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Study on the Quality Improvement of Mixed Municipal Solid Waste by Greenhouse Blackout Tarp with Biodrying System

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ABSTRACT

At the end of 2020, Talang Gulo Landfill Site 1 in Jambi City was officially closed due to overcapacity. Municipal solid waste disposal has shifted to the Talang Gulo site 2 with a life expectancy of ± 90 years based on the design plan. However, this is difficult to realize because segregation and composting are not optimal, so more than 90% of the waste transported to the final processing site (TPA) is in a landfill. Thus, landfill mining was executed to utilize excavated landfill waste as a material and energy. It was carried out at depths of 3, 5, and 7 meters with an estimated sample age of > 9 years. The mixed landfill samples contained 55.6–66.2% moisture content, 50.3–80.6% volatile content, 19.4–49.7% ash content, 2.6–4.2% fixed carbon, and 3.5–5.7 MJ/kg calorific value. Furthermore, the landfill waste was dried using the biodrying method, combining fresh and landfill waste in the pile composition. The ratio of landfill waste to the addition of fresh waste is 1:0 (control pile), 1:1, 1:2, 1:3, and 1:4. The drying method reduced moisture content of 9–29.1% with a lower calorific value of 5–6.8 MJ/kg. Based on statistical analysis, it is known that waste ratio has a significant effect on moisture content. Based on the weighting results, the optimum mixture ratio is 1:1 (pile 2).

Keywords: landfill mining, biodrying, refused-derived fuel, municipal solid waste, moisture content.

INTRODUCTION

The problem of waste management is the biggest challenge for every city in developing countries, including Jambi City. The volume of waste continues to increase as the population increases, both household and non-household waste. Waste management in Indonesia still uses the end-of-pipe concept. Talang Gulo Landfill accommodates all municipal solid waste (MSW) in Jambi City. The landfill was built in 1997. The amount of waste transported to Talang Gulo Landfill is around 350 tons/kg. The Talang Gulo 1 TPA site is officially closed at the end of 2020 due to overcapacity. Currently, the city of Jambi has a new landfill (site 2) that started operating in early 2021, and the landfill's life expectancy is 90 years. Currently, the level of waste processing at TPA site 2 is still deficient (< 95% of the waste that goes to TPA is buried in landfills). The amount of waste generated is increasing every year, but the level of processing is still low. The new landfill may be filled up quickly by waste, so its lifespan is estimated to be reduced faster than it should be. Landfill mining is the right strategy to restore material and energy resources from past waste within the framework of resource efficiency [Gavelyte et al., 2016]. One of the potential benefits of landfill mining is utilized as Refuse Derived Fuel (RDF). RDF has a calorific value almost equivalent to coal. RDF can reduce the amount of waste and become co-combustion, a secondary fuel for the cement industry and power-producing industries that use solid fuels [Nithikul, 2007]. The moisture content of landfill mining waste ranges from 48% to 66% [Quaghebeur et al., 2013]. This value is still high and does not meet the RDF standard of 10–35% [Gendebien et al., 2003]. Therefore, the moisture content in the waste must be reduced. This can be done by doing pre-treatment. One of the processes that can be done is biodrying. Biodrying aims to remove the moisture content in waste using the heat generated during the aerobic degradation of organic matter [Huilinir and Villegas, 2014; Tom et al., 2016]. In this study, the drying method uses a building similar to a greenhouse with a black tarpaulin cover to prevent solar getting into the drying system and affecting the drying process. This study aims to analyze the composition and characteristics of waste from landfill mining in Talang Gulo so that potential utilization can be known. In addition, research on the biodrying process of landfill mining waste was also carried out to determine the reduction of moisture content in waste based on variations in drying methods and waste composition ratios. The most optimum variation is determined to produce a product according to RDF standards based on the purpose of its utilization.

MATERIALS AND METHODS

In this study, two stages were carried out, namely the implementation of landfill mining to identify the potential for excavated waste from TPA Talang Gulo and the implementation of pre-treatment in the form of drying landfill waste. Variations in the treatment are the waste composition ratio.

