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LAMPIRAN 1

Waste to energy: evaluation of calorific and greenhouse gas emission in municipal solid waste treatment using biodrying

ABSTRACT:

BACKGROUND AND OBJECTIVES: Urban intensity and activities produce a lot of biodegradable municipal solid waste (MSW). It must be managed to avoid negative impacts on water, soil, air, and human health. In this research, the bio-drying process is used to process MSW into Refuse Derived Fuel and evaluation of greenhouse gases (GHG).

METHODS: This research conducted at a greenhouse using six bio-drying reactors made from acrylic material equipped with digital temperature recording, blower, and flow meters. Air flow variations (0, 2, 3, 4, 5, 6 L/min.kg) and bulking agent (15%) were carried out to evaluate the calorific value, degradation process and GHG emissions.

FINDING: The result showed that variation in air flow effect on cellulose content and the calorific value. In the bio-drying process showed that the higher aeration air flow, then the decrease in cellulose content is lower and more upper the heat value. Optimum air flow based on cellulose content and calorific valueis 6 L/min.kg with decreasing of cellulose content by 10.05% and an increase of calorific value 38.17%. The bio-drying process was also able to reduce water content from 69% to 40%. On day 0 the CH_4 concentration between control and bio-drying was very different by 2.65 ppm and 1.51 ppm respectively at the beginning of the research and the peak temperature. The concentrations of N2O in each control was about 534.69 ppb and 175.48 ppb. The lowest level of N2O was when the bio-drying process used 2 L/min.kg air flow.

CONCLUSION: The calorific value of MSW after bio-drying process has a range of about 4,713 cal/gr – 6,265 cal/gr. It can be classified in low energy coal (brown coal) category, that is equal to <7,000 cal/gr. The bio-drying process is proven to be an alternative MSW processing which can produce RDF and low GHG emissions.

KEYWORDS: *bio-drying; MSW; energy; greenhouse gas; solid recovery fuel.*

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
43	10	3

RUNNING TITLE: calorific and greenhouse gas emission in municipal solid waste treatment using biodrying.

Introduction

Urban *intensity* and activities produce much biodegradable solid waste. It must be managed to avoid a negative impact on the environment, such as odors and pollutants emissions, soil, water, gas, etc. Current methods of processing solid waste by burning or landfill are not optimal. The space available for final processing (TPA) is critical, and finding alternative new space (TPA area) is difficult and expensive, especially in big cities. Waste to Energy (WTE) technology has the potential to reduce the volume of the original waste by 90%, depending on the composition by recovering the energy (Patil et al., 2014). The water level in urban solid waste is an essential factor because it affects the efficiency of combustion and converting the process of solid waste into energy (Suksankraisorn et al., 2010). Among the methods that are developing, mechanical biological treatment (MBT) becomes a potential choice because of its environmental-friendly waste treatment system (Egan et al., 2005). Natural drying, often called bio-drying, is one of the critical components of the MBT processes. Solid waste will be through mechanical-biological bioconversions (Rada & Ragazzi, 2015; Velis et al., 2009). In practice, the solid waste that has been chopped and has high water content put into the reactor. By the bio-drying processes, the solid waste produces dry solid waste (bio-dried) which undergo a further mechanical process. This process combines the heat that generated from the aerobic decomposition process of organic compounds, and excess air which serves as a reliable waste dryer (Velis et al., 2009). The dried solid waste can be considered as Refused Derived Fuel (RDF). It is a fuel material produced from various types of waste, such as urban waste, industrial waste, or commercial waste (Scheutz et al., 2014). RDF can be used as a substitute for coal (Rada & Ragazzi, 2015).

Most of the bio-drying processes can reduce water content in solid waste which is about between 30% and 80% of the initial water content (Li et al., 2015; Zhang et al., 2008; Zhao et al., 2010). Water removal varies between 3.1 to 10.7 g water/g volatile solid consumed depending on the composition of first waste and operating conditions (Frei et al., 2004; Ma et al., 2016). Wastes that have been processed using bio-drying include manure, pulp mill sludge, food waste, MSW, and sewage sludge. The bio-drying process is carried out in batch conditions with 20 days of maximum duration. The final result of bio-drying is RDF that can be used as co-fuel in the cement industry and boiler unit (Garg et al., 2007; Wagland et al., 2011). However, critical aspects, such as greenhouse gas emissions have not been studied systematically. Most of the research discusses greenhouse gas emissions from the composting process of solid waste such as solid sludge. Even though bio-drying and composting have different purposes; composting requires rapid degradation while bio-drying experiences partial degradation (Goyal et al., 2005). Characterization of greenhouse gas (GHG) and odor compounds of solid sludge compost making at standard scale has been widely published (Maulini-duran et al., 2013; Rincón et al., 2019), while several studies have been carried out at full scale (González et al., 2019; Shen et al., 2012) emissions from the bio-drying process need advanced studied because of their impacts on global warming (Pan et al., 2018). Bio-drying is an alternative approach to evaluate MSW, and the GHG emissions from this process deserve to be investigated.

Method

In this study, MSW was manually collected from The KORPRI housing complex, Tembalang, Semarang, Central Java, Indonesia with coordinates -7.061131, 110.446709. The characteristics of the sample at this location are almost the same as MSW produced by the majority people of Semarang city. MSW needs to sort out to determine the percentage of each component (%). The MSW component, percent by weight, consists of 64% leaves, 12% paper, 16% plastic, 6% uneaten vegetables, 1,73% uneaten of meals, and 0, 27% fruit peels. Then, MSW was chopped using a chopper with dimensions of 15-20 mm, while the plastic MSW was manually cut by scissor. All MSW components were mixed and weighed, then put into a bio-drying reactor that has a bulking agent (15% v/v). The bulking agent is mature and stable compost with dimensions of ±10 mm.

The bio-drying reactor is made of polyethylene plastic with capacity 60 liters of filling level (body diameter: 38 cm; total height: 65 cm; weight: 3 kg) equipped with a heat sink (Thermoshield Universal) to minimize heat loss. The bottom of the reactor is installed a stainless steel pipe (Ø3 mm) to ensure uniform air distribution. Variations of air flow (0, 2, 3, 4, 5, 6 l/ min) use an aquarium pump (Resun LP-100). Each reactor has sampling holes with a diameter of 7 cm at 0,2 cm, 0,4 cm, and 0,6 cm height from the bottom of the reactor. The holes were tightly closed when they were not used. Temperature sensor probes were placed at the top, middle, and bottom of the reactor, and the average rate was noted down. Temperature measurement used a stainless steel temperature sensor that is waterproof to the nearest 0,01 oC. Temperature parameters were recorded automatically every 15 minutes. The recording data would be saved in an SD card in *xlsx* format. The range of temperature probe is -50 ^{o} C to 200 ^{o} C. Leachate that was produced by the reactor, was collected and measured the volume (if incurred).

During the bio-drying process, parameters of water content are analyzed every day. The water content was measured using the gravimetric method. 20 g of samples were collected from three different levels of depths (top, middle, and bottom), and mixed to analyze water content in triplicate ways with a deviation standard set on <5%. The neutral detergent fiber of each sample was determined and used to calculate the cellulose contents (Goering & van Soest, 1970). Carbon levels were tested using the Walkey-Black method that is a rapid and effective means for determining the organic carbon. Nitrogen content was analyzed using the Kjeldahl method. Organic carbon and nitrogen testing were done in triplicate ways. Caloric/heat content testing was performed using Bomb Calorimeter. Greenhouse Gas (GHG) sampling was carried out at the highest temperature for CO2, CH4, and N2O. Greenhouse Gas Analysis used Shimadzu 14A capillary gas chromatograph equipped with FTD at 250 ^{o} C. Limit of Detection CH4: 0,89 ppm, N2O: 39,22 ppb, and CO2: 88,47 ppm.

