

**Refuse Derived Fuel Production through Biodrying Process (Case study: Solid Waste from Canteens)**Mochammad Chaerul<sup>✉</sup>, Afifah FakhrunnisaDOI: <https://doi.org/10.15294/jbat.v9i1.24609>

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**Abstract**

Due to its calorific value, wastes could be treated into Refuse Derived Fuel (RDF) through several processes. In order to get higher calorific value, moisture content in the wastes could be removed by utilizing the heat generated from decomposition of organic fraction by microorganism (biodrying process). The study aims to treat solid wastes generated from canteens in Ganesha Campus of Insitut Teknologi Bandung into RDF through biodrying process. Through standard sampling procedure, total waste generated from 59 canteens was 228 kg/day and organic fraction became the dominant (74%). There were 3 biodrying piles prepared, namely aeration, windrow, and control pile. Temperature in all piles increased in first and second weeks, then it gradually decreased and the average temperature were between 23-48 °C. The heat generated during the process could be remove water content and the optimum time 17-22 days could reach 20-30% of moisture content. The highest calorific value could be obtained from aerated pile (14.98 MJ/kg). By considering several parameters, the best RDF were produced from aerated pile. The parameters which still did not comply with the international standard of RDF were ash content, fixed carbon, and organic carbon. The quality of RDF was affected significantly by the composition of the feed. Though it could not meet with all parameters as an international standard of RDF, the product could be used as co-fuel to substitute coal or other fossil fuels for industrial activities. By knowing that the wastes could be converted into valuable product, the local municipality may shift the conventional paradigm of the waste management which is only collect-haul-dispose into a new paradigm by prioritizing waste recycle.

**INTRODUCTION**

Solid wastes generated from human activities increase proportionally with the increasing of population and economic level in the community. When the wastes are handled in improper method, various negative impacts could be occurred including reducing public health, aesthetic, and environmental pollution etc. In Indonesia, main method to handle the wastes was landfill. Due to the scarcity of space available for landfill, many cities in Indonesia especially in big cities face the problems. By applying the landfill, valuable material of the

wastes could not be utilized optimally. Thus, many attempts were performed to recycle the waste and convert it into valuable product (Chaerul, 2020, Rusianto et al., 2019, Handayani et al., 2015, Handayani & Wijayanti, 2015, Megawati & Machsunah, 2016). Solid wastes generated from various sources are also potential to utilize them as a fuel, known as Refuse Derived Fuel (RDF), through several processes including biodrying process. Chaerul & Wardhani (2020) have been reviewed in detail recent research regarding with laboratory experiment using various reactors to generate RDF through biodrying process from municipal

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solid waste (MSW). Thus, it needs to enlarge the capacity of waste treated as a field experiment.

Biodrying process aims to remove moisture content in biowastes with high moisture content using the heat generated during the aerobic degradation of organic substances, in addition to forced aeration (Huilinir & Villegas, 2014, Tom et al., 2016). However, biodrying process is slightly different with composting. Biodrying process keeps the organic degradation at minimum level to maintain the calorific value in the wastes, whereas composting process degrades the organic as much as possible for full bio-stabilization aimed at producing topsoil to improve soil quality.

Recently, biodrying has been adopted for MSW with high water content to improve its combustibility and reduce potential environmental pollution during the follow up the thermal process. Shao et al. (2010) reported that the water content of MSW decreased from 73.0% to 48.3% after bio-drying, whereas its lower heating value (LHV) increased by 157%. While, Elnaas et al. (2015) reported that the biodrying process increase the waste calorific value of about 20% (from 16.79 and 15.56 MJ/kg for the untreated waste to 20.61 and 18.87 MJ/kg for the dried material), as consequence of the waste moisture reduction. The calorific value of unprocessed MSW range between 15.56-17.94 MJ/Kg.

The moisture content of the waste matrix is reduced through two main steps: 1) Water molecules evaporate (i.e. change phase from liquid to gaseous) from the surface of waste fragments into surrounding air, 2) The evaporated water is transported through the matrix by the airflow and removed with the exhaust gases (Velis et al., 2009). Elements such as carbon (C), nitrogen (N), and other material contained in waste are consumed by the microorganism to do the metabolic activities that produce heat. This heat with evaporate excess moisture content in the biomaterial (waste). This concept has been applied to treat MSW in many countries in Europe since 1986.

The important characteristics for RDF as a fuel are the calorific value, moisture content, ash content, sulphuric and chlorine content. These values vary according to the sources (i.e. households, offices, construction, etc.), according to the collection system (mixed MSW, source separated) and treatment applied such as screening, sorting, grinding, drying (European

Commission, 2003). There were several studies used in laboratory scale for closed reactor that has modified into certain condition (Sugni et al., 2005, Zhang et al., 2008). The study aims to analyze the characteristics of RDF produced from solid waste generated from canteens in Ganesha Campus of Institut Teknologi Bandung (ITB) using 3 different piles as a field experiment to accommodate microbial activities to remove moisture content (biodrying process) to get higher calorific value.

## MATERIALS AND METHODOLOGY

The study has been conducted in accordance with the standard procedures related to the analysis of solid waste. Detail materials and methods adopted in the study are explained below.

### Materials

Various sources generate MSW in a urban area including from university's premises. Most of universities provide canteens for daily consumption of the students. In this study, MSW generated from different canteens in Ganesha Campus of ITB was used to generate RDF through biodrying process.

### Sampling Method

Sampling method has been conducted in accordance with the Indonesian National Standard number 19-3964-1994. Based on that standard, the waste generation was measured for eight days consecutively in representative number of sample. In the study, the canteens were classified into five categories as explained in Table 1. There were also composition and density measurement for the heaviest canteen's waste generation in each category.

