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ORIGINAL RESEARCH PAPER

Calorific and greenhouse gas emission in municipal solid waste treatment using biodrying

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ABSTRACT

BACKGROUND AND OBJECTIVES: Urban intensity and activities produce a large amount of biodegradable municipal solid waste. Therefore, biodrying processing was adopted to ensure the conversion into Refuse Derived Fuel and greenhouse gases..

METHODS: This study was performed at a greenhouse, using six biodrying reactors made from acrylic material, and equipped with digital temperature recording, blower, and flow meters. The variations in airflow (0, 2, 3, 4, 5, 6 L/min/kg) and the bulking agent (15%) were used to evaluate calorific value, degradation process and GHG emissions.

FINDINGS: The result showed significant effect of airflow variation on cellulose content and calorific value. Furthermore, the optimum value was 6 L/min/kg, producing a 10.05% decline in cellulose content, and a 38.17% increase in calorific value. Also, the water content reduced from 69% to 40%. The CH4 concentration between control and biodrying substantially varied at 2.65 ppm and 1.51 ppm respectively on day 0 and at peak temperature. Morever, the value of N2O in each control was about 534.69 ppb and 175.48 ppb, while the lowest level was recorded after biodrying with 2 L/min/kg airflow.

CONCLUSION: The calorific value of MSW after biodrying (refuse derived fuel) ranges from 4,713 – 6,265 cal/g. This is further classified in the low energy coal (brown coal) category, equivalent to <7,000 cal/g. Therefore, the process is proven to be a suitable alternative to achieve RDF production and low GHG emissions.

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43	11	2

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INTRODUCTION

Urban intensity and activities instigate the immense production of biodegradable solid waste. Therefore, proper management is required to avoid negative impacts on the environment, through odorous and pollutant emissions in soil, water, gas, and others. The current processing method involving burning or landfill is not optimal, and the availability of space for final processing (TPA) is critical. Also, identifying an alternative new location (TPA area) is difficult and expensive, especially in big cities. Moreover, waste to energy (WTE) technologies has the potential to reduce original waste volume (up to 90%) by recovering the energy, depending on the composition (Patil *et al.,* 2014). The water content is an essential factor in urban solid waste, due to the effects on the efficiency of combustion and conversion of solid waste into energy (Suksankraisorn *et al.,* 2010). However, mechanical biological treatment (MBT) is the prospective choice amongst the methods being developed, because of the environmental-friendly characteristics (Egan *et al.,* 2005). The phenomenon of natural drying, also known as biodrying, is a critical component of the MBT processes, involving the treatment of solid waste through mechanical-biological bioconversions (Rada and Ragazzi, 2015; Velis *et al.,* 2009). During practice, chopped materials with high water content are placed into the reactor. Subsequently, dry solid waste (bio-dried) are produced through a biodrying processes, before subjecting to mechanical treatment. Therefore, the heat generated from the aerobic decomposition process of organic compounds, and excess air are combined to serve as a reliable waste dryer (Velis *et al.,* 2009). Moreover, the solid waste products are also considered as Refused Derived Fuel (RDF), derived from urban, industrial, or commercial waste sources (Scheutz *et al.,* 2014). The RDF is possibly adopted as a substitute for coal (Rada and Ragazzi, 2015), and most of the biodrying process is capable of reducing the water content in solid waste to between 30% and 80% of the initial value (Li *et al.,* 2015; Zhang *et al.,* 2008; Zhao *et al.,* 2010). Furthermore, the quantity removed varies between 3.1 to 10.7 g water/g volatile solid consumed, depending on the preliminary composition and operating conditions (Frei *et al.,* 2004; Ma *et al.,* 2016). The biodrying process is performed in batch conditions, with a 20 days maximum duration, and the raw materials previously treated include manure, pulp mill sludge, food waste, MSW, and sewage sludge. . The final outcome is RDF, which is often used as co-fuel in the cement industry and boiler unit (Garg *et al.,* 2007; Wagland *et al.,* 2011). Colomer-Mendoza *et al.,* (2013) treated gardening waste with 10 reactors, characterized by an air volume of 0.88 to 6.42 L/min/kg (dry weight) and 5% bulking agents implicated in increased weight loss. However, some important aspects, including greenhouse gas emissions have not been studied, as most studies approach this phenomenon from the composting process of solid waste, e.g., sludge. González *et al.,* (2019) discussed greenhouse gases, volatile organic compounds and odor emissions in sewage sludge, without considering possible degradations during the biodrying process. In addition, composting and biodrying serve varied purposes, which require rapid and partial degradation, respectively (Goyal *et al.,* 2005). The characterization of greenhouse gas (GHG) and odorous compounds in solid sludge compost are compiled in a widely published standard scale (Maulini-duran *et al.,* 2013; Rincón *et al.,* 2019), and several related studies have been performed in full scale (González *et al.,* 2019; Shen *et al.,* 2012). In addition, emissions from the biodrying process require advanced studies because of the potential impacts on global warming (Pan *et al.,* 2018), and investigating as an alternative approach to evaluate the release of MSW, and GHG is also important. This study aims to increase the calorific value and evaluate the MSW degradation process through biodrying, and to also provide an in depth evaluation of greenhouse gas emissions. The research was conducted in 2019 at a greenhouse to avoid the disturbance of animals and to ensure optimal manipulation to the desired environmental condition.