Result and Discussion

MSW degradation rate was analyzed based on parameters of temperature, water content, cellulose, and SEM (Scanning Electron Microscopy). The detailed discussions of these parameters are as follow:

Temperature Profile

Biodrying is an exothermic process, where an aerobic process requires oxygen for microbial activity. Temperature is a parameter for the exothermic process and a crucial factor that influence the process of water evaporation and organic degradation (Fadlilah & Yudihanto, 2013; Sen & Annachhatre, 2015; Zhang et al., 2008). Temperatures that are too high and too low can slow down the drying process because decomposer microorganisms are inactive, so there is an incomplete drying process (Sudrajat, 2006). Temperature data that occur with the variation of air flow are shown in **Fig.1.**

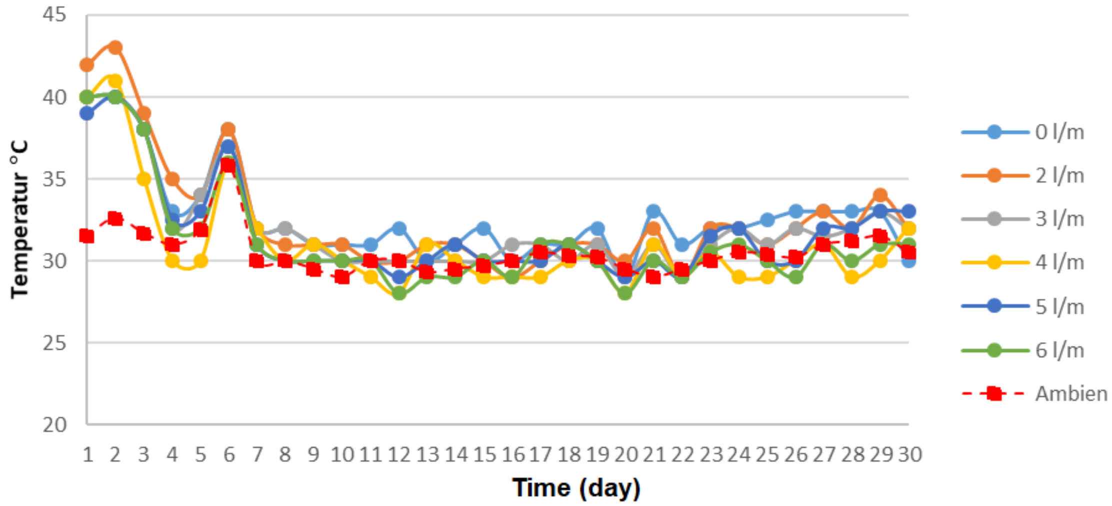

Fig.1 Temperature profile graph in the bio-drying process for 30 days.

Here, the temperature was monitored every day for 30 days to see the activities of microorganisms during the bio-drying process (Jalil et al., 2016). **Fig.1** shows the temperature of solid waste in each variation. The highest temperature occurred on day 2, about 34 °C generated from reactor number 2, which has aeration 2 l/m. The result of this research is compatible with the study of Sadaka et al (2011). They state that there was a temperature escalation of about 37.7°C – 48.8 °C (100 -120 F) in the bio-drying temperature on day 2 to day 3. These temperatures indicate a high biodegradation process due to the high metabolism of microorganisms (Fadlilah & Yudihanto, 2013; Jalil et al., 2016). According to Jalil et al., (2016) the temperature rise due to microorganism activities in a bio-drying reactor. For bio-drying method, "mesophilic" temperature and moderately "thermophilic" temperature are more applicable than "thermophilic" temperature. Mesophilic temperatures are about 35 °C, and 40 °C. Moderately thermophilic temperatures are about 40 °C to 45 °C. Thermophilic temperatures, which is about 55˚C to 70˚C. Specifically, Finstein & Hogan (1993) states that the combination of high temperature and low airflow can slow down the drying process. This condition corresponds to Sadaka et al., (2011). The temperature rises on the second day and then returns to ambient temperature.

During this bio-drying process, the phase of the moderately thermophilic temperature developed on the second day, while the mesophilic phase was on until day six. On day 7 to day 30, there was an increase and decrease in temperature, which was relatively uniform (stable) with temperature ranging 28 °C – 34 °C. This condition indicates that the large enough activity of microorganisms does not occur so as created biological stability after the bio-drying process takes place (Adani et al., 2002). Jalil et al., (2016) in their research, using solid waste samples such as food scraps, papers, plastics, and woods, find a similar condition. However, the highest temperature achieved is 45.6 °C and occurred on day 3, then the temperature decreased to 34.1 °C on day 4 and was stable in the mesophilic phase until day 8. Furthermore, the temperature gradually reduced until it reached 27.5 °C.

Moisture Profile

Water content (moisture) is an essential parameter in determining the success of the bio-drying process. Water content affects the chemical reaction associated with microbial growth and the biodegradation process of organic substances (Tom et al., 2016; Velis et al., 2009) At the beginning of the bio-drying process, initial levels are generally set in the range of 50%-75%. If the initial water content is too low, then microbial activities are too small, because of microbial metabolic need water to processes. Whereas high water content creates anaerobic conditions. Water is more dominant in filling pores than air, so oxygen availability is limited (Colomer-Mendoza et al., 2013; Fadlilah & Yudihanto, 2013; Sadaka et al., 2011). The results of measurements of water content in each reactor at different aeration air flows are shown in **Fig.2.**

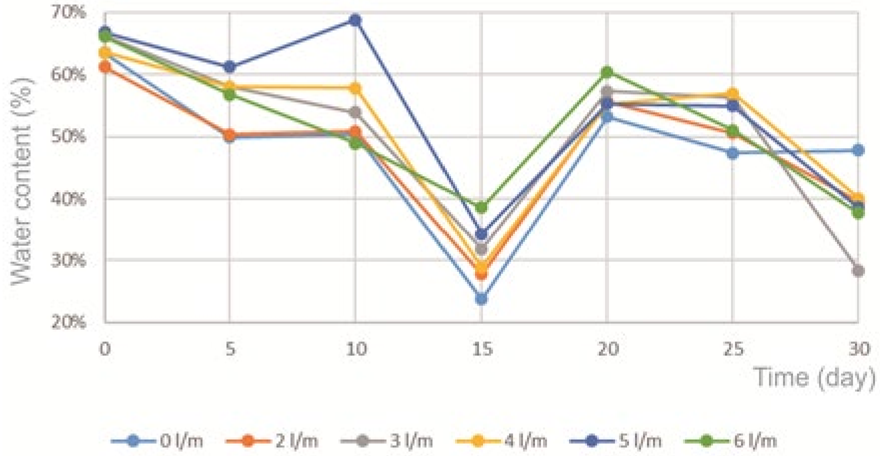

Fig.2 Graph of water content profile in the bio-drying process for 30 days

At the beginning of the bio-drying process, water content did not decrease significantly. On the day 15 there was a significant decreasing of water content compared to the first day, which is in reactor 1 (0 l/m) 63,47% to 23,75%, reactor 2 (2 l/m) 61,22% to 27,77%, reactor 3 (3 l/m) 66,26% to 31,84%, reactor 4 (4 l/m) 63,54% to 28,87%, reactor 5 (5 l/m) 66,09% to 38,60%. This reduction shows that the bio-drying process was working effectively according to the literature, which ranges between days 7 – 15 (Velis et al., 2009). The degradation condition of water content is compatible with the research of Jalil et al., (2016), on the day 14 there was a degradation of water content from 67 ± 0,24% to be 33,91 ± 2,24%. According to Adani et al., (2002), the water content can reduce the decomposition level of solid waste.

On day 20, the water level on solid waste increased in all reactors. This escalation is due to the addition of water from the condensation process inside the reactor (Widarti et al., 2015). Water will be evaporated because of the decomposition process of solid waste. Then, it turns into dew on the surface of the reactor due to the absence of a steam trap. The dew turns to be saturated steam and falls back into the pile of solid waste so that the water content increases again.

On day 30, solid waste in the reactor 1 had a water content of 47,78%. This value is higher than other reactors. It is because the reactor 1 had a configuration without aeration. This condition means that solid waste did not undergo a bio-drying process, where the process of reducing water content in solid waste was only through a biological process (Perazzini et al., 2016). On the other hand, reactor 2,3,4,5 and 6 had aeration, which helped them in drying process physically and biological process (Perazzini et al., 2016; Sen & Annachhatre, 2015). Water content in the bio-drying process can be reduced due to the evaporation of water molecules of the solid waste surface. In this process, a changed phase occurred changes the liquid into gas, and aeration accelerates the transfer of steam from inside material to the outside air (Bilgin & Tulun, 2015; Velis et al., 2009). This statement is consistent with Sen & Annachhatre research (2015). He also states that the higher air flow, the solid waste will dry up physically only, not due to the heat generated by aerobic degradation. The final results of the research produced solid waste with the lowest water level content in reactor 3 (3 l/m) of 28,37%. Based on this research, bio-drying succeeded in reducing water content in solid waste higher than control (without bio drying).

Carbon and Nitrogen Content Profile

Carbon 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 another way with composting, the nutritions or organic substances such as carbon and nitrogen in bio-drying are not fully degraded. However, the carbon and nitrogen levels are preserved as fuel (Fadlilah & Yudihanto, 2013). The following is a diagram of degradation aerobic process reaction that produces carbon and nitrogen (Sen & Annachhatre, 2015):

COHN + O_2 + Mikroorganisme Aerob → CO_2 + NH_3 + end product + Energy

Carbon level content (dry matter) in this research is shown in **Table 1.** Based on T**able 1**, carbon content at the beginning of the bio-drying process ranged from 50.96% - 64.82%. During 30 days of research, there was a decreasing in carbon content compared to the initial day of the study. The decrease was not too substantial. This decrease show s that low consumption of carbon is useful to increase the calorific value(Colomer-Mendoza et al., 2013). However, on the 6 l/m air flow, it had an escalation of carbon content. This escalation occurs due to high aeration air flow, which can stop the microbial activity until it is unable to degrade organic compounds properly (Colomer-Mendoza et al., 2013; Sadaka et al., 2011).