### Variation of Piles

There 3 (three) variation of piles were applied to observe the effectiveness of drying process. Table 2 shows the differences between each piles, namely aerated, windrow, and control pile. The waste for each pile was taken from three different days because of the waste generation availabilities; therefore the height for each pile is different.

In aerated pile, waste was placed on the ventilation duct in the shape of triangle prism-like, as can be seen on Figure 1. The ventilation duct was made from flat-cut bamboos. The base part

Table 1. Sample Size from Canteens in Ganesha Campus of ITB.

Categories	Definition	Sample Size	Population
Buffet canteen	Serve food and beverages in buffet	3	10
Menu canteen	Serve food based only the ordered menu	7	22
Beverages canteen	Serve beverages only	2	5
Snack	Selling packaged food and beverages	4	11
Kiosk	Serve only specific type of food	4	11
Total		20	59

Table 2. Variation of the Piles

No.	Pile	Turning Pile	Aeration	Dimension (meter)		
				Length	Width	Height
1	Aerated	X	V	1.2	1.5	0.75
2	Windrow	V	X	1.2	1	0.8
3	Control	X	X	1.2	1	0.7

Note: X= Not applied, V = Applied

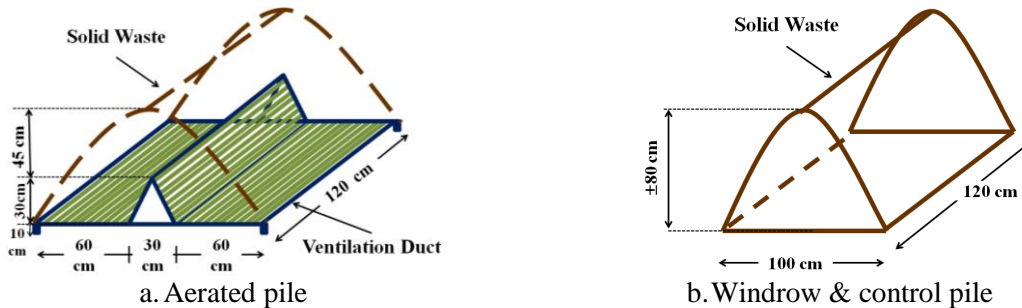


Figure 1. Variation of Piles.

was consisted of 17 sticks (3 centimeter width) and arranged with the range of 0.5 to 0.7 cm, making 16 spaces. For the oblique part, 8 bamboo sticks were arranged as the base part. The ventilation duct construction allows high airflow recirculation to the waste, since the air can flow through the above, under and in the middle of the duct. Therefore, turning process is not needed. The height and wide of the pile between aerated and windrow were set differently to produce relatively same of the volume of the piles.

For variation of windrow and control, waste were placed in the ground and shaped triangle prism -like to keep the waste more stable. Air flow from the top and side of the pile and go through the waste gap, but the air will not maximally recirculate. Hence, for the windrow pile, the turning was conducted once a week to recirculating the air in the pile; meanwhile, turning was not conducted for the control pile.

**Field Work**

The field study was conducted in a tent that constructed from tarpaulin in the side and transparent plastic on top to prevent the rain water

drip into the pile but allow the sun rays. Temperature of pile and surrounding environment, and height of waste were measured daily to observe the condition changes. The pile temperature was measured using mercury thermometer, the surrounding environment was measured using sound level meter (to measure the humidity, temperature, noise level, and light intensity). The pH (acidity level) was measured weekly using pH meter. Measurement in the pile (pH, temperature) and sample for laboratory test were conducted by dividing the pile into 9 sections. For pile temperature, measurement in each section was conducted in the surface ( $\pm$  3-5 cm from the surface) and in the inner of the pile ( $\pm$  20-25 cm from the surface), thus there were 18 measurement points consists of 9 points at the surface and 9 points at the inner.

**Laboratory Work**

The laboratory tests were conducted periodically using sample from all piles above. Those periods of measurement were done according to fluctuation of values and data needed (Table 3). In the third week, the moisture content

Table 3. Parameter Measurement and the Frequency of Measurement.

Parameter	Week 1	Week 2	Week 3 until stable	1 week after stable	2 weeks after stable	3 weeks after stable
Moisture, ash and volatile content	Every 3 day	Every 2 day	Every day	Every 2 day	Every 3 day	On the seventh day
Calorific value, carbon organic & nitrogen content	First day		On the seventh day of stable			

Table 4. Standard Analysis of Parameters.

No.	Parameter	Standard Analysis
1.	Moisture content	ASTM E D 2116
2.	Ash content	ASTM E 830 – 87
3.	Volatile content	ASTM E 897 – 88
4.	Fixed Carbon	ASTM D 3175
5.	Organic Carbon	Black and Walkley
6.	Nitrogen value	ASTM E 778 – 87
7.	Clorin value	ASTM D 4208
8.	Sulfur value	ASTM D 3177
9.	Calorific value	ASTM E 711 – 87
10.	Sieve analysis	ASTM E 828-81

Table 5. Waste Generation from Canteens

Categories	Sample Number	Average (kg/canteen/day)	Population Number	Total generation (kg/category/day)
Buffet canteen	3	10.474	10	104.741
Menu canteen	7	4.848	22	106.657
Beverages canteen	2	0.980	5	4.901
Snack	4	0.507	11	5.579
Kiosk	4	0.573	11	6.306
Total	20		59	228.184

were measured daily until reach stable phase. The pile can be stated has been on stable phase when the moisture content within the same certain range for seven days consecutively. While, standard analysis of the parameters can be seen in Table 4.