MATERIALS AND METHODS

MSW was manually collected from the KORPRI housing complex, Tembalang, Semarang, Central Java, Indonesia, with coordinates -7.061131, 110.446709. The sample characteristics were highly similar to those produced by most people in Semarang city, which were further sorted to determine the percentage of each component (%). In addition, the percent by weight of the MSW component comprises 64% leaves, 12% paper, 16% plastic, 6% uneaten vegetables, 1,73% uneaten of meals, and 0.27% fruit peels. This material was chopped using a chopper measuring 15-20 mm, while the plastic variety was manually cut with a scissors. Subsequently, all MSW components were mixed and measured in terms of volume, before placing into a biodrying reactor. The bulking agent is mature and stable compost measuring ± 10 mm, and comprising 0.051 m^3 of MSW (85% of total volume) and 0.009 m^3 of bulking agent (15% of total volume). Therefore, the MSW volume calculation was based on the maximum reactor capacity of 60 liters (body diameter: 38 cm; total height: 65 cm; weight: 3 kg), while the biodrying reactor was constructed using polyethylene plastic, and equipped with a heat sink (Thermoshield Universal) to minimize heat loss. The reactor base is installed a stainless-steel pipe (Ø3 mm) to ensure uniform air distribution, while airflow variations (0, 2, 3, 4, 5, 6 l/ min/kg) was achieved using an aquarium pump (Resun LP-100). Furthermore, each reactor comprise of sampling holes, measuring a diameter of 7 cm, at a height of 20 cm, 40 cm, and 60 cm from the base. These orifice were tightly closed when not in use. The temperature sensor probes were placed at the top, middle, and bottom area, and the average rate was noted. Moreover, temperature measurements required stainless steel sensors, with waterproof characteristics against the nearest 0.01 °C. The degree of heat was automatically recorded every 15 minutes, and the data is saved as *xlsx* format in an SD card. The temperature probe range was -50 ° C to 200 ° C, while the leachate produced by the reactor was collected, and the volume was measured (if incurred). Fig. 1 shows the biodrying reactor scheme.

The water content parameter was measured using the gravimetric method and the analysis was performed every day, during the biodrying process. This involved measuring and mixing a total of 20 g sample obtained from three different levels of depths (top, middle, and bottom) in triplicate ways, with deviation standard set on <5%. The respective neutral detergent fiber was determined and used to calculate the cellulose content (Goering and van Soest, 1970). In addition, C-Organic was evaluated using the rapid and effective Walkey-Black method, while Nitrogen content was analyzed using the Kjeldahl method, where both assessments were performed in triplicates. Specifically, caloric/heat content was tested using Bomb Calorimeter, while Greenhouse Gas (GHG) sampling was performed at the highest temperature for CO_2, CH_4, and N_2O, using Shimadzu 14A capillary gas chromatograph, equipped with FTD at 250 °C. Limit of Detection CH_4: 0,89 ppm, N_2O: 39,22 ppb, and CO_2: 88,47 ppm. Fig. 2 shows the study flowchart.

RESULTS AND DISCUSSION

MSW degradation rate was analyzed based on the parameters of temperature, water content, cellulose, and SEM (Scanning Electron Microscopy). The GHG emissions consist of CO_2, CH_4, and N_2O.

Temperature Profile

Biodrying is an exothermic phenomenon, where aerobic processes utilize oxygen for microbial activity. In addition, temperature is a significant parameter, which serves as a crucial factor influencing

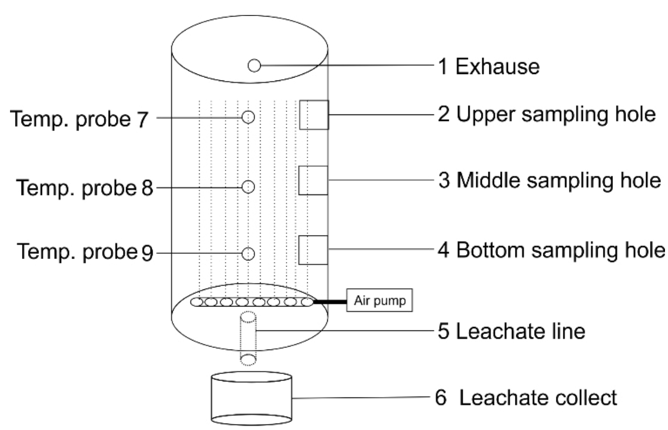

Fig. 1: The biodrying reactor scheme

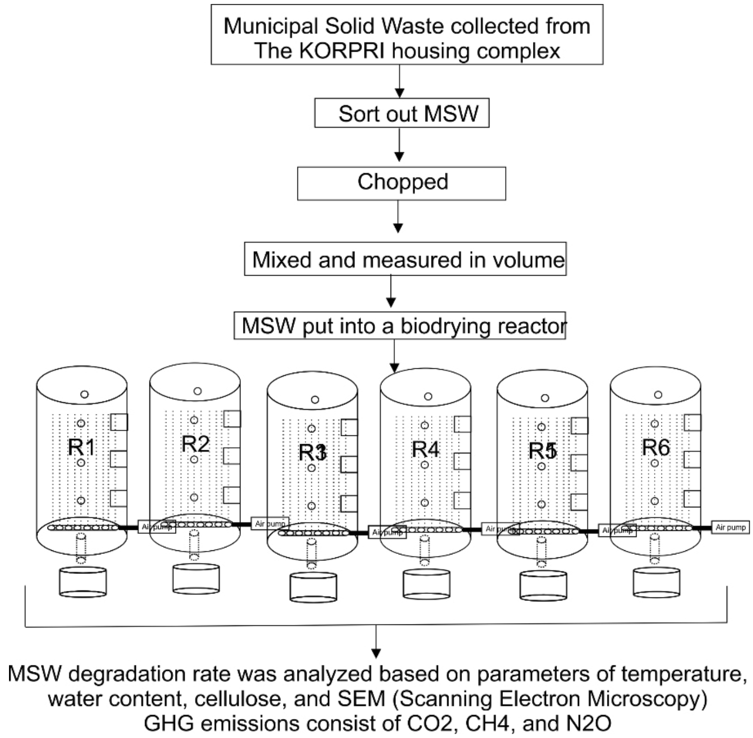

Fig. 2: Flowchart research on calorific and greenhouse gas emission in municipal solid waste treatment using biodrying

