue transportation, also including affects increase funds of process utilizing waste as solid material standard. To support the improvement of value volatile content needs continuous drying process, necessary reversal and large air volume. Increasing volatile content makes material more flammable and ignite, and resulting in a faster burning rate. By improving volatile content, landfill mining at landoh landfill can be used as raw material for RDF.

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