Though it may not affect directly to the quality of the RDF produced, Sulfur content was also measured. As stated in the Dulong equation (Eq. (1)) the higher the levels of sulfur in the compound, the higher the calorific value can be generated. Thus, increasing the value of sulfur content is allowed, as long as does not exceed the quality standards RDF.

$$\text{ENERGY CONTENT (Btu/lb)} \\ = 145C + 610\left(\text{H}_2 - \frac{1}{8}\text{O}_2\right) + 40S + 10N \quad (1)$$

## RESULTS AND DISUCUSSION

### Waste Generation and Composition

Measurement of waste generation was performed for 8 consecutive days during the in study period. The measurement results can be seen in Table 5. The average waste generation canteen was 228.184 kg/day with a density of 135.628 kg/m<sup>3</sup>. Since the educational institution has only five working days, there were differences in the amount of waste generated on weekdays and weekends.

Measurement of waste composition was conducted by categorizing waste into leftovers food (organic), paper-cardboard, wood, fabric-textile, rubber, leather, plastic, ferrous metals, non-

metals, glass and others (such as soil, sand, rock, ceramics). Detail composition of canteen's waste can be seen in Figure 2. The three dominant types of waste were then put into the pile, consisted of organic (80 %), plastics (8%), and paper (12%). The metal and glass are separated because they were biologically non-degradable.

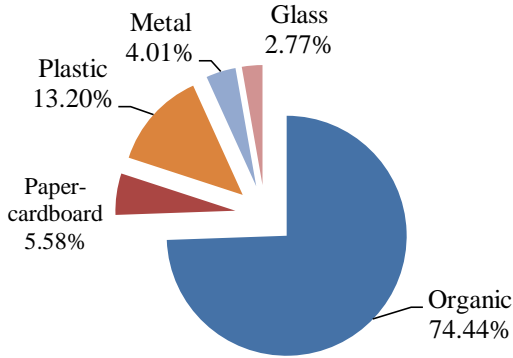


Figure 2. Waste Composition from Canteens

**Temperature in The Pile**

Results of temperature measurement in three piles can be seen in Figure 3. It shows a

tendency that the temperature increase in the first and the second week, then it gradually decrease. It can be seen that the temperature increase of the three piles in the beginning shows similar trend, but longer, pile temperature of control tend to be more stable at high temperatures, while the pile aerated and windrow tend to decrease regularly. This phenomene in line with Frei (2004) research result, which biodrying process occur in temperature range 15-55°C.

In the temperature range of 20-40°C, mesophilic bacteria can optimally live. The activities of microorganism in degraded organic fraction contains in waste produced heat, resulting in the temperature in the pile remains high. Despite the reduction of organic fraction in the pile, pile heating occurs due to sunrays and surrounding environment.

Figure 4 shows the temperature changes that occur in aerated pile. It can be seen that since day 1-21, the inner pile temperature is higher than the surface, then in the following days, the inner and surface pile temperature is about similar. Air, which flow from the triangle (inner) part and

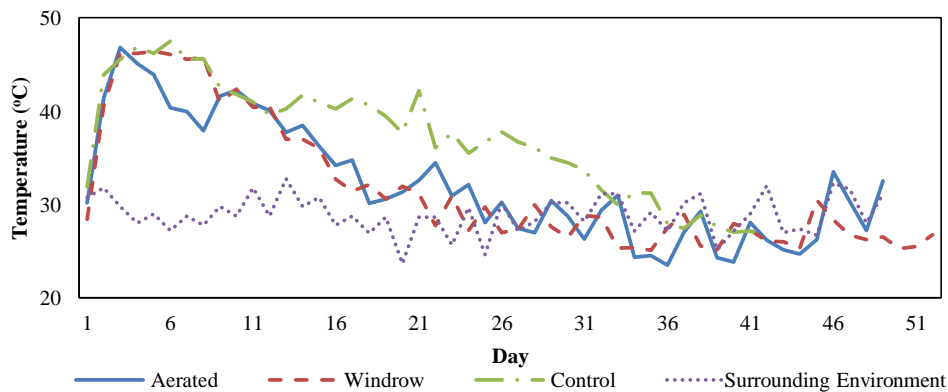


Figure 3. Temperature in the Pile.

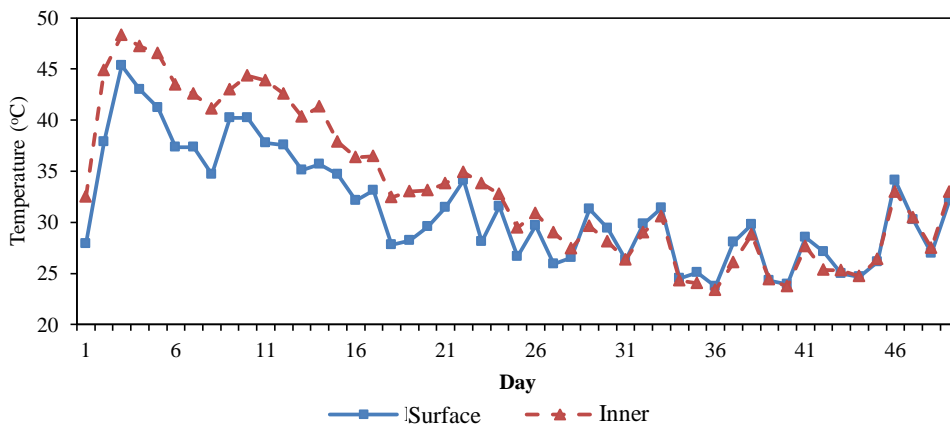


Figure 4. Temperature Changes in Aerated Pile.