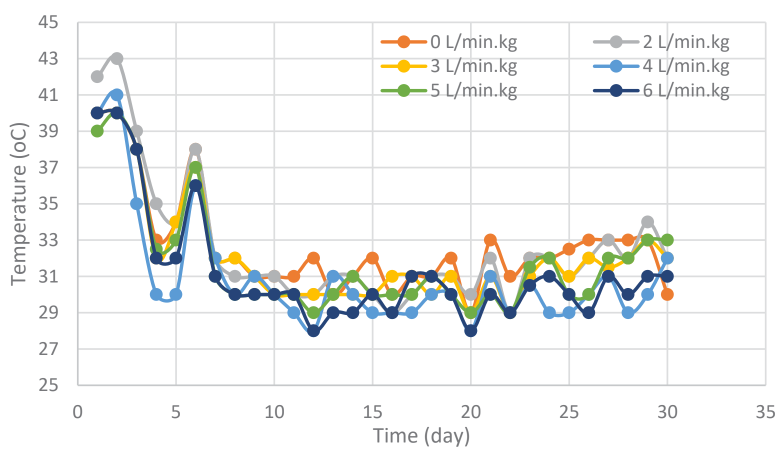

Fig. 3: Temperature profile in the biodrying process for 30 days

water evaporation and organic degradation (Fadlilah and Yudihanto, 2013; Sen and Annachhatre, 2015; Zhang *et al.*, 2008). Moreover, too high or significantly low values have the potential to slow down the drying process, due to the inactivity of decomposer microorganisms, subsequently leading to an incomplete course of action (Sudrajat, 2006). Fig. 3 shows the temperature data recorded in relation to varied air flow.

Temperature was monitored every day for 30 days to assess microorganism activities during the biodrying process (Jalil *et al.*, 2016). Fig. 3 shows the matrix temperature in each variation.

Furthermore, each reactor produces different temperatures, in relation to the distinct MSW decomposition speed, while the airflow rate influences aerobic conditions (Velis *et al.,* 2009). The amount of air in reactor 6 was more than the quantity in reactor 2, hence the variation in speed. Moreover, the highest temperature from reactor 2 (airflow 2 L/min/kg) was 43 °C on the 2nd day, followed by a decline to 39 °C on the 3rd day, and stablility was consequently achieved in the mesophilic phase up to the 8th day. Therefore, the temperature was gradually reduced to 29 °C, and the research outcome was compatible with the study of Sadaka *et al.,* (2011). This stated the presence of a temperature escalation from about 37.7 °C to 48.8 °C during biodrying on day 2 to day 3, indicating a high biodegradation process resulting from substantial microorganism metabolism (Fadlilah and Yudihanto, 2013; Jalil *et al.,* 2016). This is congruent with the report by Jalil *et al.,* (2016), based on a study performed using a reactor. Also, "mesophilic" (35 °C and 40 °C) and moderately "thermophilic" temperatures (40 °C to 45 °C) are more applicable compared to the "thermophilic" type (55˚C to 70˚C). Specifically, Jokiniemi and Ahokas, (2014) reported on the ability for a combination of high temperature and low airflow to slow down the drying process. This condition corresponds to Sadaka *et al.,* (2011). In addition, there is a rise in temperature on the second day, followed by a retraction to ambient level. Also, the moderately thermophilic as well as the mesophilic phases developed on the second and sixth day, respectively. Moreover, relatively uniform (stable) but fluctuating temperature values were recorded from day 7 to 30, ranging from 28 °C – 34 °C. This condition indicates the absence of adequately large microorganism activity required to create biological stability after the biodrying process (Adani *et al.,* 2002). Jalil *et al.,* (2016) recognized a similar condition, in the study using solid waste samples, including food scraps, papers, plastics, and woods.

Water content

Water content is an essential parameter in determining the success of a biodrying process. This constraint influences the chemical reactions associated with microbial growth and biodegradation of organic substances (Tom *et al.,* 2016; Velis *et al.,* 2009). The initial levels at the onset are generally set in the range of 50%-75%. Furthermore, extremely low values lead to reduced microbial activities, while higher amount creates anaerobic conditions. Moreover, water is more dominant in filling pores compared to air, thus limiting the oxygen availability (Colomer-Mendoza *et al.,* 2013; Fadlilah and Yudihanto, 2013; Sadaka *et al.,* 2011). Fig. 4 show the measurement results of water content in each reactor at different aeration airflows.

Water content at the inception of biodrying is not substantially low. Comparably, a significant decline was recorded on day 15, at 63,47% to 23,75% in reactor 1 (0 L/min/kg), 61,22% to 27,77% for reactor 2 (2 L/min/kg), reactor 3 (3 L/min/kg) was 66,26% to 31,84%, reactor 4 (4 L/min/kg) 63,54% to 28,87%, while 66,09% to 38,60% was observed in reactor 5 (5 L/min/kg). This reduction indicates the