Sampling of landfill mining

Landfill sampling was conducted at TPA Talang Gulo, Jambi City, at site 1, which had been closed. Sampling was carried out at one vertical point at a depth of 3, 5, and 7 meters with an excavator. At a depth of 5 and 7 meters, ± 200 kg of samples were taken. While at 3 meters, the samples excavated were ± 800 kilograms. A total of 3–5 kg of samples from each depth is analyzed in the laboratory. Then, the remaining samples were separated by composition using the quadrant method. The data obtained will be analyzed to determine the potential utilization of landfill waste.

Biodrying sample preparation

Samples from a depth of 3 meters are used as feed for drying process waste. The sample's composition was adjusted by adding fresh waste based on a predetermined ratio. Fresh waste comprises organic waste (vegetables, leaves), non-recycled plastic, and paper. In this study, there are five piles consisting of pile 1 (1:0) as the control pile and pile 2 to pile 5 (1:2, 1:3, 1:4) with an adjustment of the mixture ratio of landfill and fresh waste. Adjustment of the composition ratio using the landfill waste composition approach in Jambi City.

Dryer configuration

The drying method used is a passive aerated pile by making a simple aerator made of extended wooden arrangements, and there is a triangular prism-shaped ventilation duct in the middle. The configuration of this study is similar to previous studies [Chaerul and Fakhrunnisa, 2020]. In Figure 1, you can see an illustration of the pile used. The dryer building used measures 4.35 × 3.5 × 2.2 m. Biodrying's covering wall is black tarpaulin. Ventilation also provides air circulation, reducing humidity [Ngamket et al., 2021]. The dryer illustration can be seen in Figure 2.

Analysis of sample characteristics

Initial characteristics test

The parameters analyzed to determine the characteristics of the waste are the proximate test, organic carbon, NTK, and the waste properties

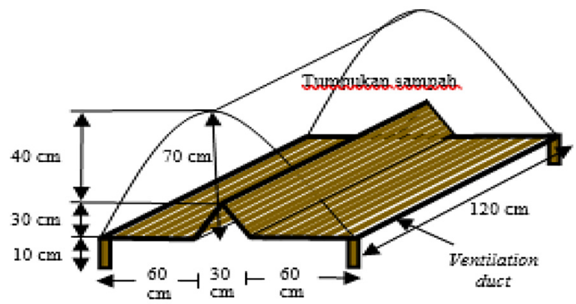

Figure 1. Passive aerated pile configuration

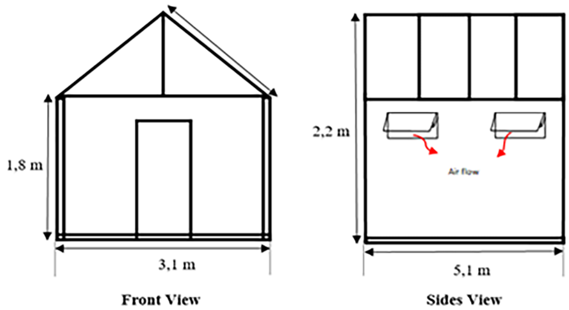

Figure 2. Dryer building

index. Next, the potential utilization of the TPA excavated waste, such as compost, cover soil, recycled material, and RDF, will be analyzed based on the RDF standard according to the intended utilization. Meanwhile, the preliminary test on feed biodrying is proximate. This preliminary test was carried out on mixed waste samples, namely landfill mining waste with fresh waste, to determine the initial characteristics of the sample, especially the value of the moisture content of each pile.

Index properties test

According to SNI 19-1964-1995, waste is sorted manually into several types of waste: organic (food waste and garden waste), plastic, cloth, paper, rubber/leather, metal, glass, soil, and others (stone, ceramics, B3). This study measured density on the landfill's surface (± 1 meter depth). Density measurements were carried out using a box as a reference for waste volume. The waste measured based on the box's volume was excavated and moved into the box earlier. The weight of waste is recorded. Waste size measurements were carried out using a mesh screen measuring 50.8 mm, 38.1 mm, 25.4 mm, 19 mm, 12.7 mm, 9.5 mm, 0.6 mm, 0.3 mm, and 0.075 mm.

Parameter test during the biodrying process

The drying process is carried out for 30 days. Environmental parameters, such as waste and ambient temperature, are measured during waste drying. Measurement of moisture content as the main parameter in this study every three days. Waste temperature measurements were carried out with an analog compost thermometer every day.