Table 1 Carbon content in the bio-drying process

Air flow (l/m)	**Carbon content (%)**			
	day			
	0	**2**	**15**	**30**
0	64,82	64,37	32,89	52,62
2	76,53	77,66	49,67	60,35
3	79,08	76,31	46,77	47,30
4	67,69	65,64	44,54	52,19
5	66,59	72,41	40,34	49,94
6	50,96	86,67	47,36	53,75

Table 2 Nitrogen content in the bio-drying process

Air flow (l/m)	**Nitrogen content(%)**			
	day			
	0	**2**	**15**	**30**
0	1,23	0,96	0,45	0,90
2	1,63	0,97	0,48	1,45
3	1,30	1,32	0,46	0,62
4	1,21	1,07	0,39	0,63
5	1,44	0,87	0,41	0,66
6	1,07	0,73	0,53	0,64

The measurement of nitrogen content based on dry weight is shown in table 2. Nitrogen levels decreased during the process of 30 days of research. Initial nitrogen levels was ranged between 1,07% - 1,63%. While on the day 30 was ranged about 0,62% - 1,45%. Nitrogen levels are volatile. The less nitrogen content, the slower organic matter decomposes (Widarti et al., 2015). The slower decomposing of organic matter will lead to no overall degradation of the research sample, which can be used as fuel (Fadlilah & Yudihanto, 2013). This research is corresponding with the research of Colomer-Mendoza et al., (2013) by using a sample garden solid waste without additional bulking agents and variations in air flow. The result of carbon content does not show any significant degradation between initial carbon content about 26.45% with final carbon content about the range 26.09%-28.32%. These levels indicate the proper bio-drying process because the consumption of carbon is low. Whereas. the nitrogen content decreases in all reactors. from 3.99% to 2.07% - 3.90%.

Cellulose

In aerobic conditions, microbes in the bio-drying process can degrade semi-biodegradable organics and are challenging to degrade like cellulose (Wardhani et al., 2017). Cellulose is one of the first growing cells of polysaccharides (carbohydrates), which are attacked by microorganisms in the early stages of decomposition (Evangelou, 1998). The source of cellulose in this research derived from solid waste samples used that was leaf litter, paper, and food scraps. The cellulose content in leaves is about 15-20% and paper about 85-99% (Howard et al., 2003). While cellulose level of food scraps is about 13% (Astuti, 2016). However, in general, cellulose level in the dry-weight of solid waste is various from 15-60% of its dry-weight (Evangelou, 1998). One of the potentials that can be used by cellulose materials is as necessary materials for fuel (Anindyawati, 2010). **Fig.3** shows the graph of measurements of cellulose levels for 30 days.

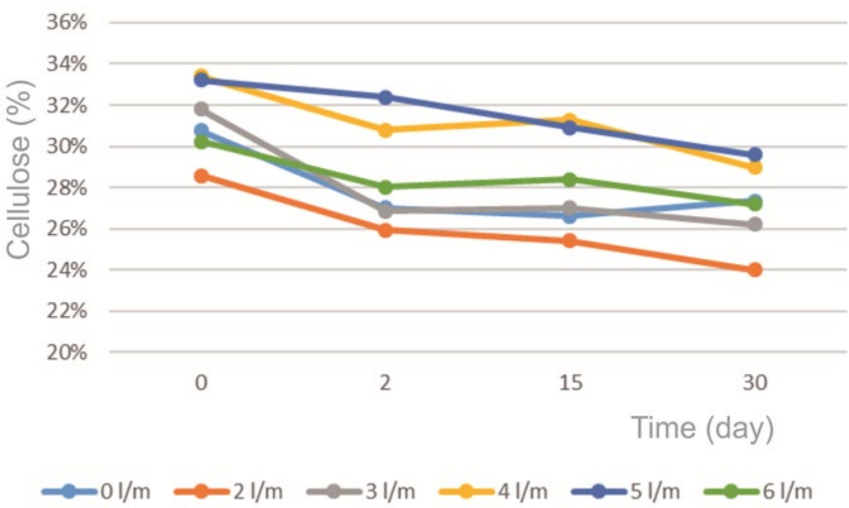

Fig.3 Graph of cellulose content based on variations in air flow (flow rate)

Fig.3 is the level of cellulose produced for 30 days. On day 0, during the process, the level of cellulose in each reactor is ranged about 29%-30%. On day two there was the highest degradation cellulose level until 26-32% with the lowest level of cellulose at aeration flow of 2 liters/minute. The highest temperature followed on day 2 with a range of about 40 ° C – 43 ° C. This temperature is included in the thermophilic phase. In that phase occurs the most considerable degradation of cellulose (Huang, 2010). It can happen because the activity of the carboxymethyl enzyme of cellulose is indicated to be active in the thermophilic phase. After the thermophilic period, there is a temperature derivation of organic matter that has been metabolized, so that the degradation of cellulose continues to occur until the day 30 but not as much as in the thermophilic phase (Huang, 2010). This research is consistent with the Huang (2010) research, where the highest degradation of cellulose comes on day three up to 15 at the time of the thermophilic phase. Whereas, rapid decomposition happens in the thermophilic phase.

The derivation in cellulose content during 30 days research in each reactor is shown in **Fig.4**

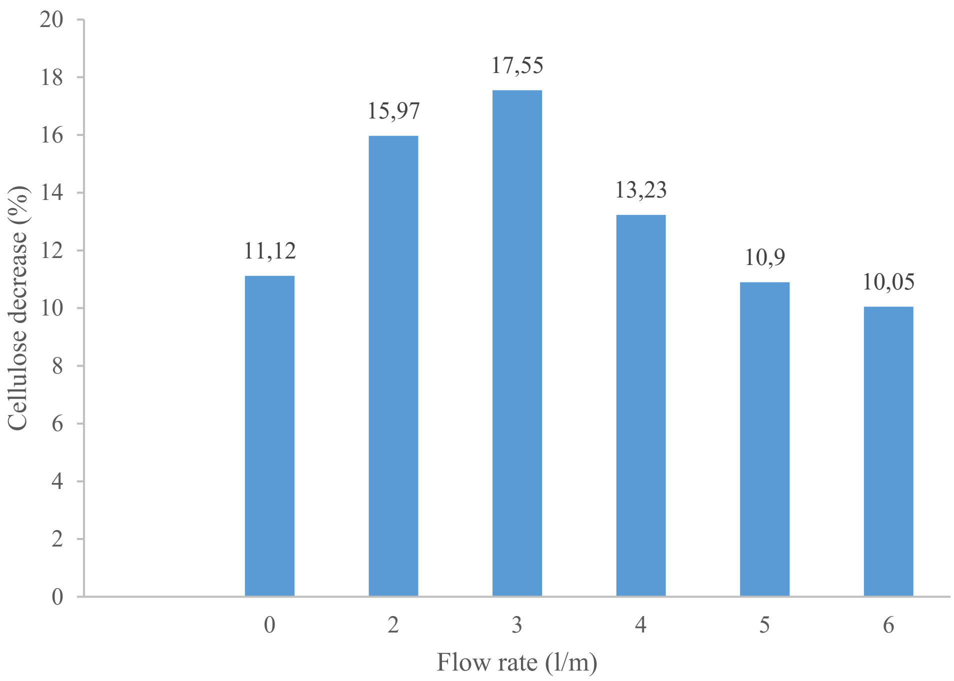

Fig.4 Derivationcellulose levels (%) at various flow rate variations

Based on **fig.4**, there is a derivation of the cellulose level in each reactor. It shows that there was a degradation of cellulose during the bio-drying process. Based on the statistical test, the significance result obtained is 0,032 (sig < 0,05), which means that there is a significant effect due to variations in air flow on cellulose level.

Degradation of cellulose breakdown occurs due to the presence of microbial enzymes into oligosaccharides subsequently into glucose. These microbial enzymes are cellulose enzymes which are extracellular (enzymes produced in cells and released into the media) that can hydrolyze macromolecules, one of which is cellulose. Cellulose degradation produces CO_2 and water. The most significant deterioration comes up in aeration 3 l/m, which is 15,97% while the smallest decreased is in aeration 6 l/m, which is 10,05%. This phenomenon indicates that higher air flow can stop the activity of microbes. Then makes it unable to degrade organic compounds properly and also the consumption of nutrients is low (Colomer-Mendoza et al., 2013; Sadaka et al., 2011). Thus, variations in air flow affect cellulose degradation in the bio-drying process.