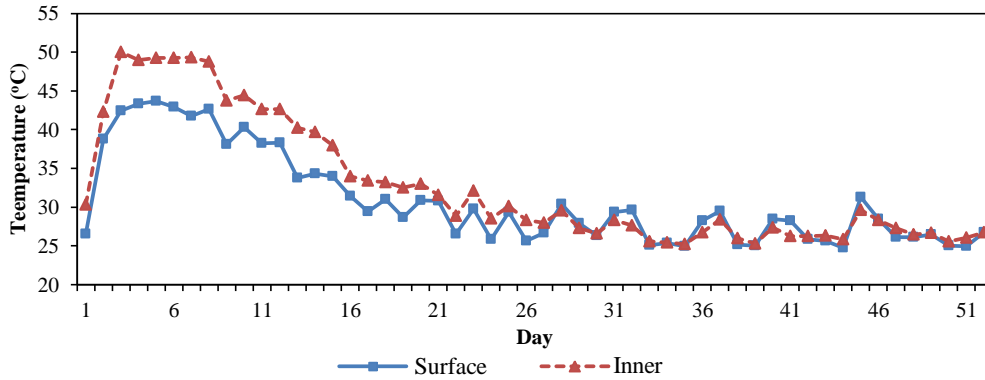


Figure 5. Temperature Changes in Windrow Pile.

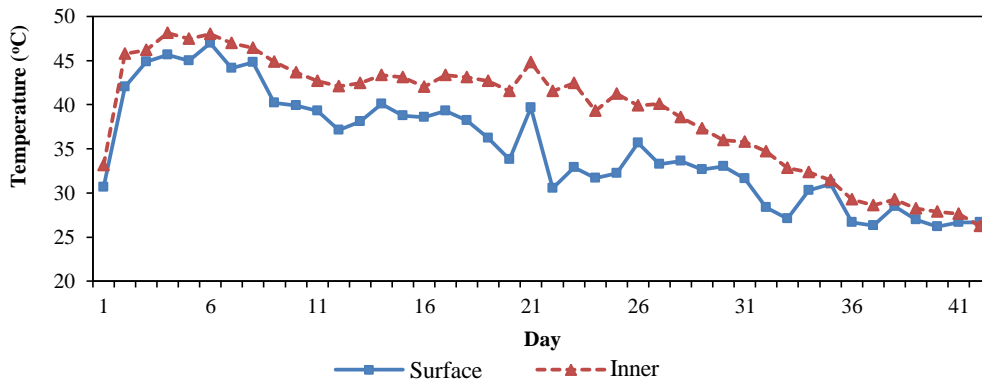


Figure 6. Temperature Changes in Control Pile.

below the ventilation duct, affected considerably the temperature difference between the surface and inner pile, this is in line with Adani et al. (2002). Air flow techniques must be considered, because if the air flow is too high, then the material will be too cool and inhibit the microorganism activities. But if the air flow is too low, then moisture content evaporation will not be significant.

Temperature changes that occur in windrow pile can be seen in Figure 5. Similar to the aerated pile, since day 1-21, the inner pile temperature is higher than the surface. But in the following days, the inner and surface pile temperature is quite similar. In addition, it can be observed that windrow pile temperature tends to stable for every 7 days (at day 9 and 16). This phenomenon can be related to the weekly turning process to avoid poor air distribution and uneven degradation of the waste in the windrow.

Figure 6 shows the temperature changes in control pile. The inner pile temperature is higher than the surface within day 1-34, after that, the temperature decrease gradually until the surface and inner temperature were not too different. Inner control pile was stable in high temperature for

longer period compared with those in aerated and windrow pile. This can be related to the limited air flow circulation in the inner part of the pile, since there was no waste turning.

**Acidity Level (pH)**

Based on weekly measurement, the pH of three pile variation was in range 6.00 – 7.00, this is in line with Sadaka et al. (2011) that stated optimum pH for biodrying process is 5.5 – 8.0. This also can be an indicator that biodrying process was in aerobic condition.

**Volume and Weight of Pile**

Result of volume and weight measurement of three piles variation can be seen on Table 6. Based on the results of this study, it can be seen that the volume and weight reduction that occurred in three pile was in the range of 70-80% and 75-83%. Besides influenced by the reduction of the moisture content of the waste, volume and weight reduction are also predicted to be affected by the activity of the black soldier flies larvae (*Hermetia illucens*, *Diptera: Stratiomyidea*) that were discovered during observations. The

**Table 6.** Mass and Volume Reduction of the Pile.

Pile	Volume			Weight			Measured at Day-
	Intial	Final	Reduction	Intial	Final	Reduction	
Aerated	0.569	0.130	77.16%	109.87	24.47	75.42%	49
Windrow	0.340	0.096	71.76%	99.54	15.32	81.99%	52
Control	0.416	0.086	79.22%	101.63	15.57	82.50%	42

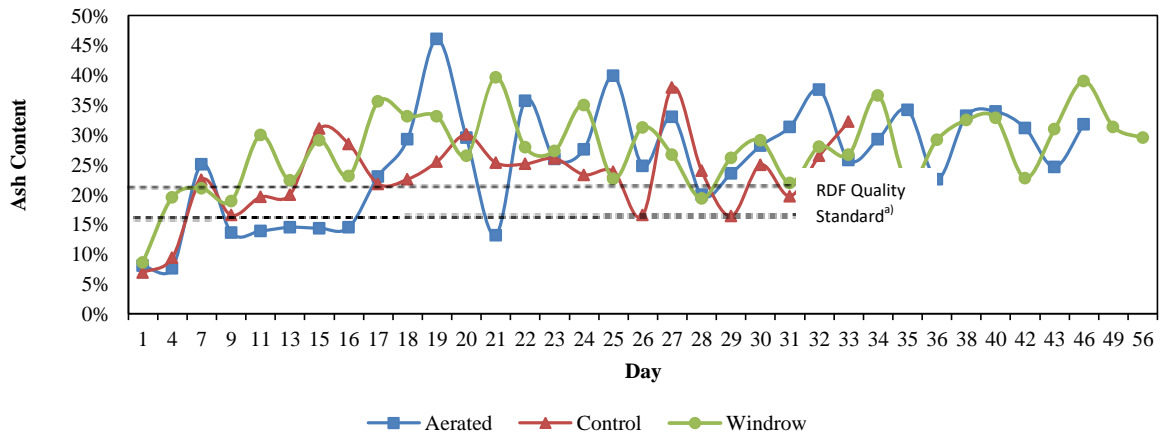


Figure 7. Ash Content.