Final product characteristics test

At the end of the process, final characteristic tests were carried out as proximate, ultimate (C, H, O, N, S, Cl) tests and calorific values, then compared with the RDF standard. The sample analysis procedure can be seen in Table 1.

Table 1. Sample analysis procedure

Parameter	Standard analysis
Permeability	ASTM D 2434-68
Temperature	SNI 06-6989.23-2005
Moisture content	ASTM D 2216-98
Ash content	ASTM E 830–87
Volatile content	ASTM E 897–88
Fixed Carbon	ASTM D 3175
Organic carbon	Black & Walkley
NTK	ASTM E 778-87
Calorific value	ASTM E 711–87
Sieve analysis	ASTM E 828–81

RESULTS AND DISCUSSION

Composition and density of landfill waste

Plastic waste is the most significant composition, with a 49.94% percentage. Then followed by the soil fraction of 26.35%. This is following previous studies at the Nonthaburi TPA, which found that materials similar to soil (27–57%) and plastic (25–45%) dominate the composition of the landfill excavation [Chiemchaisri et al., 2010]. Meanwhile, the least common composition is paper/cardboard, with a percentage of 0.13%. The paper found was only cardboard or paper protected by plastic, such as cigarette packs, so it is likely that the paper will also be degraded in the landfill. The density obtained on the landfill's surface is 397.5 kg/m^3. In full-scale landfills with moderate to high compaction, the density is between 400–750 kg/m^3 [Tchobanoglous et al., 1993]. The low density can be caused by waste that tends to dry on the surface. The landfill waste composition of the Talang Gulo landfill can be seen in Figure 3.

Landfill waste particle size

Large particles at any depth measuring > 38.1 mm are generally dominated by flammable waste such as plastic, textiles, and wood. In this study, it was found that the average size of large particles

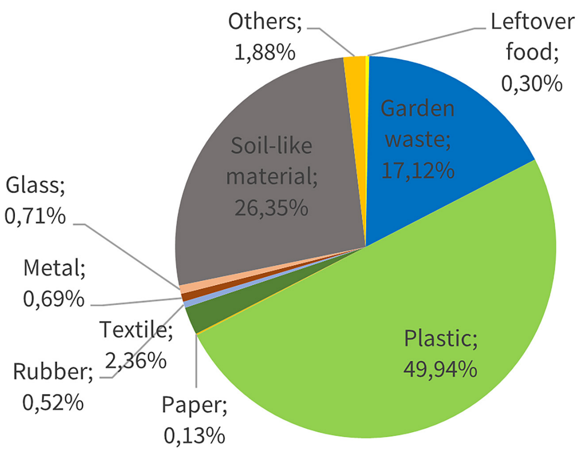

Figure 3. Composition of landfill waste

(> 38.1 mm) at the third depth was around 38.3%, while the rest (61.7%) were smaller-sized particles that were dominated mainly by soil-like materials. The particle size distribution of Talang Gulo TPA landfill waste can be seen in Figure 4.

Landfill waste permeability

The permeability coefficient of landfill waste tends to fluctuate. Waste permeability at a depth of 3.5 and 7 meters, respectively, is 3.52968 × 10–6 cm/s, 2.08474 × 10–5 cm/s, and 1.27575 × 10–5 cm/s: the more plastic, glass, and ash waste, the smaller the permeability coefficient. Conversely, the more food waste, wood, paper, and textiles, the greater the permeability coefficient [Yang et al., 2017]. The small permeability of the 3-meter sample can be caused by the composition of plastic waste, which dominates > 50%. Permeability relies explicitly on the physical characteristics of waste, for example, density, moisture content, particle size, and gas velocity on the surface of the waste layer [Rahardyan et al., 2010]. The smaller the particle size, the smaller the permeability coefficient [Gavelyte et al., 2016]. This follows this study where the particle size at a depth of 3 meters is dominated by particles < 38.1 mm as much as 67.4%. The permeability values obtained in this study can be seen in Figure 5.