Calorific

Calor value is an indicator of energy content possessed by a substance, including in solid waste. Reliable waste treatment using the bio-drying method is expected to function to increase energy content by drying solid waste to produce RDF products (Fadlilah & Yudihanto, 2013). The following is calorific value in this research shown in **Fig.5**

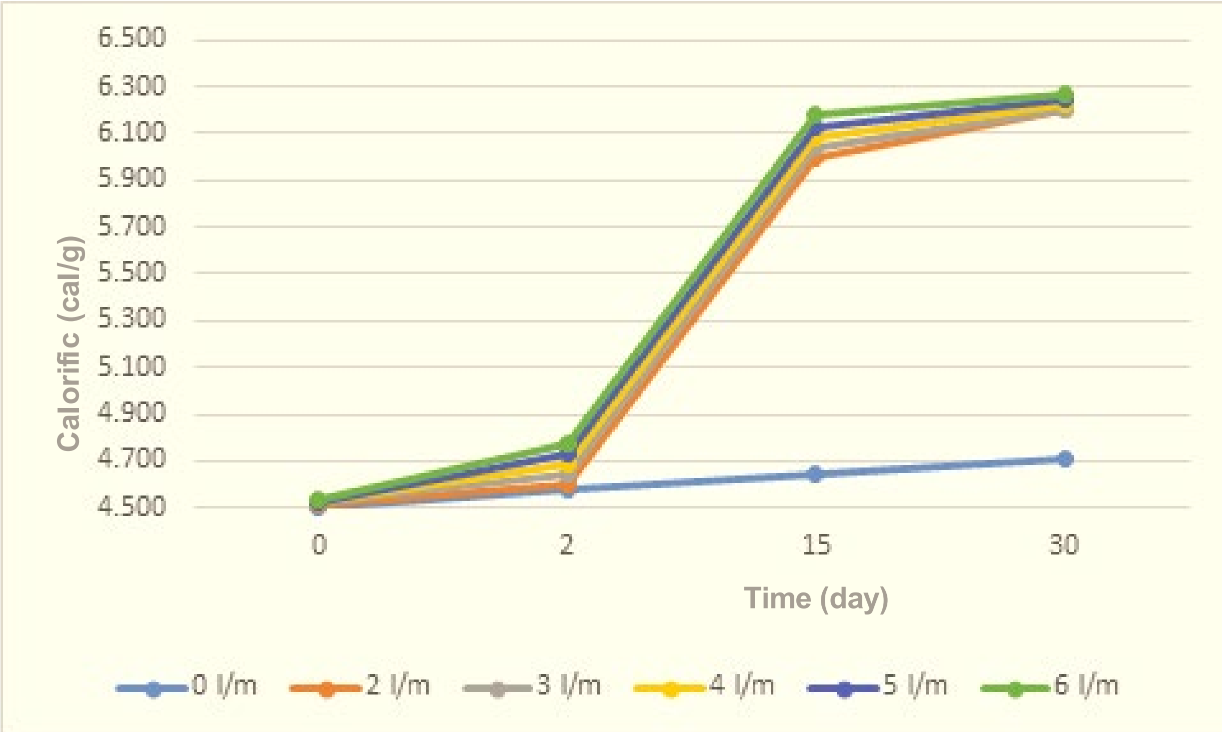

Fig.5 Calorific value graph based on variation in air flow (flow rate)

Fig. 5 shows an increase of calorific value in each reactor during 30 days research. Based on the statistical test, the significant result is 0.032 (sig<0.05), which means there is a significant effect due to the variation of air flow on calorific value. In the first two days of the bio-drying process, each reactor did not experience a significant calorific value, only in range 4,575.07 – 4,777.91 cal/gr. This condition is influenced by the high activities of microorganisms which are shown by the moderately thermophilic temperature phase (40 ^oC to 50 ^oC) in each reactor. By the increase of microorganisms activity, the consumption of nutrients needed by microorganisms is significant, so that effects on the calorific value produced. A significant escalation in calorific value is occurred on day 15 to be 4,643.70 – 6,175.22 cal/gr and becomes stable until day 30 with a range between 4,713.36 – 6,265.37 cal/gr. This escalation is because of the decrease in water content. On day 15, a significant reduction in water content becomes 23.75%-38.60% compared to day 2, where the water content ranged about 54.51%-65.56%. It is because on day two, the water content was still high, and the calorific value is low. It is because some of the heat is used to evaporate the water at the beginning of the process. Whereas on day 15, water content was lower, so the heat for water evaporation was not as much as when the water content is still high. Thus, when the water content is lower than the calorific value increases. This escalation is also because of the derivation of microorganisms activity, which is characterized by a decrease in temperature **(Fig.1)**, so that nutrient consumption is low (Colomer-Mendoza et al., 2013). This condition is compatible with research by Fadlilah & Yudihanto (2013) and Sen & Annachhatre (2015) the most massive increase in calorific value occurred between days 12 and 16.

The increase in calorific value during 30days research in each reactor is shown in **Fig.6**

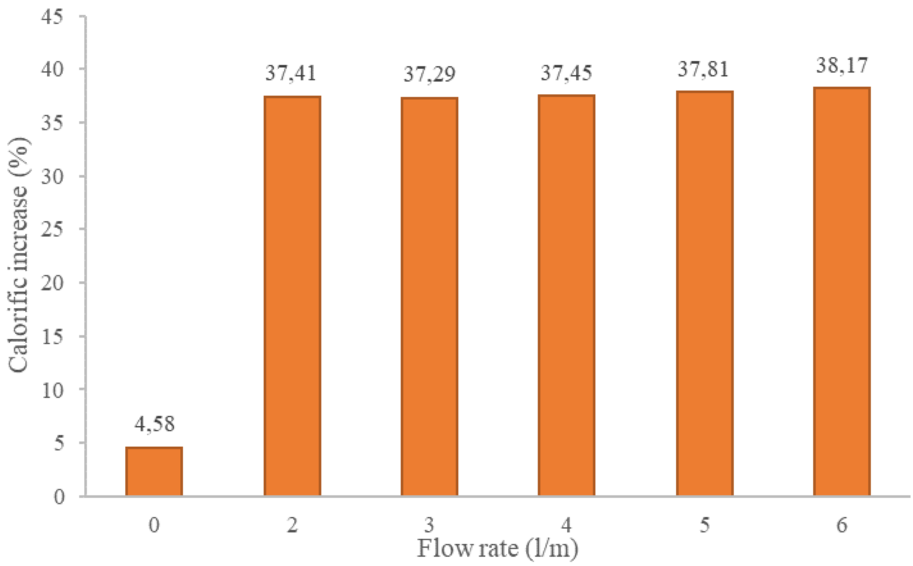

Fig. 6 Percentage increase in calorific value due to variations in flow rate (aeration)

Based on **Fig.6** for 30 days of research, there was a difference between the control reactor (without the addition of flow rate) and the bio-drying reactor. In the reactor without additional flow 0 l/m, the calorific value did not significantly increase. It was only 4,58% with initial calorific value 4,507.46 cal/gr and the final value of 4,713.36 cal/gr. While in the reactor with additional flow rate, calorific value increased about 37.29% - 38.19%. The minimal calorific value enhancement was at the rate 3 l/m with initial calorific value 4,520.98 cal/gram and final calorific value of 6,206.78 cal/gr. The maximum calorific value enhancement was at the rate 6 l/m with initial calorific value 4,534.51 cal/gram, and the final calorific value is about 6,265.37 cal/gr. These conditions indicate that the aeration (flow) rate influence the enhancement of calorific value in the bio drying. This research is compatible with Fadlilah & Yudihanto (2013). Where the bio-drying process at solid food waste produces the calorific value of about 4,952 cal/gr for flow rate 7 l/m and 4,064 cal/gr for flow rate 4 l/m. The calorific value of the bio-drying process has a range of about 4,713 cal/gr – 6,265 cal/gr. Also, according to SNI 13-6011-1999 concerning about the classification of resources and coal reserves, the calorific value of the bio-drying process can be classified in low energy coal (brown coal) category, that is equal to <7,000 cal/gr.

The increase in calorific value is influenced by the degradation of organic substances, one of which is cellulose. In this research, when the flow rate experienced maximum degradation of cellulose, then it produced the lowest calorific value in its final result. Conversely, the maximum escalation of calorific value when the flow rate experiences the lowest cellulose degradation. It is consistent with Sugni, Calcatera, & Adani research (2005), which explains that maximum degradation of organic matter produces a low energy content.

SEM Analysis (Scanning Electron Microscopy)

SEM analysis is one analysis to determine the morphology of the surface of a sample. SEM shows physical changes that occur during the degradation process of solid waste by microbes (Sharma et al., 2019). **Fig.7** is the result of the SEM test from a solid waste sample of one of the reactors, which is reactor 2 with a flow rate of 2 liters/minute.