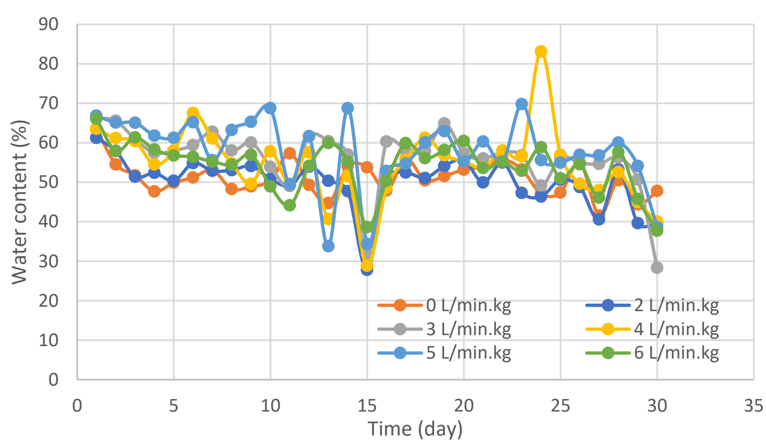

Fig. 4: Water content profile in the biodrying process for 30 days

process effectiveness, according to the literature, which ranges between days 7–15 (Velis *et al.,* 2009). The degradation characteristics of water content is compatible with the research of Jalil *et al.,* (2016), as observed on day 14 (67 ± 0,24% to 33,91 ± 2,24%). According to Adani *et al.,* (2002), it is possible for water content to reduce the decomposition level of solid waste. The level recorded in solid waste increased on day 20 for all reactors, resulting from the addition of water from the condensation process inside the reactor (Widarti *et al.,* 2015). Subsequently, evaporation is performed because of decomposition, and converted into dew on the reactor surface, due to the absence of a steam trap. This dew is further converted into saturated steam, and falls back into the pile of solid waste for another cycle of water content increase. Moreover, the solid waste in reactor 1 comprises a relatively higher water content value of 47.78%, compared to than others. This is due to the configuration without aeration, thus the absence of a biodrying process. Therefore, water content was reduced only through a biological approach (Perazzini *et al.,* 2016). Conversely, reactor 2,3,4,5 and 6 L/min/kg were equipped with aeration, which helped in physical and biological drying (Perazzini *et al.,* 2016; Sen and Annachhatre, 2015), by evaporation. In addition, a change in phase occurs and the liquid is converted to gas, as aeration accelerates the transfer of steam from the inside material to the outside air (Bilgin and Tulun, 2015; Velis *et al.,* 2009). This statement is consistent with Sen and Annachhatre (2015), where higher air flow was assumed to influence the physically dry up of solid waste, and not due to the heat generated by aerobic degradation. The final results of the research comprise the production of solid waste, with the lowest water content of 28.37% recorded in reactor 3 (3 L/min/kg). Based on this research, biodrying successfully reduced the moisture level in solid waste, compared to the control (without bio drying).

C-Organic and Total Nitrogen

C-Organic is a source of energy for the process of decomposition and cell formation, while nitrogen is an element needed by microorganisms for protein synthesis (Siswanto, M. Hamzah, Mahendra, 2012). In addition, both constituents not fully degraded in biodrying, after development with composting, hence the levels are preserved as fuel (Fadlilah and Yudihanto, 2013). Eq. 1 shows the degradation reaction of aerobic process responsible for the production of carbon and nitrogen (Sen and Annachhatre, 2015).

$$COHN + O_2 + \text{Microorganism Aerobe} \rightarrow CO_2 + NH_3 + \text{end product} + \text{Energy} \quad (1)$$

Table 1 shows the C-Organic in this study, and an insignificant decline was recorded from 50.96% - 64.82% at the beginning of the biodrying process to 47,30-60,35% after 30 days. This reduction indicates the usefulness of low carbon consumption in increasing the calorific value (Colomer-Mendoza *et al.,* 2013). However, the carbon content escalated on the 6 L/min/kg airflow, due to high level of aeration. This is assumed to inhibit microbial activity to the extent where proper organic compounds degradation is impossible (Colomer-Mendoza *et al.,* 2013; Sadaka *et al.,* 2011).

Table 1 also shows the decline in total Nitrogen (dry matter) during the 30 day period, from an initial value range of 1.07% - 1.63% to about 0.62% - 1.45%. This constituent is volatile and lower levels have been implicated in slower organic matter decomposition (Widarti *et al.,* 2015), therefore leading to the absence of any overall research sample degradation,

Table 1: C-Organic and Total Nitrogen in the biodrying process

Airflow (L/min/kg)	C-Organic (%)				Total nitrogen (%)			
	day				day			
	0	2	15	30	0	2	15	30
0	64.82	64.37	32.89	52.62	1.23	0.96	0.45	0.90
2	76.53	77.66	49.67	60.35	1.63	0.97	0.48	1.45
3	79.08	76.31	46.77	47.30	1.30	1.32	0.46	0.62
4	67.69	65..64	44.54	52.19	1.21	1.07	0.39	0.63
5	66.59	72.41	40.34	49.94	1.44	0.87	0.41	0.66
6	50.96	86.67	47.36	53.75	1.07	0.73	0.53	0.64

and for further application as fuel (Fadlilah and Yudihanto, 2013). This research corresponds with the study of Colomer-Mendoza *et al.,* (2013), where a sample garden solid waste was used in the absence of any additional bulking agents, and treated with varied airflow.

Cellulose

Under aerobic conditions, the microbes in the biodrying process have the ability to degrade semi-biodegradable organics, which is challenging as observed with cellulose (Wardhani *et al.,* 2017). This is one of the first growing cells of polysaccharides (carbohydrates), frequently attacked by microorganisms in the early stages of decomposition (Evangelou, 1998), sourced from solid waste samples, including leaf litter, paper, and food scraps. The respectivel cellulose content is about 15-20%, 85-99% (Howard *et al.,* 2003), and 13% (Astuti, 2016), although the level in the dry-weight generally varies from 15-60% (Evangelou, 1998). Furthermore, one of the potential application is as a necessary materials for fuel (Anindyawati, 2010), and Fig. 5 shows the graph of cellulose levels over a 30 day period.