Meanwhile, at a depth of 5 meters, there was a lot of garden and plastic waste, and around 59.1% was > 38.1 mm in size. Larger particles will allow more water to pass through so that the permeability of the waste at a depth of 5 meters is higher. At a depth of 7 meters, the plastic composition is more than 50%, and soil waste is around 30% and is dominated by small waste (< 38.1 mm) of 76.7%. Based on the analysis of the three sample depths, it is known that the permeability coefficient is more influenced by the decomposition stage per depth and the particle size distribution.

Potential utilization of landfill waste

Recyclable materials

Based on sorting the composition of the landfill excavated waste, several types of waste cannot be processed into energy, such as glass and metal. However, glass and metal have the potential to be recycled materials. The potential for metal recycling is 3,139.97 tons, and glass is 3,261.92 tons. Utilizing these materials requires pre-treatment, such as sorting (manual/mechanical) and contaminant cleaning. Even though it has been contaminated, recycling glass and metal is more possible from an economic and technical point of view [Kuo et al., 2007]. From a sustainable materials perspective, metals are important because they are non-renewable resources, and their demand and consumption continue to increase, which means that natural supplies continue to decline rapidly [IPCC, 2007; Hermann et al., 2014].

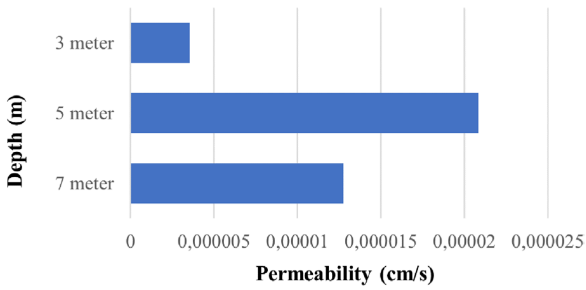

Figure 5. Landfill waste permeability

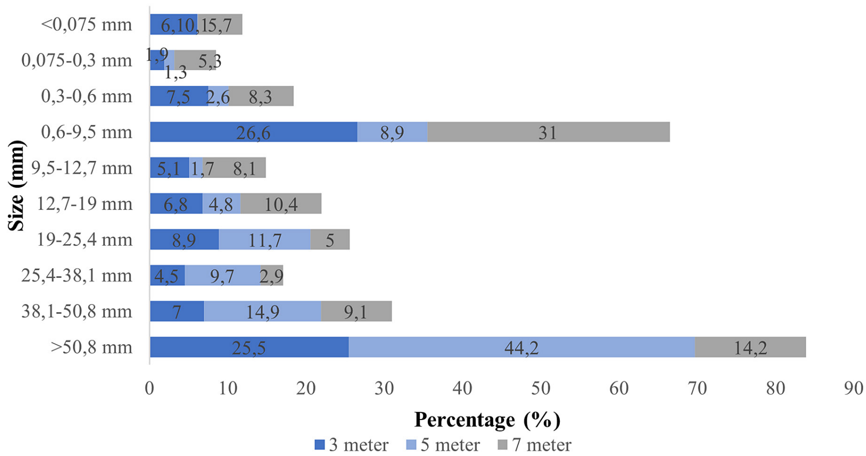

Figure 4. Landfill waste particle size distribution

Compost/ cover soil

The amount of soil fraction that has the potential to become compost and cover soil is around 120,477.5 tons of the total waste. Based on the moisture content in the soil fraction, the landfill did not meet the compost parameter standard with a value of > 50%. In addition, the C/N value is relatively high, reaching 30.54. A very high C/N ratio will make N a limiting factor. Meanwhile, the C/N ratio stimulates better biodegradation [Riadi et al., 2020]. So, to actualize the utilization of excavated waste as compost and cover the soil in waste management at the Talang Gulo Landfill, it is recommended to carry out further research related to efforts to improve parameters that do not meet the requirements, such as adjusting the organic content of compost in the soil fraction. This is done by mixing other materials with high NTK levels so that the C/N ratio can decrease, and a further composting process is needed. In addition, it is necessary to reduce the moisture content of the waste if energy utilization is to be carried out using the thermochemical conversion method. In the advanced stages of this research, waste drying will be carried out using the biodrying method for the Talang Gulo TPA landfill excavated waste for approximately 30 days.