Note: a) based on RDF quality standard of European Commisison (2003)

differences of volume and weight reduction in three piles can be affected by different pile conditions in support of environmental larvae of the black soldier flies. BSF larvae can reduce 67.9 % of kitchen waste at the optimum temperature 32.3°C (Nguyen et al., 2015).

### Proximate Analysis

Proximate analysis parameters are consist of ash content, volatile content, fixed carbon content, and moisture content.

#### Ash Content

The ash content is burning unburnt residues, therefore the ash content in the waste needs to be reviewed as a consideration for ash storage in the combustion installation. The higher levels of ash in the waste, then the possibility of the formation of the ash will be higher. Ash content measurement results can be seen in Figure 7.

Standard of ash content value for RDF by the European Commission (2003) for the household waste (predominantly organic, as in this study) is in range 15-20 %. From the figure above, it can be seen that the ash content measurement results are likely to increase over time. Based on the compliance of ash content, on day 7 the three pile variations were able to comply the RDF quality standards, but in the following day, the ash

content of each variation exceeds the quality of RDF standard.

#### Volatile Content

Volatile content is a component of waste that will be in gas form in the combustion process. In Figure 8, it can be seen the result of volatile content measurement for three piles. Standard values for the volatile levels based on RDF quality standards Lechthenberg (Germany) is in the range 50-80 %. From the measurement results, the three variations of the pile has reached a value above 50 % volatile content ranging from days to 9 (Aerated and Windrow) and day 21 (Control) then continuously increased but not exceeding 80 %. From the figure above, it can be seen that the level of volatile waste tends to increase over time. Volatile content is generally used to measure the level of biodegradability of an organic fraction of waste, but in its development, the determination of biodegradability is not only influenced by the concentration of volatile matter, but also other content in waste such as lignin.

#### Fixed Carbon Content

Fixed carbon is the material that remains in solid after volatile material is separated (in combustion process). The value of the fixed carbon is affected by the waste basis composition Fixed

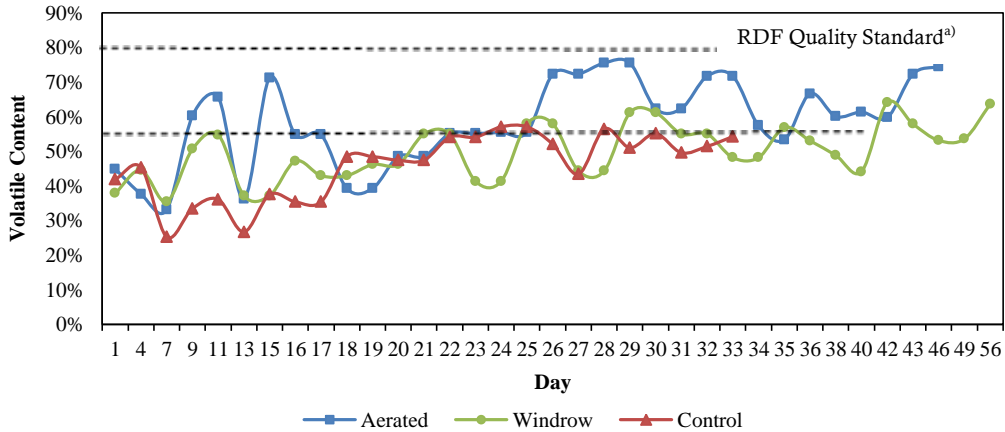


Figure 8. Volatile Content.  
 Note: a) based on RDF quality standard of German (2003)

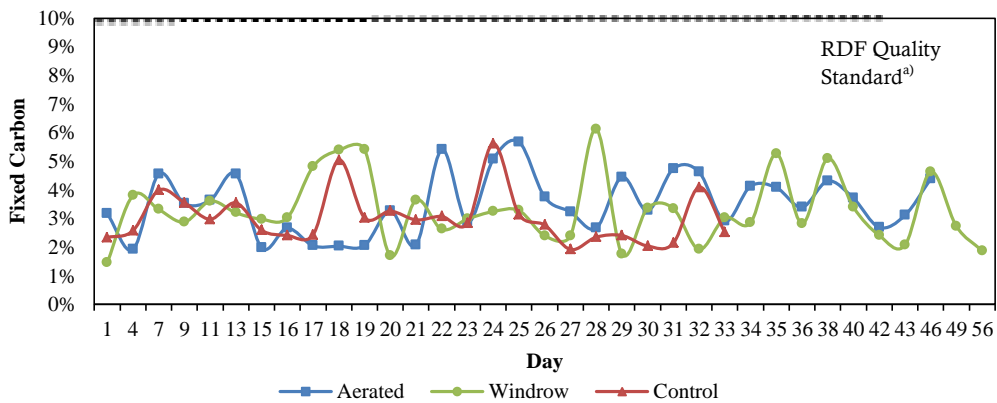


Figure 9. Fixed Carbon.  
 Note: a) based on RDF quality standard of United Kingdom (2003)

carbon content measurement results from sample can be seen in Figure 9. Fixed carbon content standard values based on United Kingdom (UK) RDF quality standard is 10 % dry weight. From the measurement results, it can be seen that the value of the fixed carbon does not reach 10 % of dry weight, even less than 7 %. This can be affected by the differences in the composition of sample (80% organic) and UK standard (80% paper or cardboard). Therefore, the determination of biodrying process optimum time cannot be measured by the fixed carbon content. On the application of RDF, the value of fixed carbon needs to be reviewed as a consideration for ash storage in the combustion installation.