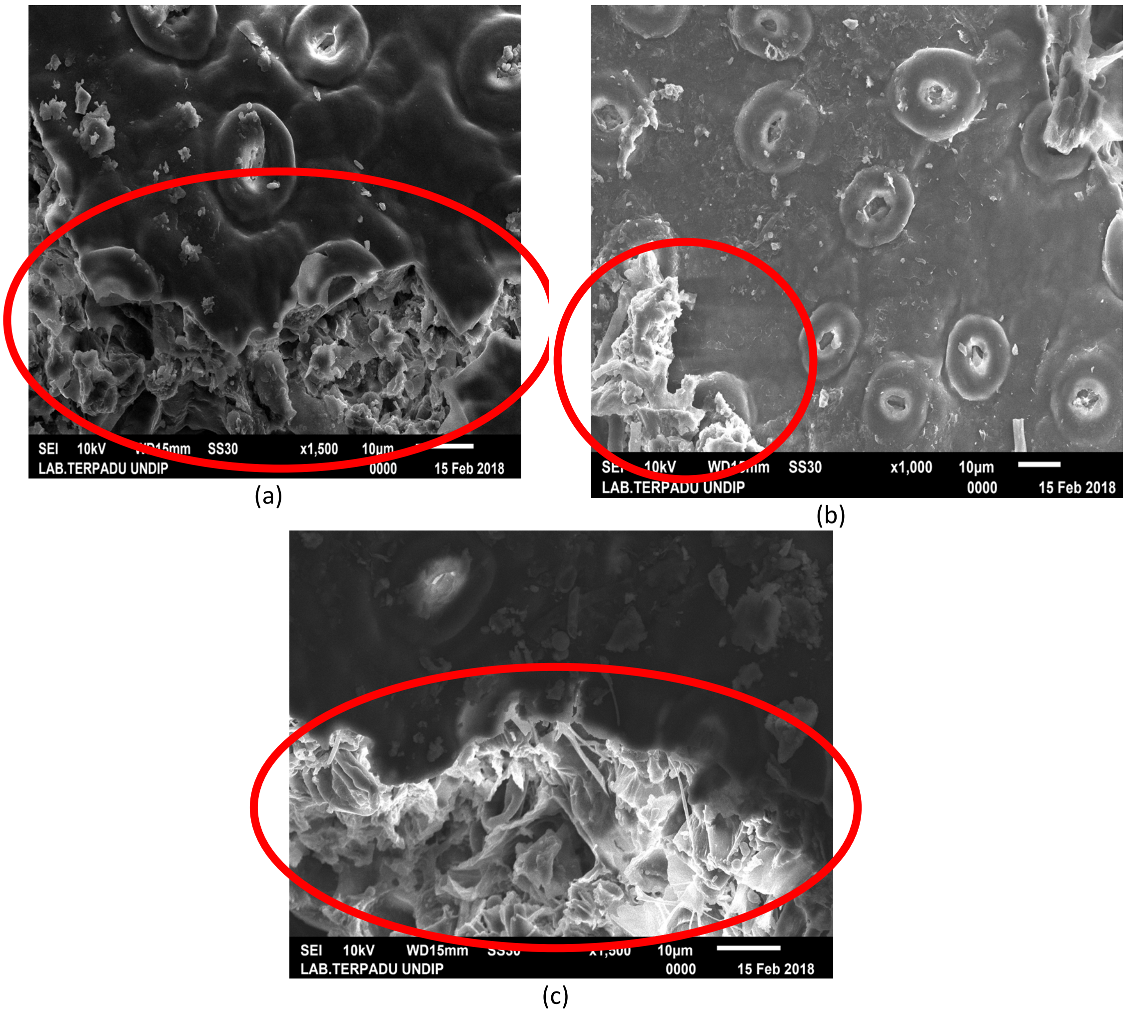

Fig.7 SEM test result from solid waste sample with flow rate 2 liter/minute (a) day 0 magnification 1,000x , (b) day 15 magnification 1,500x, (c) day 30 magnification 1,500x

Fig.7 is SEM results on solid waste samples on day 0, 15, and 30 with aeration flow 2 liters/ minute. The surface morphology of solid waste on day 0 shows a larger size with smaller cavities/pores. By the time in research (day 15 to 30), there is a degradation process that causes shrinkage of particle size and escalation of cavities on the surface. SEM results are in line with Sharma et al., (2019) research, which states that the size of solid waste cavities is getting bigger due to the degradation process. It indicates there was a degradation process in the bio-drying process that lasts for 30 days.

Green House Emission (GHG)

Air emissions are measured to determine the effects of the bio-drying process in solid waste toward gasses that cause the greenhouse effect consisting of CH_4, CO_2, and N_2O. The gas measurement is done at day 0 and at the time when the temperature reaches its peak (42.5 °C). The result of the greenhouse gas test is shown in **Table 3.**

Table 3 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.

Air flowd (l/m)	CH_4 (ppm)		CO_2 (ppm)		N_2O (ppb)	
	1st	2nd	1st	2nd	1st	2nd
0	2.65	11.59	68888.95	83153.13	534.69	175.48
2	3.00	3.46	42804.56	12706.55	107.78	120.82
3	2.63	3.38	15920.42	10848.54	274.57	268.87

Air flowd (l/m)	CH_4 (ppm)		CO_2 (ppm)		N_2O (ppb)	
	1st	2nd	1st	2nd	1st	2nd
4	1.62	2.72	8408.12	5602.61	39.22	202.64
5	1.68	3.18	10069.00	6621.92	110.33	267.25
6	1.51	3.14	5153.67	4393.74	78.80	200.27

CH_4 emissions during the bio-drying process

The results of the CH_4 concentration test in the bio-drying process are shown in **Fig.8.** On day 0, CH_4 concentration was very different between the control (without aeration) and solid waste with bio-drying treatment, respectively 2.65 ppm and 1.51ppm. Methane emission was quite high during the decomposition process of solid waste, but the presence of aeration was able to reduce methane emissions. Hellebrand (1998) states that methane emissions increase during decomposition of grass and green waste. He is also observed an increase in methane emissions for 30 days during the decomposition process of urban waste. They noted that methane emissions were reduced drastically by adding aeration. Yusuf, Noor, & Abba (2012) calculated methane emissions 28% higher during anaerobic decomposition than during windrow composting.

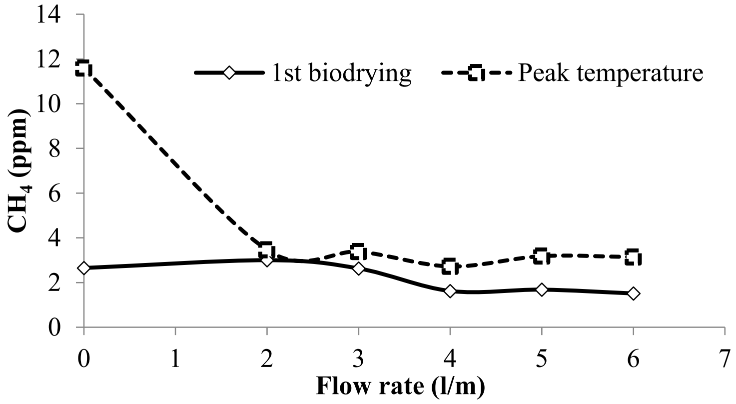

Fig.8 Graph of CH_4 levels (ppm) at 0 days and at the time the temperature reaches its peak.

CO_2 emissions during the bio-drying process

The results of the CO_2 concentrations test during the bio-drying process are shown in **Fig.9.** The graph describes that CO_2 levels using bio-drying are lower than without-bio drying. On the day 0 the difference of CO2 concentration between control (without aeration) and solid waste with bio-drying treatment was very significant, respectively 68888.95 ppm and 5153.67 ppm (13:1 in comparison).

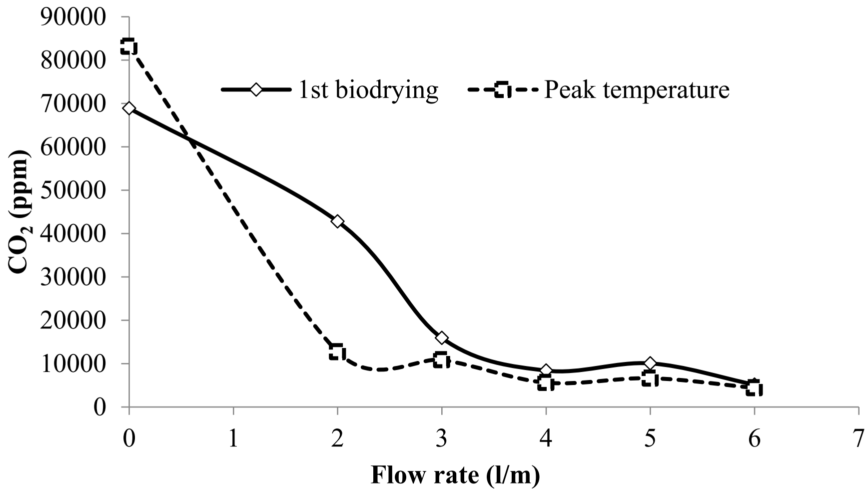

Fig.9 Graph of CO_2 levels (ppm) at 0 days and when the temperature reaches its peak

N_2O Emissions during the bio-drying process

The results of N_2O concentration testing during the bio-drying process are shown in **Fig.9.** The bio-drying process produces N_2O emission higher at the time of the temperature reached its peak (Thermophilic). According to Paul 2001, nitric oxide emissions are generally higher during thermophilic composting. Nitrous oxide emissions are as a side product from nitrification and denitrification. Nitrification involves the oxidation of ammonium into nitrate. The heterotrophic nitrification process contributes to N_2O emissions.