Refused derived fuel (RDF)

A comparison of the characteristics of landfill waste with the RDF standard on SNI can be seen in Table 2. Based on Table 3, it can be seen that the average moisture content of landfill waste is 59.57% and does not meet RDF standards. The average values of ash and fixed carbon content also do not meet RDF specifications, reaching 35.57% and 3.53%, respectively. Meanwhile, the volatile content of 850 °C meets the RDF specifications because it is within the range. The calorific value obtained by excavated waste is deficient and does not meet RDF specifications. The sulfur and chlorine levels obtained are still in the range to meet the RDF specifications.

Landfill mining waste drying as RDF pre-treatment

Based on the analysis of the Talang Gulo TPA landfill mining waste samples, it is known that the moisture content in the waste is very high, and the calorific value of the excavated waste is relatively low. In this study, pre-treatment will be carried out by drying landfill mining waste using the biodrying method. Several parameters are analyzed from the biodrying process, both related to the process and characteristics of the waste.

Temperature

The results of temperature measurements on the five piles in biodrying building can be seen in Figure 6. Temperature is one of the influential factors in the biodrying process. Temperatures in the range of 50–60 °C are considered the most suitable temperature for the biodrying process [Slezak et al., 2019]. Based on the observation of the temperature values on the graph, it can be seen that the dryer temperature tends to be below 40 °C more often. The peak temperature was reached at pile two on the third day, at 51 °C. Meanwhile, piles 1, 3, and 5 reached peak temperatures on the second day, namely 37.5 °C, 56.5 °C, and 58 °C, respectively. The highest temperature occurred in the pile four on the third day, 61 °C. The thermophilic phase of the biodrying process takes place a little faster, ending on the tenth day, to be exact. Then, the temperature in each pile tends to be stable until the thirtieth day. Meanwhile, the temperature of pile 1 tends to be stable since the fourth day and has a gap that is not much different from the outside air temperature.

Table 2. Comparison of characteristics of landfill waste with RDF standards

Parameter	Sample				RDF standard
	3 m	5 m	7 m	Mean	
Moisture (%)	56.9	66.2	55.6	59.6	< 25[a]
Ash content (%)	37.6	19.4	49.7	35.6	8–12[b]
Volatile (%)	66.2	83.2	54.6	68	50–80[b]
Fixed carbon(%)	3.7	2.6	4.2	3.5	< 10[c]
Calorific value (Kcal/kg)	1.201	834.5	1.363	1.133	2.866.2–3.821.5[d]
Sulfur (%)	0.11	–	–	0.11	0.1–0.5[c]
Klorin (%)	0.32	–	–	0.32	0.15–1.5[e]

Note: (a) Italia, (b) Jerman, (c) Inggris, (d) European Commission, (e) Finland.

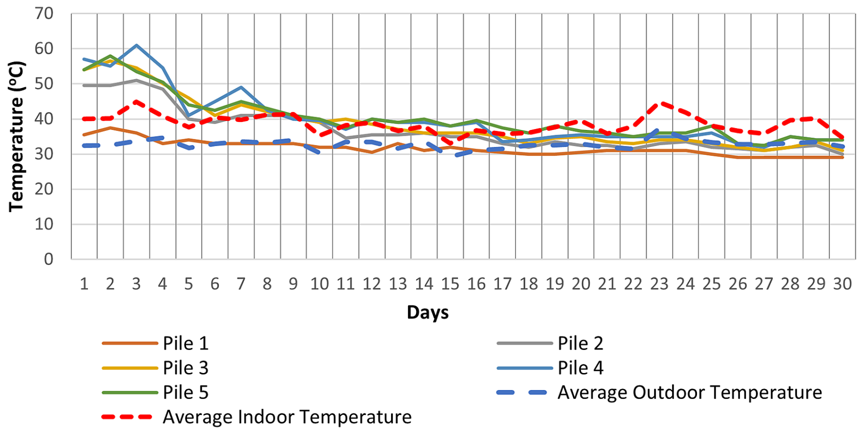

Figure 6. Temperature of biodrying system

Ash content

The results of measuring the ash content in each pile tended to decrease on the 30th day. The highest reduction was achieved by pile B1, which was 21.4%. The ash content of the measurement results can be seen in Figure 7.