**Moisture Content**

Moisture content is the percentage of water contained in a material, in this study is the waste. The results of measurements of moisture content can be seen in Figure 10. RDF quality standard for moisture content base on European

Commission for the types of waste that comes from household is in the range of 10-35%. Moisture content for aerated windrow, and control pile were under 35% started on day 18, 22, 19, respectively. Based on the calculation of standard deviation (<0.05), the stable time for aerated, windrow, and control pile were ranging from days to 27-33, 29-35, and 19-25, respectively. Fluctuations of moisture content in every pile can be affected by the temperature of the pile and the direction of air flow that carries water vapor out of the pile. It can be correlated with the temperature of the aerated and windrow pile that higher than the ambient temperature in the first 3 weeks (days 1-21). Thus, there was excessive water evaporation that affects the decline of moisture content. After week 3, the aerated and windrow pile's temperature is relatively equal to the ambient temperature and stable, as well as the moisture content measurement results has been quite stable. For control pile, even the temperature of pile is the highest and the first one that stable, but because



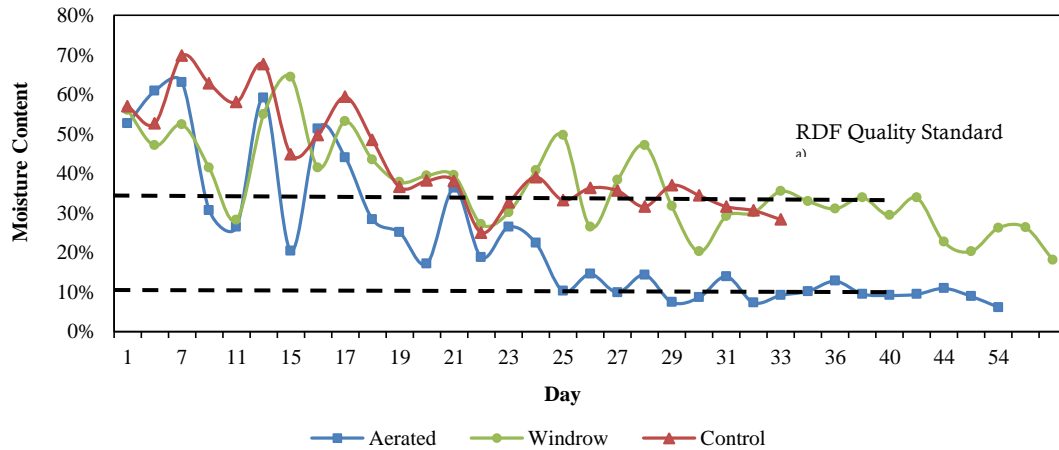


Figure 10. Moisture Content.

Note: a) based on RDF quality standard of European Commission (2003)

Table 7. Chemical Characteristics and Calorific Value

Parameter	Condition	Aerated	Windrow	Control
Sulfur (% weight)	Initial	0.46	0.39	
	Final	0.33	0.46	
	Changes	-28.54%	16.24%	
Chlorine (%weight)	Initial	0.97	0.81	
	Final	0.96	1.68	
	Changes	-1.03%	107.41%	
Nitrogen (%weight)	Initial	2.37	1.66	1.77
	Final	1.63	1.78	1.80
	Changes	-31.48%	7.05%	1.16%
Organic Carbon (%weight)	Initial	46.30	32.12	34.59
	Final	59.59	33.59	39.52
	Changes	28.71%	4.57%	14.27%
Calorific Value (MJ/kg)	Initial	10.11	5.85	7.34
	Final	14.98	9.91	8.25
	Changes	48.23%	69.24%	12.37%

lack of air supplies so the final moisture content is still the highest.

**Optimum time for Biodrying**

Biodrying process aims to accelerate the evaporation of water (Adani et al., 2002), therefore, in determining the optimal time of biodrying process, the moisture content is the main parameter. However, other parameters such as ash content, volatile content, and the content of fixed carbon is also considered to see the chemical characteristics of the waste and RDF compliance to existing standards. Based on Sadaka, et al., (2011) research result, optimum time for biodrying is 21 days. That fact is inline with this research result, aerated, windrow, and control pile were complete the moisture and volatile content at day

18, 22, 19, respectively. Thus, those times can be claimed as the optimum time for biodrying.

In this research it was shown that the moisture content of three piles tends to still fluctuating decrease after reach the minimum quality standard (35%), therefore, in this study the measurement of moisture content continues to be stable. The last day of stable range for these pile variation are 33 days (Aerated), 35 days (Windrow) and 25 days (Control). Final ultimate testing analysis and calorific value is done by using a sample biodrying product from those days.

**Analysis of Chemical Parameter and Calorific Value**

The results of chemical parameters and calorific value in this study can be seen in Table 7.

**Sulfur Content**

The sulfur content in samples were less than 0.5 m/m, this is complying with RDF quality standard in Finland, Italy and UK (European Commission, 2003). The difference of increase of sulfur in windrow and decrease of sulfur in aerated pile could be affected by microorganism biological degradation and influence of pile condition. Increasing the value of sulfur content is allowed, as long as does not exceed the quality standards RDF.