Fig. 5 shows the level of cellulose produced for 30 days, and a range of about 29%-30% was reported in each reactor at the inception. Subsequently the highest degradation was recorded on day two at 26-32%, in treatments with the lowest aeration flow of 2 liters/minute, followed by those with the highest temperature, in a range of 40 °C – 43 °C, included as thermophilic. This phase facilitates the most considerable degradation (Huang, 2010), due to the optimized activity of the carboxymethyl enzyme. Hence, the subsequent period is characterized by a temperature derivation of metabolized organic matter, allowing for relatively lower degradation up to day 30, which is continuous (Huang, 2010). This research is consistent with Huang (2010), where the most significant cellulose degradation was observed from day three to 15, where the thermophilic phase occurred. However, rapid decomposition was also recorded, and Fig. 6 shows the derivation in cellulose content in each reactor over the study period.

Based on Fig. 6, a derivation of cellulose level was observed in each reactor, confirming the occurrence of degradation during the biodrying process. The statistical test shows a significance result at 0.032 (sig < 0.05), indicating the substantial effect on cellulose level, at varied air flow. In addition, cellulose is broken down to oligosaccharides and subsequently into glucose, due to the presence of extracellular microbial enzymes. This form of enzyme is produced in cells, and released into the media, with the ability to hydrolyze macromolecules. Therefore, CO_2 and water is produced. The most significant deterioration of 15.97% was observed in aeration 3 L/min/kg, while the least was recorded in aeration 6 L/min/kg, at 10.05%. This phenomenon indicates the ability for higher airflow to stop microbial activity, and inhibits proper organic compound degradation, as well as nutrient consumption (Colomer-Mendoza *et al.,* 2013; Sadaka *et al.,* 2011). Hence, airflow variation affects cellulose degradation in the biodrying process.

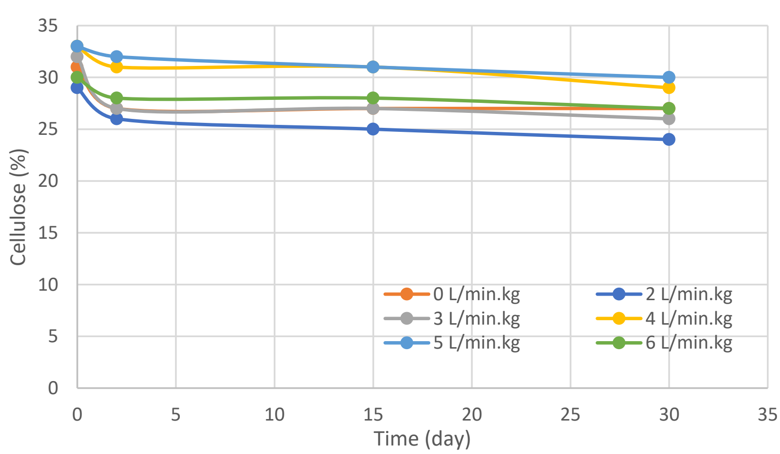

Fig. 5: The cellulose content based on variations in airflow (flow rate)

Calorific

Calor value is an indicator of energy content in a substance, including in solid waste. In addition, reliable treatment through biodrying method is expected to increase energy content by drying the solid waste, in order to produce RDF products (Fadlilah and Yudihanto, 2013). Meanwhile, each reactor produced a range 4,575.07 – 4,777.91 cal/g within the first two days. This condition was influenced by the high activities of microorganisms, shown by the moderately thermophilic temperature phase (40 °C to 50 °C). Based on the increased microorganism activity, there was significant consumption of nutrients needed by microorganisms, which influenced the calorific value. Furthermore, a significant escalation was observed on day 15, at 4,643.70 – 6,175.22 cal/g, which was stable up to day 30, in a range of 4,713.36 – 6,265.37 cal/g. This escalation results from a decline in water content. Also, there was a significant reduction on day 15 to 23.75%-38.60%, compared to 54.51%-65.56% reported on day 2. This was due to the markedly high water content and low calorific value on the second day, resulting from the use of heat during evaporation at the process inception. However, the lower value observed on day 15 was due to the relatively lower heat during evaporation, hence reduced water content is directly proportional to increased calorific value. The escalation also occurs because of the derivation of microorganisms activity, and declining temperature (Fig. 3), resulting in low nutrient consumption (Colomer-Mendoza *et al.*, 2013). This condition is congruent with the study by Fadlilah and Yudihanto (2013); Sen and Annachhatre (2015), where the most massive increase in calorific value was observed between days 12 and 16. Based on the statistical test, a significant result of 0.032 (sig<0.05) indicates the significant effect of airflow variation on calorific value, as shown in Fig. 7.

Based on Fig. 7, there was a difference between the control (without the addition of flowrate) and the biodrying reactor. This is evidenced by the insignificant increase in calorific observed in treatments without additional flow 0 L/min/kg, at only 4.58%, with an initial and final value of 4,507.46 and 4,713.36 cal/g, respectively. Conversely, the treatment reactor had an increased value by about 37.29% - 38.19%, where the minimal enhancement was recorded at the rate 3 L/min/kg, with an initial andfinal value of 4,520.98 and 6,206.78 cal/g, respectively. Meanwhile, the maximum change was recognized in the reactor of 6 L/min/kg, with corresponding initial and final value of 4,534.51 and 6,265.37 cal/g. These conditions indicate the influence of airflow rate on calorific value during the bio drying. This research is compatible with Fadlilah and Yudihanto (2013), where the biodrying process performed on solid food waste generated about 4,952 cal/g in flow rate of 6 L/min/kg and 4,064 cal/g for 4 L/min/kg. In addition, the calorific value of the biodrying process was within a range of 4,713 cal/g - 6,265 cal/g, and is further classified in the low energy (brown) coal category, according to SNI 13-6011-1999 concerning the classification of resources