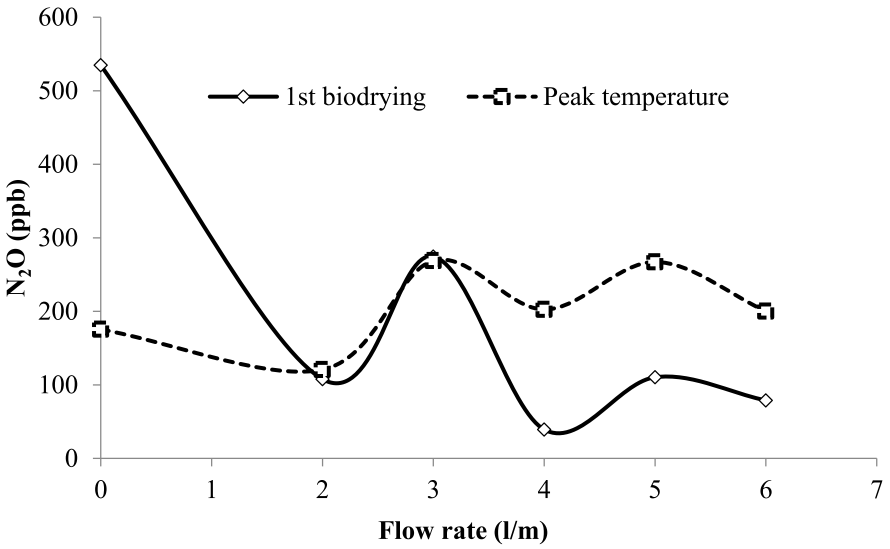

Fig. 10 Graphs of N_2O levels (ppm) at day 0 and when they reach their peak temperature

Conclusion

There is an effect of various aeration (flow) rate toward cellulose content and calorific value. In the bio-drying process. the higher aeration (flow) rate derives into the lower cellulose level derivation. and the calorific value is getting higher. The optimum aeration rate is based on cellulose content and calorific value. On the scale 6 l/m the decrease of cellulose content is about 10.05%. and the increase of calorific value is about 38.17%. Process bio-drying can reduce water content from 69% to 40% on day 30. On day 0, there is a significant difference in CH_4 concentration between control (without aeration) and solid waste with bio-drying treatment 2.65 ppm and 1.51 ppm respectively. The highest CH_4 emissions are at its peak temperature (42.5 ^{o}C) with levels of 11.59 ppm. CO_2 concentration between control (without aeration) and solid waste with the bio-drying treatment is 68888.95 ppm and 5153.67 ppm. respectively (ratio 13:1). N_2O concentration each control is about 534.69 ppb and 175.48 ppb at the beginning of research and its peak temperature. The lowest level of N_2O is when the bio-drying process using rate 2 liters/minute.

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Forecast generation model of municipal solid waste using multiple linear regression

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ABSTRACT:
BACKGROUND AND OBJECTIVES: The objective of this study was to develop a forecast model to determine the rate of generation of municipal solid waste in the municipalities of the Cuenca del Cañón del Sumidero, Chiapas, Mexico.
METHODS: Multiple linear regression was used with social and demographic explanatory variables. The compiled database consisted of 9 variables with 118 specific data per variable, which were analyzed using a multicollinearity test to select the most important ones.
FINDING: Initially, different regression models were generated, but only 2 of them were considered useful, because they used few predictors that were statistically significant. The most important variables to predict the rate of waste generation in the study area were the population of each municipality, the migration and the population density. Although other variables, such as daily per capita income and average schooling are very important, they do not seem to have an effect on the response variable in this study.
CONCLUSION: The model with the highest parsimony resulted in an adjusted coefficient of 0.975, an average absolute percentage error of 7.70, an average absolute deviation of 0.16 and an average root square error of 0.19, showing a high influence on the phenomenon studied and a good predictive capacity.

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34	**5**	**6**

RUNNING TITLE: Forecast generation model of municipal solid waste.

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INTRODUCTION

Because of its high management cost, the amount of Municipal Solid Waste (MSW) generated in population settlements is a significant factor for the provision of public services. According to Intharathirat *et al.* (2015); Keser *et al.* (2012); Khan *et al.* (2016), the amount of MSW and its composition vary depending on social, environmental and demographic factors. Several researchers have developed models to predict the amount of MSW generated (Mahmood *et al.,* 2018; Kannangara *et al.,* 2018; Pan *et al.,* 2019; Soni *et al.,* 2019), while others analyze the variables that influence their generation and composition (Chhay *et al.,* 2018; Grazhdani, 2016; Liu and Wu, 2010;

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Liu *et al.,* 2019; Rybová *et al.,* 2018). Unfortunately, due to the social, economic and geographical heterogeneity of the different regions of the world, it is difficult to make inferences or projections with the proposed models, and therefore, the models and their variables have to be adapted to the conditions of other regions, sometimes with little success. Kumar and Samandder (2017) and Shan (2010) reports that some of the difficulties for the adaptation of these models are related to limited or inaccessible information in other countries (databases). In addition, some variables are theoretically valid, but difficult to measure. In other cases, the variables used do not provide information leading to the explanation of the phenomenon, but have to be used, because the model incorporates them. Mexico, this topic has also been addressed, particularly in the center and north of the country (Buenrostro *et al.,* 2001; Márquez *et al.,* 2008; Ojeda *et al.,* 2008; Rodríguez, 2004). However, it is evident that the models proposed are not applicable to the entire national context. According to the OECD (2015), there are notable differences between the central, northern and especially southern regions of Mexico; these include disparities in income, education, access to services, dispersion of localities and other factors, which cause that the consumption patterns, and therefore the amount of MSW, vary greatly. This study presents a model to forecast the generation rate of MSW in the municipalities of the Cuenca del Cañón del Sumidero (CCS), Chiapas State, Mexico. The model considers the information of the most relevant and easily accessible social and demographic variables for the study area, which correspond to statistical data for the years 2010-2015. This model will allow the decision makers of the municipalities of the CCS to determine the quantities of MSW generated, operate properly the waste management systems, and even acquire infrastructure. This study has been carried out in municipalities of the Cuenca del Cañón del Sumidero, Chiapas State, Mexico during 2010 - 2015.

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MATERIALS AND METHODS

Description of the study area and context

The CCS is located in the State of Chiapas, in the southeast of Mexico, between the coordinates 15° 56' 55" and 16° 57' 26" North Latitude, and 92° 30' 44" and 93° 44° 35" west longitude (Fig. 1). The CCS has 24 municipalities and 2,847 localities; 2,816 localities are rural while 31 are urban. 83% of the population of the study area lives in urban areas (INEGI, 2010). The degree of dispersion is high, especially in the rural localities farthest from the municipal seat.

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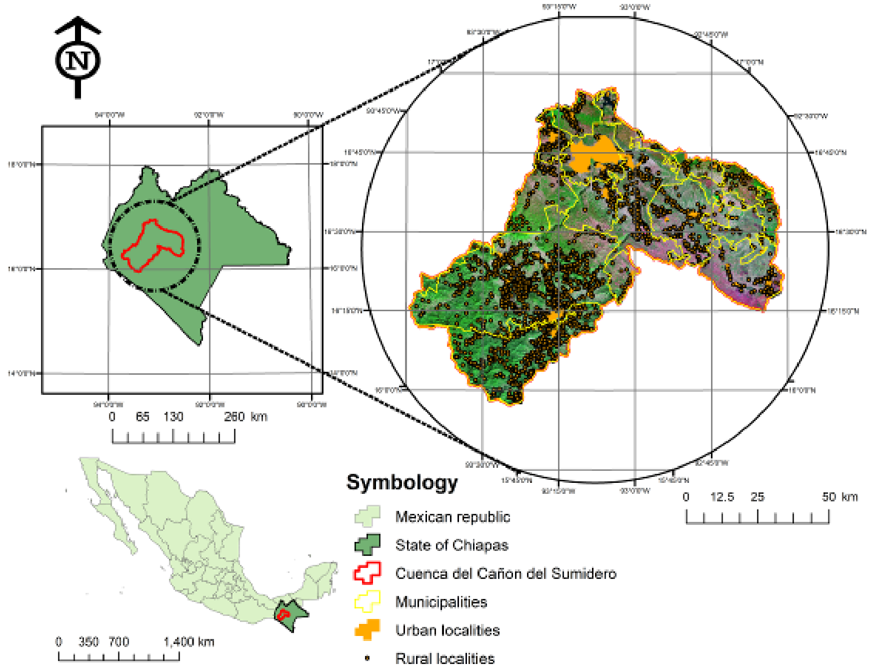

Fig. 1: Geographic location of the study area in Cuenca del Cañón de Sumidero in Mexico

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Development of the model

This study uses a multiple linear regression (MLR) model to obtain the generation rates of MSW. Because of their versatility and well-founded theory, MLR models have been widely used in various scientific fields. Their main disadvantage is the preparation of the database (Pires *et al.,* 2008). The hypothesis to use the MLR in this study is based on the effect of the explanatory variables (social and demographic variables) on the response variable (generation rate of MSW). The linear function is shown in Eq. 1.