**Chlorine Content**

RDF quality standard in Finland and UK are 0.15-1.5 and 0.3-1.2, respectively, (European Commission, 2003). From the sample's chlorine content measurement, only the product of windrow pile that not complied those standards. In the pile aerated, no significant changes between samples in initial and final results biodrying process (a decrease of 1.03%) which is in line with the Rada & Ragazzi (2014) which states that biological processes do not affect the levels of chlorine in the waste. But the pile windrow, chlorine content increase more than doubled. Measurements of chlorine in the waste is required to minimize the technical problems caused by the alkali chlorine and air pollution that polychlorinated dibenzo -p- dioxins (PCDDs) and polychlorinated dibenzofurans (PCDF), which are harmful to health.

**Nitrogen Content**

Nitrogen content were less than 2.5% by weight, this is complying with RDF quality standard in Finland (European Commission, 2003). In biodrying process, with the influence of temperature and pH, biochemical processes such as nitrification occurs that changes the  $\text{NH}_4^+$  to  $\text{NH}_3$ . This condition can occur in aerobic conditions (available oxygen). In aerobic microorganisms, nitrogen in the waste is required for the metabolism process to form a network of cells.

**Organic Carbon Content**

Organic carbon content in the aerated pile product (59.588%) is close to the Turkey RDF standard (57.5% maximum), while the pile windrow product (33.588 %) and control (39.524 %) already meet with the standard. Organic carbon content in waste can be affected by the living

conditions of microorganisms in the waste. Fraction of organic carbon made up of organic materials soluble or insoluble in water, which can be influenced by presence of bacterial and fungal spores. Fluctuation and differences of organic content in waste can be affected by the difference of microorganisms' presence.

**Calorific Value**

Biodrying product of aerated pile has Low Heating Values (LHV), 14.98 MJ/kg, that meet the European Commission RDF standard for calorific value (12-16 MJ/kg), but not with the variation windrow (9.91 MJ/kg) and control (8.25 MJ/kg). LHV increasement that occurred in the third pile is for 34% (Aerated), 20% (Windrow), and 4% (Control). Those differences in line with the difference in the reduction of the moisture content of the aerated pile, windrow, and control that is 80.83%, 46.37% and 39.21% respectively. Therefore, it can be seen that the moisture content in the waste can be a factor that significantly influences the calorific value. Calorific value is one of the major parameters to determine the efficiency of RDF combustion as fuel.

**Particel Size Distribution**

The particle size is considered to be the RDF standard because it affects the combustion efficiency in terms of surface area to react. In Table 8, it can be seen that the particle size distribution tested in this study. The percentage of particle size (matter) in three piles which is greater than 38.1 mm were as follows; 50.58%, 48.44% and 51.15% respectively for aerated pile, windrow, and control. Types of waste that dominate that particle size are plastic and paper, almost no organic waste. As for the type of waste that goes into a sieve (<38.1 mm) is dominated by organic waste, there were some types of paper and plastic that goes into sieve but in small amounts. The difference of particle size in biodrying product can be affected by biodegradation processes that occur during the process biodrying. Organic waste (food scraps) tend to be more easily biodegradable than other types of plastic and paper waste.

**Selection of Optimum Variation**

Selection of biodrying variations that produce the best RDF quality has been done by weighting the compliance of biodrying product (final sample) to several parameters tested to the

Table 8. Sieve Analysis Result.

Sieve Diameter (mm)		0.425	0.85	2.00	4.75	6.50	12.70	25.40	38.10
% Lose Cumulative	Aerated	2.60	5.26	10.30	23.80	25.57	37.18	47.89	50.58
	Windrow	0.82	2.62	7.89	20.72	23.67	35.66	45.55	48.44
	Control	0.65	3.40	12.63	29.97	31.73	42.31	49.07	51.18

Table 9. Resume of the Characteristics of the Product.

Parameter	<i>Aerated</i>	<i>Windrow</i>	<i>Control</i>	RDF Standard
Calorific Value (MJ/kg)	14.98	9.91	8.25	12-16 <sup>a)</sup>
Moisture Content %w	10.07	30.05	34.63	10-35 <sup>a)</sup>
Ash Content %DM <sup>d)</sup>	28.45	27.17	25.58	15-20 <sup>a)</sup>
Volatile Content %DM	70.15	55.06	52.21	50 - 80 <sup>b)</sup>
Fixed carbon Content %DM	3.70	3.07	3.41	> 10 <sup>c)</sup>
Sulfur Content %DM	0.33	0.46	0.46	0.2 - 0.5 <sup>d)</sup>
Klorin Content %DM	0.96	1.68	1.68	0.15 - 1.5 <sup>d)</sup>
Nitrogen Content %DM	1.63	1.78	1.80	1.0 - 2.5 <sup>d)</sup>
Karbon Organik Content. %DM	59.59	33.59	39.52	< 57.5 <sup>e)</sup>
Drying time (day)	33	35	25	-

Note: a) European Commission; b) German; c) United Kingdom; d) Finland; e) Turkey; f) DM=Dry Mass

RDF quality standards, as can be seen in Table 9. If the parameter complies, then it scored 10, but if it does not comply, then the score is the negative of gap value between the standard and the biodrying product parameter value. Then, that scores were multiplied with a specific weight, based on the importance of that parameters to biodrying process and RDF utilization. The maximum value if all parameters complied are 1.435, the weighting results of the three variations of pile is obtained 866.7, 132.83, 139.21 for variations aerated, windrow, and control respectively. Thus, aerated pile is the most effective biodrying method to achieve the best RDF.