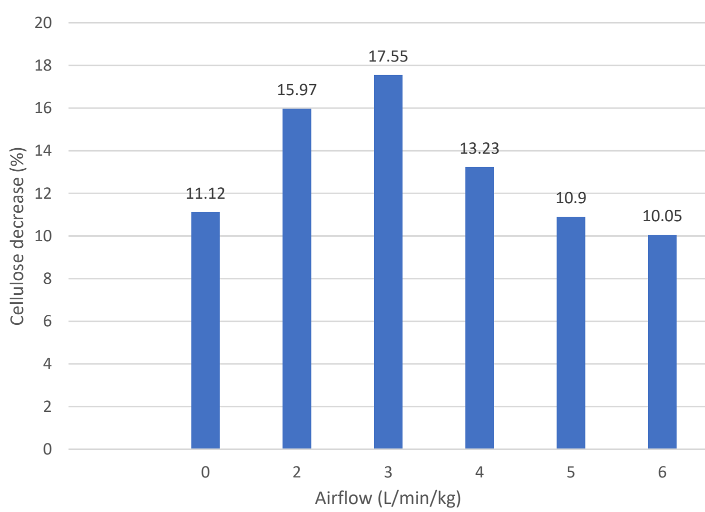

Fig. 6: Derivation cellulose levels (%) at various flow rate variations

and coal reserves, equivalent to <7,000 cal/g. The increase in value is influenced by organic substance degradation, including cellulose. This research showed the least final calorific value in treatments with maximum raw material deterioration, and vice versa. This finding is consistent with Sugni *et al.* (2005), where maximum organic matter degradation produced lower energy content.

SEM analysis (Scanning electron microscopy)

SEM analysis is used to determine the surface morphology of a sample. This shows the physical changes caused by the microbial degradation of solid waste (Sharma *et al.,* 2019). Fig. 8 demonstrates the test result from reactor 2, with an airflow of 2 L/min/kg.

Fig. 8 shows the SEM of solid waste samples on day 0L/min/kg. This features a relatively large size, with smaller cavities/pores, compared to, 15, and 30, with characteristic shrinkage of particle size and escalation of surface cavities. The findings are in line with Sharma *et al.,* (2019), where the cavity size was bigger after the degradation process. This indicates the occurrence of degradation during the 30 days of biodrying.

Greenhouse emission (GHG)

Air emissions are measured to determine the effects of biodrying on solid waste toward the gasses responsible for greenhouse effect, comprising CH_4, CO_2, and N_2O. The measurements are collected on day 0 and at the time when a peak temperature of 42.5 °C is reached. Table 2 shows the result of greenhouse gas emmitted from the decomposition of biodegradable organic matter in MSW, comprising CH_4, CO_2, and N_2O. The sources include leaves (64%), paper (12%), uneaten vegetables (6%), uneaten of meals (1.73%), and fruit peels (0.27%), while plastic waste (16%) are non biodegradable.

CH_4 emissions during the biodrying process

Fig. 9 shows the result of the CH_4 concentration test in the biodrying process, and the output on day 0 was very different between the control (without aeration) at 2.65 ppm (1.34 mg/kg) and solid waste with biodrying treatment at 1.51 ppm (0.73 mg/kg). The conversion of ppm to mg/kg for CH_4, CO_2, and N_2O was based on the calculation of fluxes used to evaluate the experimental data, through second order polynomial equation (gas concentration vs. time) (Hao *et al.,* 2002). In addition, the CH_4 emissions were very low compared to the research of Wang, *et al.,* (2018), which was performed using the combination of biochar, zeolite and wood vinegar for composting pig manure where 8.83 g/kg gas was produced. This current research shows a reduced methane yield with the presence of aeration during the biodrying process. Hellebrand (1998) reported higher values during a decomposition of grass and green waste, and also a more significant output after 30 days of urban waste decomposition. This escalation was considerably reduced by aeration. Yusuf *et al.* (2012) calculated a 28% higher methane emission during anaerobic decomposition, compared to windrow composting.

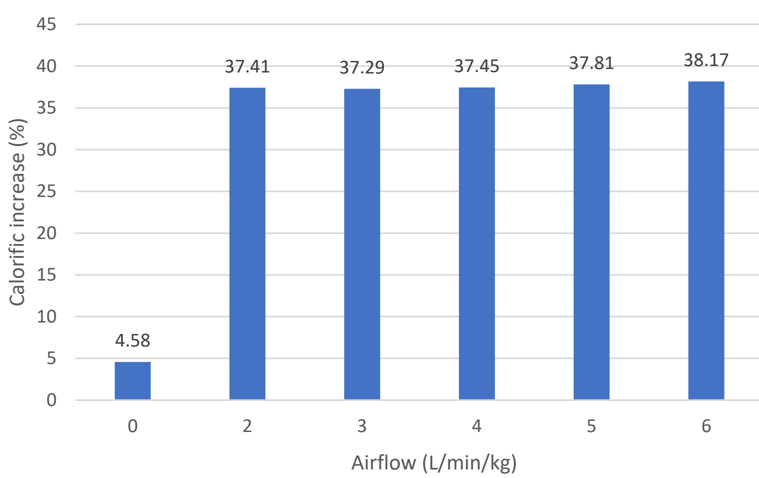

Fig. 7: Percentage increase in calorific value due to variations in flow rate (aeration)