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$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k + \varepsilon \quad (1)$$

Where, Y is the response variable, X_i (1, 2, 3 ... k) are the explanatory variables, β_i (1, 2, 3 ... k) are the regression coefficients and ε is the residual error.

According to Agirre (2006), the MLR is based on two assumptions: i) the explanatory variables must be independent, i.e., free of multicollinearity and ii) the dependent variable must be normally distributed, with zero mean and constant variance. In order to determine the regression coefficients, the least squares method, which is based on minimizing the sum of squared errors (SSE), using Eq. 2.

$$SSE = \sum_{i=1}^{n} \left(Y_i - \widehat{Y_i}\right)^2 \quad (2)$$

Where Y_i is the value of each observation and $\widehat{Y}_i$ is the predicted value. Theoretically, low *SSE* values reflect a better fit of the regression model (Kumar and Samandder, 2017). In order to determine the best regression model (most parsimony), the statistical significance of the explanatory variables and the general model were analyzed. The analysis of the explanatory variables was performed with the t-test, while the degree of adjustment and usefulness of the proposed model was performed by evaluating the F-test and the value of $R^2{}_{adj}$ using Eqs. 3 and 4, respectively.

$$F = \frac{(SS_{YY} - SSE)/k}{SSE/[n-(k+1)]} \tag{3}$$

$$R^2{}_{adj} = 1 - \left[\frac{(n-1)}{n-(k+1)}\right](1 - R^2) \tag{4}$$

Where $SS_{YY} = \sum(Y_i - \bar{Y})^2$ represents the sum of the squares of the difference of the observed data (Y_i) and the average of the data ($\bar{Y}$); *k* is the number of explanatory variables included in the model; *n* is the sample size; and R^2 is the coefficient of determination. The value of R^2 was not considered to measure the explanatory power of the regression model, because its value increases when adding more explanatory variables, and it can be a deceptive measure (Chang *et al.,* 2007).

Data collection

According to Beigl *et al.* (2008) and Kolekar *et al.* (2016), the methods of data collection depend on the scale of the study. In investigations carried out at household or locality levels, the acquisition of information is usually carried out through surveys or interviews; while at district or country scales, the information comes from a database registered by government agencies. This study was made at district scale and therefore the study area includes several municipalities. MSW generation was obtained from SEMANH (2013), the studies by Alvarado *et al.* (2009) and Araiza *et al.* (2015). The social and demographic information (explanatory variables) was obtained from CONAPO (2017) and INEGI (2010). The compiled information allowed the elaboration of a database of 9 variables, with 118 specific data per variable, coming from all the municipalities of the state of Chiapas (Table 1). The inferences of the proposed model were made on the municipalities of the CCS. This database was analyzed with the MINITAB software version 16.

Table 1: Description of variables

No.	Name of the variable	Symbol	Type of variable	Measure
1	MSW generation	Y_{Gen}	Dependent	Tons/day
2	Population	X_{Pop}	Independent	Inhabitants
3	Population density	X_{Pd}	Independent	Inhabitants/km^2
4	Population born in another municipality	X_{Pbam}	Independent	Inhabitants
5	Average schooling	X_{As}	Independent	Years of study
6	Household with goods and services	X_{Hgs}	Independent	Percent (%)
7	Commercial establishments and services	X_{Ces}	Independent	Number of establishments
8	Daily per capita income	X_{Dpi}	Independent	Mexican pesos/day
9	Marginalization index	X_{Mi}	Independent	Percent (%)

Exploratory analysis of variables

An exploratory analysis of the 9 variables used to check the normality of the data was carried out. The test used was Kolmogorov-Smirnov, with a level of significance of $\propto$= 0.05. This test showed that the variables Y_{Gen}, X_{Pop}, X_{Pd}, X_{Pbam}, X_{Hgs}, X_{Ces}, X_{Dpi}, did not follow a normal distribution, because their p-value was smaller than the $\propto$ value considered. In order to adjust their values, the variables were transformed with natural logarithms. The variables X_{As} and X_{Mi} were not transformed because their data followed a normal distribution (Table 2).

Table 2: Normality test and transformation of variables

Original variable			Transformed variable		
	Kolmogorov-Smirnov			Kolmogorov-Smirnov	
	Statistical	p-value		Statistical	p-value
Y_{Gen}	0.338	<0.010	$ln\text{-}Y_{Gen}$	0.050	>0.150
X_{Pop}	0.281	<0.010	$ln\text{-}X_{Pop}$	0.066	>0.150
X_{Pd}	0.271	<0.010	$ln\text{-}X_{Pd}$	0.039	>0.150
X_{Pbam}	0.387	<0.010	$ln\text{-}X_{Pbam}$	0.065	>0.150
X_{As}	0.053	>0.150	X_{As}	---	---
X_{Hgs}	0.183	<0.010	$ln\text{-}X_{Hgs}$	0.054	>0.150
X_{Ces}	0.349	<0.010	$ln\text{-}X_{Ces}$	0.056	>0.150
X_{Dpi}	0.117	<0.010	$ln\text{-}X_{Dpi}$	0.056	>0.150
X_{Mi}	0.054	>0.150	X_{Mi}	---	---

Multicollinearity analysis and variable screening

An analysis of the explanatory variables was made prior to the selection of the best MLR model. Through a multicollinearity test, some of the variables initially considered were eliminated. Especially, the variance inflation factor (VIF) and the Pearson correlation coefficient (r) were used. Similar to Keser *et al.* (2012), the r coefficient was used to detect the bivariate association, while the VIF was used to detect the multivariate correlation. Eqs. 5 and 6 describe the tests used.

$$VIF_k = \frac{1}{(1-R_k^2)} \quad (5)$$

$$r = \sqrt{1-\frac{SSE}{SS_{YY}}} \quad (6)$$

VIF value is calculated using the R^2 of the regression equation; the explanatory variables denoted by k are analyzed as dependent variables, while the others are used as independent variables; thus, VIF is calculated for each explanatory variable k.

The cut-off value of VIF used in this study was 4. According to Ghinea *et al.* (2016), when VIF < 1, the explanatory variables are not correlated; when 1 < VIF < 5, the explanatory variables are slightly correlated; and when VIF > 5 or 10, the explanatory variables are highly correlated. The value of r indicates the relationship between two variables (positive or negative); its value ranges between -1 and 1. There are no clearly defined cut-off in the literature. Arriaza (2006) indicates that with values of r greater than 0.3, there may be signs of correlation, with values greater than 0.8, there are serious problems of multicollinearity. As in Grazhdani (2016), in this study it was considered that a value of $r \geq 0.6$ (positive or negative), indicates correlation between the explanatory variables. The elimination of explanatory variables was performed in an iterative procedure, i.e., the VIF values were initially determined for the 8 variables; subsequently, the variable with the highest VIF was eliminated and the next iteration with 7 variables was performed. This elimination procedure ended when a VIF cut-off value of 4 was found. Finally, other eliminations were made based on the values of r. Subsequently, 3 explanatory variables were used in the search stage for a better model (of greater parsimony). The first variable selected was X_{Pop}, i.e., the "total population" of each municipality, under the hypothesis that the larger the population, the greater the consumption and thus the greater the amount of MSW generated. The second explanatory variable used was X_{Pd}

"population density", under the premise that dispersion patterns or agglomeration of inhabitants per unit area influences MSW generation. The third variable used was X_{Pbam} "population born in another municipality", which can be seen as migration, i.e., people who move to other places to seek better living conditions. The process of mobilization of people causes changes in consumption patterns of a new place of settlement. Other models that do not follow the principle of parsimony were also created (more than 3 explanatory variables), but they should not be used to forecast waste generation rates, since they have very low accuracy values and some of their explanatory variables are not significant.

Accuracy of the model and validation

In order to determine the accuracy of the best model found, 3 widely used measures were employed: the Mean Absolute Percentage Error (MAPE), the Mean Absolute Deviation (MAD) and the Root Mean Square Error (RMSE) (Eqs. 7, 8 and 9, respectively). A value of these measures close to zero indicates a high precision of the model (Azadi and karimí 2016).