Volatile content

A higher volatile content indicates more organic contents inside the food waste; the amount of organic substances is essential, as this material will be biodegraded. The smallest increase in volatile content occurred in pile five at 1.07%, where on day 1, the volatile value was 59.24% and then increased to 60.31%. Volatile levels can be observed in Figure 8.

Fixed carbon

A total of 4 piles experienced a decrease in fixed carbon content, while the rest experienced an increase. This fixed carbon value is influenced by the content of volatile matter and ash, which

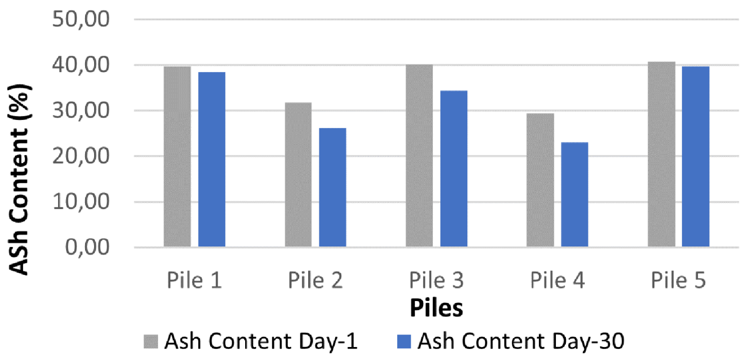

Figure 7. Ash content in all pile variations

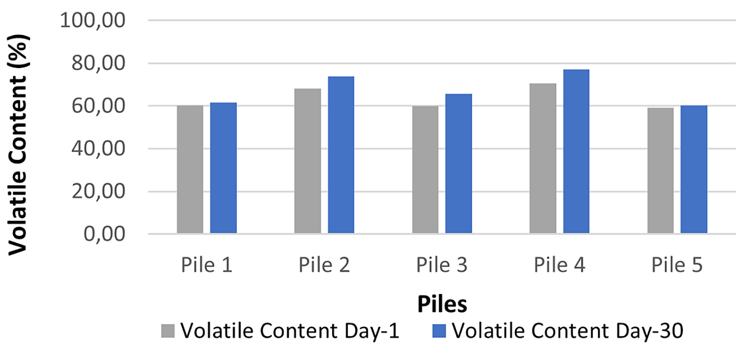

Figure 8. Volatile content in all pile variations

also depends on the influence of the basic composition of the waste. Fixed carbon measurement results can be seen in Figure 9.

Based on the observation of the graph, pile 1 had a constant carbon content of 3.59% on day one and then significantly decreased to 1.32% on day 30. Pile 1, as the control pile, is dominated by plastic waste from landfill excavations containing soil fraction. In contrast, the other piles contain a mixture of fresh waste (organic waste and new plastic and paper waste). Plastic waste from landfill excavations has the highest fixed carbon content compared to other materials. This is caused by plastic waste having undergone a long-term physiochemical reaction process and a soil fraction rich in carbon content attached to the plastic [Widyarsana and Tambunan, 2022]. Compared with this study, the decrease in fixed carbon content in pile one can be caused by the drying process, which releases the soil fraction from the plastic material.

Moisture content

The moisture content of piles during the drying process can be seen in Figure 10. The graph shows fluctuations along the drying process for 30 days. The reduction in the moisture content of the five piles is < 30%. The highest reduction in moisture content was achieved by pile 1 of 29.07%. Pile 1 (control) has the lowest moisture content at the end of the drying process, which can be caused by its composition, which only consists of landfill excavated waste (plastic, coconut fiber), which is dominant with large particles. This causes the waste matrix to have a larger free air space (FAS) so airflow can more easily enter each layer of the waste pile. Paper and plastic waste in the biodrying process acts as a bulking agent (additional material) which gives porosity to the reactor waste pile so that oxygen can enter and make microorganisms more active.

Waste mass and volume reduction

The mass reduction in piles ranges from 41.24–54.52%. The decrease in mass that is linear with the reduction in moisture content is due to the mass being very dependent on the moisture content in the material and the partial degradation of organic matter [Ab Jalil et al., 2016]. The mass reduction of each pile can be seen in Figure 11.