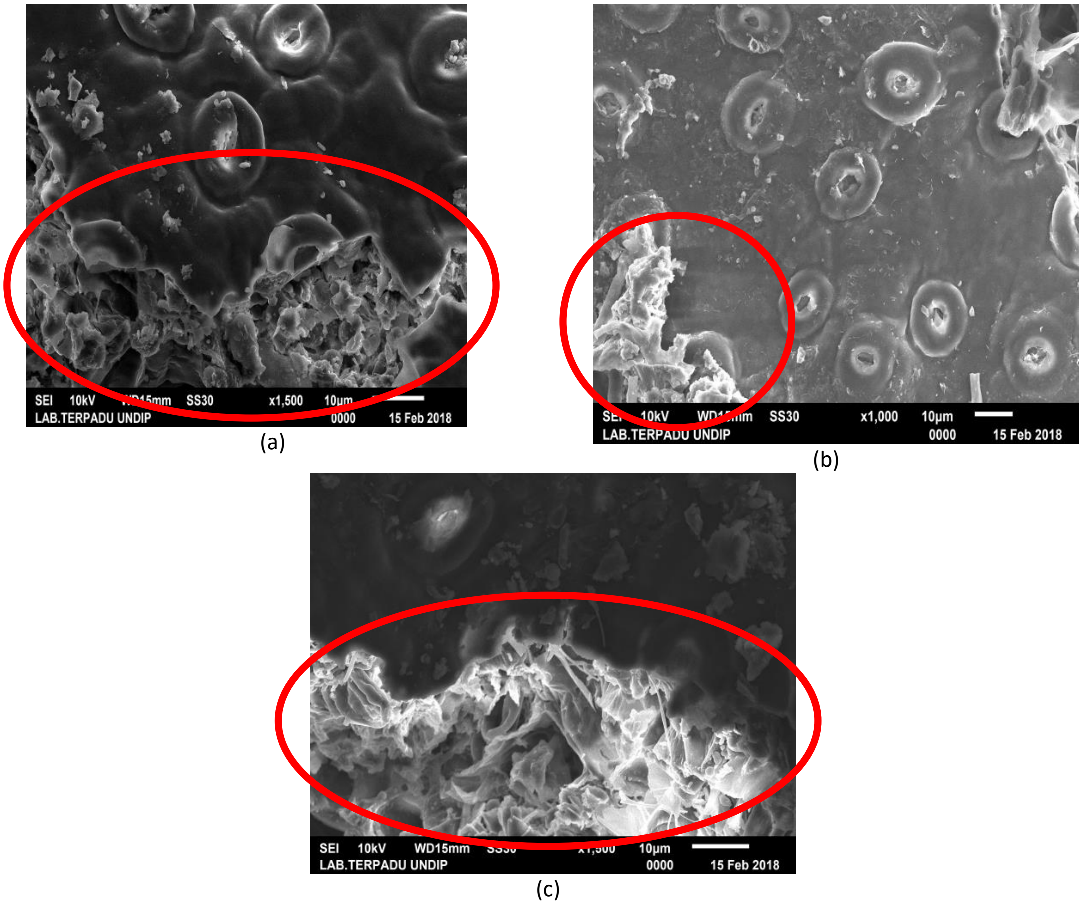

Fig. 8: SEM test result from solid waste sample with flow rate 2 L/min/kg (a) day 0 magnification 1,000x , (b) day 15 magnification 1,500x, (c) day 30 magnification 1,500x

Table 2: Concentrations of CH_4 (ppm), CO_2 (ppm), N_2O (ppb) at day 0, and when the bio is drying reactor temperature reaches its peak

Airflow	CH_4 (ppm)		CO_2 (ppm)		N_2O (ppb)	
(L/min/kg)	1st	2nd	1st	2nd	1st	2nd
0	2.65	11.59	68,888.95	83,153.13	534.69	175.48
2	3.00	3.46	42,804.56	12,706.55	107.78	120.82
3	2.63	3.38	15,920.42	10,848.54	274.57	268.87
4	1.62	2.72	8,408.12	5,602.61	39.22	202.64
5	1.68	3.18	10,069.00	6,621.92	110.33	267.25
6	1.51	3.14	5,153.67	4,393.74	78.80	200.27

CO_2 emissions during the biodrying process

Fig. 10 shows the results of CO_2 concentration test during biodrying, and the graph describes lower levels compared to the treatments without bio-drying. Furthermore, the differences in value between control (without aeration) and solid waste with biodrying treatment was very significant on day 0, at 68.888,95 ppm (2.75 g/kg) and 5,153.67 ppm (0.27 g/kg), respectively (13:1 in comparison). Awasi *et al.,* (2016) reported a CO_2 emission of 10 g C /m^2/d on the 22nd day of sewage sludge composting. Moreover, the study conducted by Wang, *et al.,* (2018), using a combination of biochar, zeolite and wood vinegar for the composting of pig manure yielded 116.5 g/kg/d.

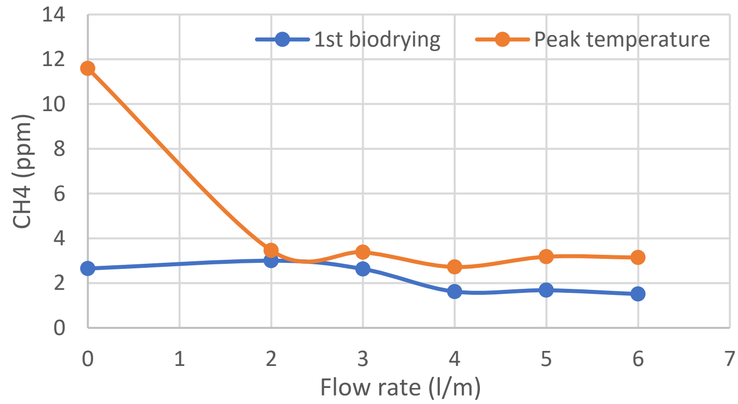

Fig. 9: The CH_4 levels (ppm) at 0 days and at the time the temperature reaches its peak.