## CONCLUSION

Wastes can be generated from various sources, including from canteen. From 8 consecutively days of sampling, it was predicted that 228.18 kg of waste generated daily from total 59 of canteens available in Ganesha Campus of Institut Teknologi Bandung (ITB). Organic fraction (74%) was dominantly found in the waste stream, followed by plastics (13.2%), paper (5.58%), metals (4.01%), and glass (2.77%). In order to produce Refuse Derived Fuel (RDF) from the wastes, there were 3 biodrying piles prepared, namely aeration, windrow, and control pile.

Due to the heat generated from organic waste decomposition by microorganism, the moisture content in the waste reduced to 20-30%.

It leads also the reduction of volume and weight of the waste in the end of process. By considering the moisture content, the optimum time of drying process for aerated pile, windrow, and control piles were 33, 35, 26 days, respectively.

The most important parameter in the waste as RDF is calorific value. The highest calorific value could be obtained from aerated pile (14.98 MJ/kg) and it meets with the international standard of RDF (12-16 MJ/kg). While the calorific value of RDF generated from windrow and control pile were 9.91 dan 8.25 MJ/kg, respectively. By considering several parameters and its compliance of biodrying product to the international standard of RDF, the aerated pile was the most efficient biodrying method. Though it could not meet with all parameters as an international standard of RDF, the product could be used as co-fuel to substitute coal or other fossil fuels for industrial activities. Thus, RDF generated from wastes categorized as renewable energy resources.

## REFERENCES

- Adani, F., Baido, D., Calcaterra, E., Genevini, P. L. 2002. The Influence of Biomass Temperature on Biostabilization-Biodrying of Municipal Solid Waste. *Bioresource Technology*. 83(1): 173-179.
- Chaerul, M. 2020. Performance of Bioplant for Municipal Solid Waste at Jatiningor

- Campus of Institut Teknologi Bandung. E3S Web of Conferences. 148: 02009 (2020).
- Chaerul, M., Wardhani, A. K. 2020. Refuse Derived Fuel (RDF) dari Sampah Perkotaan dengan Porses Biodrying: Review. *Jurnal Presipitasi*. 17(1): 62-74.
- Elnaas, A., Belherazem, A., Müller, W., Nassour, A., Nelles, M. 2015. Biodrying for Mechanical Biological Treatment of mixed municipal solid waste and potential for RDF production. *Proceeding 3<sup>rd</sup> International Conference on Sustainable Solid Waste Management*. Tinos Island, Greece. 2-4 July 2015.
- European Commision. 2003. Refuse Derived Fuel, Current Practice and Perspectives: Final Report.
- Frei, K. M., Cameron, D., Start, P. R. 2004. Novel Drying Process Using Forced Aeration Through A Porous Biomass Matrix. *Dry Technology*. 22(5):1191-1215.
- Handayani, P. A., Nurjanah, E., Rengga, D.P. 2015. Pemanfaatan Limbah Sekam Padi menjadi Silika Gel. *Jurnal Bahan Alam Terbarukan*. 4(2): 55-59.
- Handayani, P. A., Wijayanti, H. 2015. Pembuatan Film Plastik Biodegradable dari Limbah Biji Durian (*Durio Zibenthinus Murr*). *Jurnal Bahan Alam Terbarukan*. 4(1): 21-26.
- Huilinir, C., Villegas, M. 2014. Biodrying of Pulp and Paper Secondary Sludge Kinetics of Volatile Solids Biodegradation. *Bioresource Technology*. 157(1): 206-213.
- Megawati, Machsunah, E. L. 2016. Ekstraksi Pektin dari Kulit Pisang Kepok (*Musa paradisiaca*) menggunakan HCl sebagai *Edible Film*. *Jurnal Bahan Alam Terbarukan*. 5(1): 14-21.
- Nguyen, T. T. X., Tomberlin, J. F., Vanlaerhoven, S. 2015. Ability of Black Soldier Fly (*Diptera Stratiomyidae*) Larvae to Recycle Food Waste. *Environmental Entomology*. 44(2): 406-410.
- Rada, E. C., Ragazzi, M. 2014. Selective Collection as a Pretreatment for Indirect Solid Recovered Fuel Generation. *Waste Management*. 34(2): 291-197.
- Rusianto, T., Yuniwati, M., Wibowo, H. 2019. Effect Carrageenan to Biodegradable Plastic from Tubers. *Jurnal Bahan Alam Terbarukan*. 8(2): 148-155.
- Sadaka, S., Van Devender, K., Costello, T., Sharara, M. 2011. Partial Composting for Biodrying Organic Materials (FSA1055-PD-4-11N). University of Arkansas: Arkansas.
- Shao, L. M., Ma, Z. H., Zhang, H., Zhang, D. Q., He, P. J. 2010. Bio-drying and Size Sorting of Municipal Solid Waste with High Water Content for Improving Energy Recovery. *Waste Management*. 30(7): 1165-1170.
- Sugni, M., Calcaterra, E., Adani, F. 2005. Biostabilization-Biodrying of Municipal Solid Waste by Inverting Air-Flow. *Bioresource Technology*. 96(12): 1331-1337.
- Tom, A. P., Pawels, R., Haridas, A. 2016. Biodrying Process: A Sustainable Technology for Treatment of Municipal Solid Waste with High Moisture Content. *Waste Management*. 49(1): 64-72.
- Velis, C. A., Longhurst, P. J., Drew, G. H., Smith, R., Pollard, S. J. T. 2009. Biodrying for Mechanical-Biological Treatment of Waste: A Review of Process Science and Engineering. *Bioresource Technology*. 100(11): 2747-2761.
- Zhang, D. Q., He, P. J., Jin, T. F., Shao, L. M. 2008. Bio-Drying of Municipal Solid Waste with High Moisture Content by Aeration Procedures Regulation and Inoculation. *Bioresource Technology*. 99(18): 8796-8802.