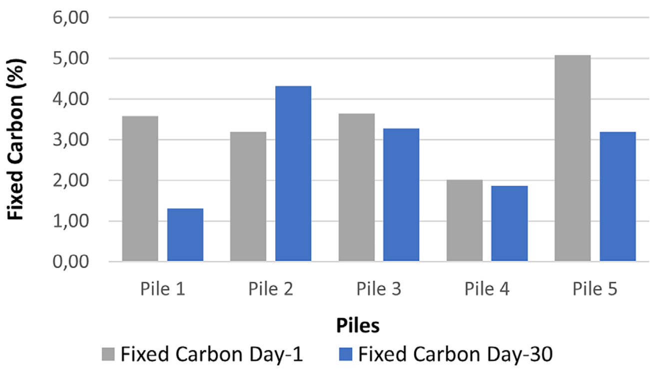

Figure 9. Fixed carbon content in all pile variations

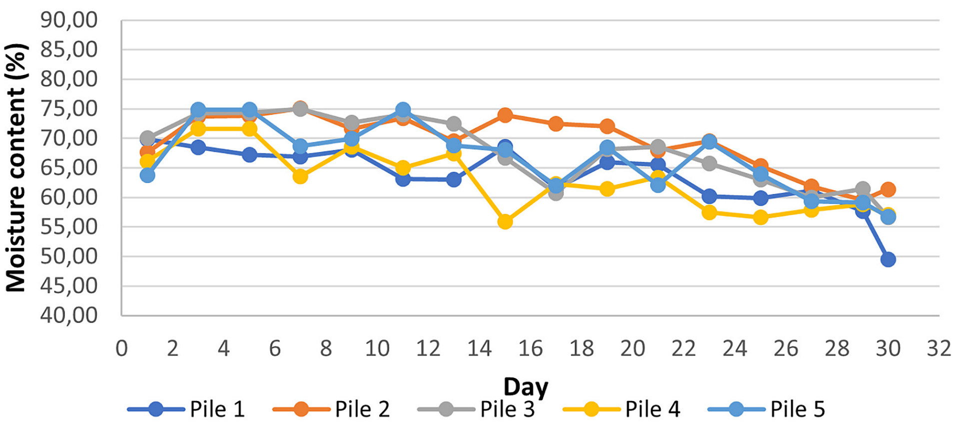

Figure 10. The moisture content of each pile

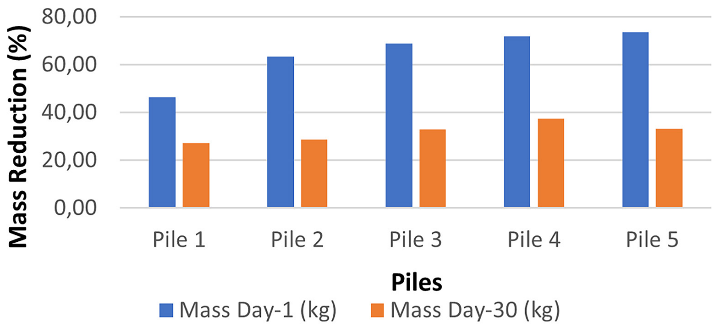

Figure 11. Decrease of pile mass

Volume reduction of each pile ranges from 41.54–44.62%. Overall, pile volume can be reduced by > 40%. These results are similar to the previous study, where the volume reduction was 35.1–43.5% [Tom et al., 2016]. The reduction in pile volume can be seen in Figure 12.

Ultimate analysis

The high and low chemical content in each pile is influenced by biological degradation by microorganisms and the influence of pile conditions. The chemical characteristics of the waste on the 30th day can be seen in Table 3.

Calorific value

The calorific value of the biodrying system ranges from 6.34–7.99 MJ/kg. When it is correlated with composition and moisture content, it is known that samples with low moisture content tend to have a higher calorific value than samples with high moisture content. The moisture content significantly determines the heating value [Pasek et al., 2013]. Data from the measurement of calorific value on the 30th day can be seen in Table 4.

Comparison of product characteristics with standards

A comparison of the quality of RDF obtained with standards in several countries can be seen in Table 5. Overall, it can be concluded that RDF products primarily need to meet the RDF criteria in several countries. The calorific, moisture, and ash values are still relatively high.