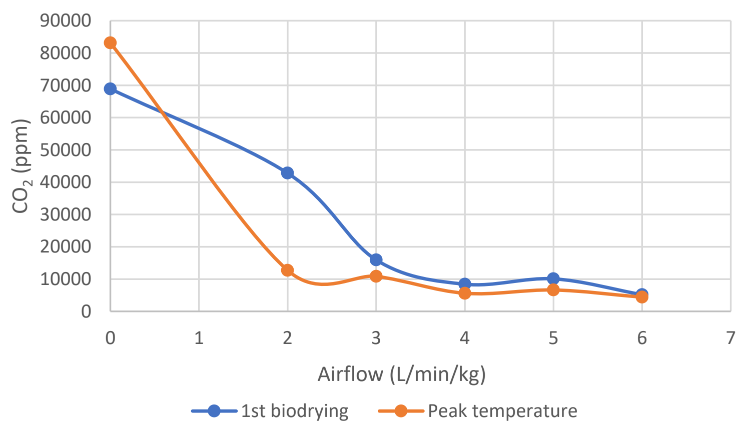

Fig. 10: Graph of CO_2 levels (ppm) at 0 days and when the temperature reaches its peak

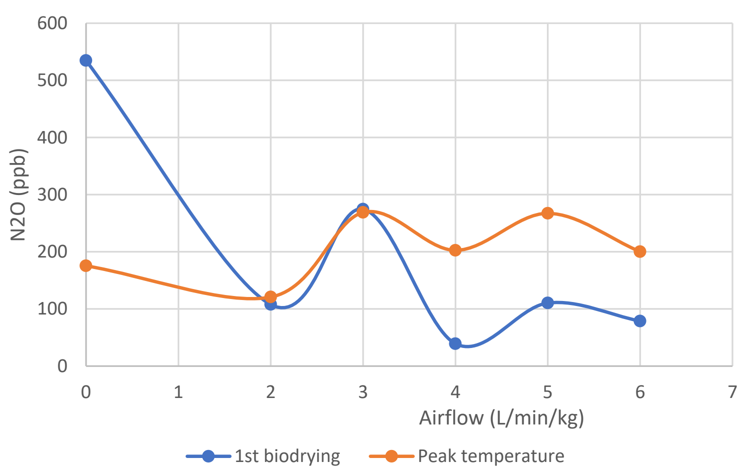

Fig. 11: Graphs of N_2O levels (ppm) at day 0 and when they reach their peak temperature

N_2O emissions during the biodrying process

Fig. 11 shows the result of N_2O concentration testing during the biodrying process, and a higher value was recorded at the peak temperature (Thermophilic). A study conducted by Wang, *et al.,* (2018), using a combination of biochar, zeolite and wood vinegar for composting pig yielded 47.29 mg/kg of N_2O emissions. According to Paul (2001), the nitric oxide released during thermophilic composting is generally higher. This often occurs as a side product of nitrification, involving the oxidation of ammonium into nitrate and denitrification. In addition, heterotrophic nitrification processes also play a major contributory role during production.

CONCLUSION

This research aims to evaluate the increase in calorific value, as well as the degradation process, and greenhouse gas emissions from MSW (refuse derived fuel), using biodrying. The results showed a higher calorific value to about 37.29% - 38.19% or 4,713 cal/g - 6,265 cal/g, which is classified in the low energy coal (brown coal) category, being <7,000 cal/g. Furthermore, the most significant temperature reached was 43 °C on second day, as observed in reactor 2 (airflow 2 L/min/kg). The lowest water content of 28.37% was produced by the solid waste in reactor 3 (airflow 3 L/min/kg). Therefore, the biodrying process ensured a successful reduction in sample moisture compared to the control. The lowest cellulose reduction of 10.05% was observed in reactor 6 (6 L/min/kg). In addition, degradation of C-Organic and Total Nitrogen was slow and not significant, hence the potential for application as fuel. Based on SEM, MSW morphology on day 0 showed larger sized molecules with smaller cavities/pores. The treatment process results in lower GHG emissions compared to the control. Furthermore, the highest CH_4 emissions, measuring 11.59 ppm was observed at the peak temperature of 43 °C, while the CO_2 concentration of control (without aeration) and solid waste exposed to biodrying was 68,888.95 ppm and 5,153.67 ppm, respectively (13: 1 ratio). Meanwhile, the N_2O concentration was 534.69 ppb and 175.48 ppb at the inception of research and during the peak temperature. The lowest level was recorded in reactor with air flow rate of 2 L/min/kg. The MSW biodrying was confirmed to increase the calorific value and reduce greenhouse gas emissions. This inhibits the possibility of sample discharging into the final processing. Appropriate Therefore, proper strategy is needed to understand other factors influencing the heat value and GHG emissions.

AUTHOR CONTRIBUTIONS

B. Zaman performed idea, developing theories, and funding. M. Hadiwidodo performed ideas, developed theories and calculations. W. Oktiawan performed ideas, verified research methods, encouraged B. Zaman and M. Hadiwidodo to investigate specific aspects, and supervised research. Purwono performed verifying research methods, analyzing data, and conducting research. E. Sutrisno performed verification methods and helped supervise the study. All authors discuss the results, and contribute to the preparation of the manuscript.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

°C	Derajat celcius
cal/g	Calorie/gram
cm	Centimeter
CH_4	Methane
CO_2	Carbon dioxide
FTD	Flame Thermionic Detector
$gC/m^2/d$	Gram carbon per square meter per day
g/kg/d	Gram per kilogram per day
GHG	Greenhouse gas
m^3	Cubic metre
MBT	Mechanical biological treatment
mg/kg	Milligram per kilogram

MSW	Municipal Solid Waste
N_2O	Nitrous oxide
L/min/kg	Liters per minute per kilogram
ppb	Part per billion
ppm	Part per million
RDF	Refused Derived Fuel
SEM	Scanning electron microscopy
SD card	Secure Digital Card
SNI	Indonesian National Standard
TPA	Final processing

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