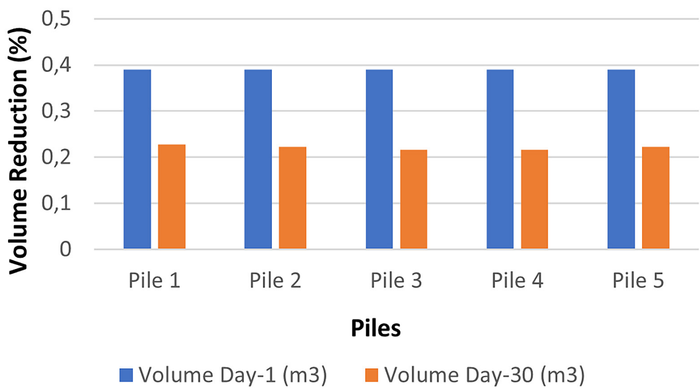

Figure 12. Decrease of pile volume

Table 3. Chemical characteristics of the waste on the 30th day

Samples	C	H	O	N	S	Cl
Pile 1	42.39	4.96	33.22	1.12	0.24	0.52
Pile 2	42.21	4.56	31.01	1.95	0.20	0.57
Pile 3	44.44	5.34	27.62	1.22	0.44	0.53
Pile 4	42.61	5.68	26.14	1.21	0.41	0.57
Pile 5	47.23	6.96	30.93	0.95	0.45	0.67

Table 4. The calorific value of the waste on the 30th day

Samples	Moisture content (%)	HHV (MJ/kg)	LHV (MJ/kg)
Pile 1	49.52	15.83	7.99
Pile 2	61.39	19.13	7.38
Pile 3	56.59	14.62	6.34
Pile 4	57.03	16.63	7.14
Pile 5	56.72	16.75	7.24

Table 5. Comparison of characteristics with RDF standards

Parameter	Samples					Standard
	Pile 1	Pile 2	Pile 3	Pile 4	Pile 5	
Calorific value (MJ/kg)	6.8	5.9	5	5.75	5.9	12–16[a]
Moisture content (%)	49.5	61.4	56.6	57.0	56.7	10–35[a]
Ash content (%)	37	21.8	31.1	21.1	36.5	15–20[a]
Volatile (%)	61.6	73.8	65.6	77.1	60.3	50–80[b]
Fixed carbon (%)	1.3	4.3	3.3	1.9	3.2	> 10[c]
S (%)	0.2	0.2	0.4	0.4	0.4	0.1–0.5[c]
Cl (%)	0.5	0.6	0.5	0.6	0.7	0.15–1.5[d]

Note: (a) European Commission, (b) Jerman, (c) Inggris, (d) Finland

Statistic analysis

Kruskal-Wallis analyzed the effect of the waste ratio on moisture content and showed that both factors had a significant influence. So, it can be concluded that adding fresh waste to landfill waste with a specific ratio affects the activity of microorganisms so that it generates heat, which can indirectly affect the moisture content of the waste.

Selection of optimum variation

Based on the weighting results, the best mixture ratio of landfill waste to fresh waste is 1:1 (pile 2), which results in better RDF quality among other piles with a total value of 602.

CONCLUSIONS

The composition of the excavated waste from TPA Talang Gulo TPA Jambi City consists of 49.94% plastic waste, 26.35% soil fraction, 17.12% garden waste, 2.36% textiles, 0.71% glass, 0.69% metal, rubber 0.52%, paper/cardboard 0.13%, organic food waste (fruit peels and others) 0.3% and other waste 1.88%. Several parameters in landfills still need to meet the standards for their utilization, such as compost, cover soil, or RDF. One of the critical parameters in this study is the moisture content, where the moisture of mixed waste from TPA is relatively high, reaching 56.89–66.24%, while the calorific value is low, 6.41–7.06 MJ/kg. Waste drying using the biodrying method can reduce the moisture content by 9.02–29.07%. The calorific value of the pile ranges from 5–6.8 MJ/kg. Most of the piles still need to meet the RDF standard. Based on the weighting results, the pile variation that produces the best RDF quality is pile 2, with a ratio of landfill waste to fresh waste of 1:1. From the result of the study, it can be concluded that it is still necessary to research another variation of drying method to obtain the best result of product characteristics that meet RDF standard.

Acknowledgment

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