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| * 100 \quad (7)$$

$$MAD = \frac{1}{n}\sum_{t=1}^{n}|A_t - F_t| \quad (8)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(A_t - F_t)^2} \quad (9)$$

In these equations, A_t is the observed value, F_t is the predicted value and *n* is the sample size. MAPE is expressed in terms of percentage of error, MAD expresses the precision in the units of the data analyzed, and RMSE indicates how concentrated the data are around the line of best fit. In order to perform the external validation of the model, the technique called $R^2 jackknife$ using Eq. 10. This equation is calculated by systematically eliminating each observation from the data set, estimating the regression equation and determining to what extent the model is able to predict the observation that was removed.

$$R^2 jackknife = 1 - \frac{\sum(y_i - \hat{Y}_{(i)})^2}{\sum(y_i - \bar{Y})^2} \quad (10)$$

The $R^2 jackknife$ coefficient varies between 0 and 100%, larger values suggesting models with greater predictive capacity; $\hat{Y}_{(i)}$ denotes the predicted value for i-th observation obtained when the regression model fits the data with y_i omitted (or removed) from the sample; and $\bar{Y}$ is the simple average of the observed data.

Verification of model assumptions

The validity of the MLR models is subject to the behavior of the residual errors "ε" (difference between observed and predicted values of the dependent variable), particularly their normal distribution, their independence and homoscedasticity (Kumar and Samandder, 2017). The verification of normality was carried out through the Kolmogorov-Smirnov test, with a level of significance of $\propto$ = 0.05. In order to verify the independence of residues, the Durbin-Watson test (d) was applied, looking for values close to 2, because "d" varies between 0 and 4 (Mendenhall and Sincich, 2012). The homoscedasticity assumption was evaluated with the plot of residuals vs predicted, both standardized, looking for a residue behavior that does not fit any known pattern.

RESULTS AND DISCUSSION

Statistical analysis of variables

The initial exploratory analysis was performed on the response variable Y_{Gen}, which has the behavior shown in Fig. 2. It is observed that some municipalities, which appear to be outliers, show a very high rate of MSW generation.

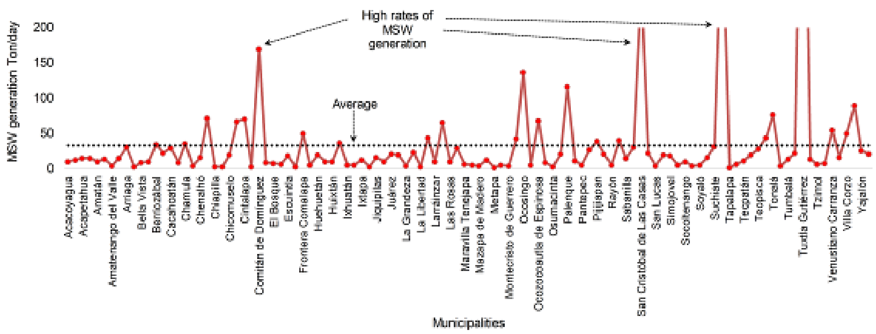

Fig. 2: MSW generation rates in the state of Chiapas

These atypical values were not eliminated from the analysis because they are not errors, but rather data that come from the most important municipalities of Chiapas, such as "Tuxtla Gutiérrez, Comitán, San Cristóbal de las Casas and Tapachula". These municipalities are regional heads, therefore, the number of inhabitants, their patterns of consumption and MSW generation, differ significantly from the rest of the studied area. The normality test of the response variable and of the 8 explanatory variables is shown in Fig. 3. The non-normality of the variables Y_{Gen}, X_{Pop}, X_{Pd}, X_{Pbam}, X_{Hgs}, X_{Ces} and X_{Dpi}, can be seen. For this reason, these variables were transformed using natural logarithms (Fig. 3a, 3b, 3c, 3d, 3f, 3g and 3h).

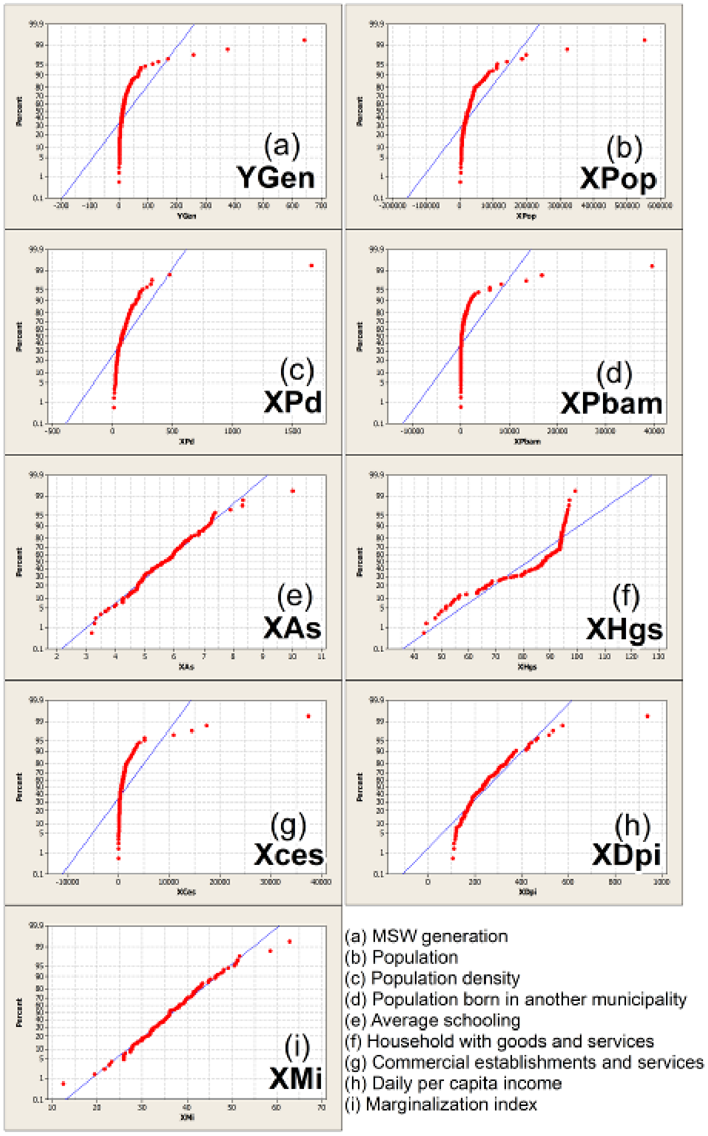

Fig. 3: Behavior of the variables analyzed with respect to normality

Forecast model

The coefficients of the MLR model were determined using the Minitab software. Only the explanatory variables that fulfilled the multicollinearity criterion were used. Initially, 2 theoretically valid models were determined; the first one is shown in Eq. 11.

$$lnY_{Gen} = -8.91 + 1.10\ ln_{X_{Pop}} + 0.0259\ ln_{X_{Pd}} + 0.0688\ ln_{X_{Pbam}} \qquad (11)$$

This first model consists of 3 variables, X_{Pop}, X_{Pd}, X_{Pbam} (all transformed). The F-test associated with a variance analysis indicated that the model is statistically valid because p-value < 0.05. This model can thus also be used for forecast purposes. However, it is important to be careful because the explanatory variable X_{Pd} is not statistically significant since the null hypothesis that the coefficient of the variable is equal to zero (H_0: $\beta_i = 0$) is met. Therefore, the explanatory variable is not related to the dependent variable, i.e., it should not be interpreted.

The second model is presented in Eq. 12, which consists of 2 explanatory variables "X_{Pop} and X_{Pbam}". Similar to the first model, here also the p-value and the F-test indicate that it is a statistically valid model that can be used for forecasting purposes. Particularly this model is the one of greater parsimony, because it uses only 2 variables.

$$lnY_{Gen} = -8.86 + 1.11\, ln_{X_{Pop}} + 0.0658\, ln_{X_{Pbam}} \quad (12)$$

All the information associated with the analysis of variance is presented in Table 3.

Table 3: Analysis of variance of the proposed models

Model	Source	Degree of freedom (df)	Sum of Squares	Mean square	F	Sig.
1	Regression	3	150.591	50.197	1,449.33	0.000
	Residual	107	3.706	0.035		
	Total	110	154.297			
2	Regression	2	150.549	75.274	2,169.16	0.000
	Residual	108	3.748	0.035		
	Total	110	154.297			

The verification of assumptions of the proposed models, especially model 2, is presented in Fig. 4. The probability-probability plot (p-p plot) (Fig. 4a) shows the values of the residuals with a linear pattern indicating normality; additionally, the Kolmogorov-Smirnov value and its associated p-value confirm it (p-value > 0.15). The result of the Durbin-Watson independence test gave a value of 1.979 for model 2, which indicates that the residuals are not correlated. The homoscedasticity test presented in Fig. 4b shows a behavior of the residuals that does not fit any known pattern; therefore, this situation is adequate.

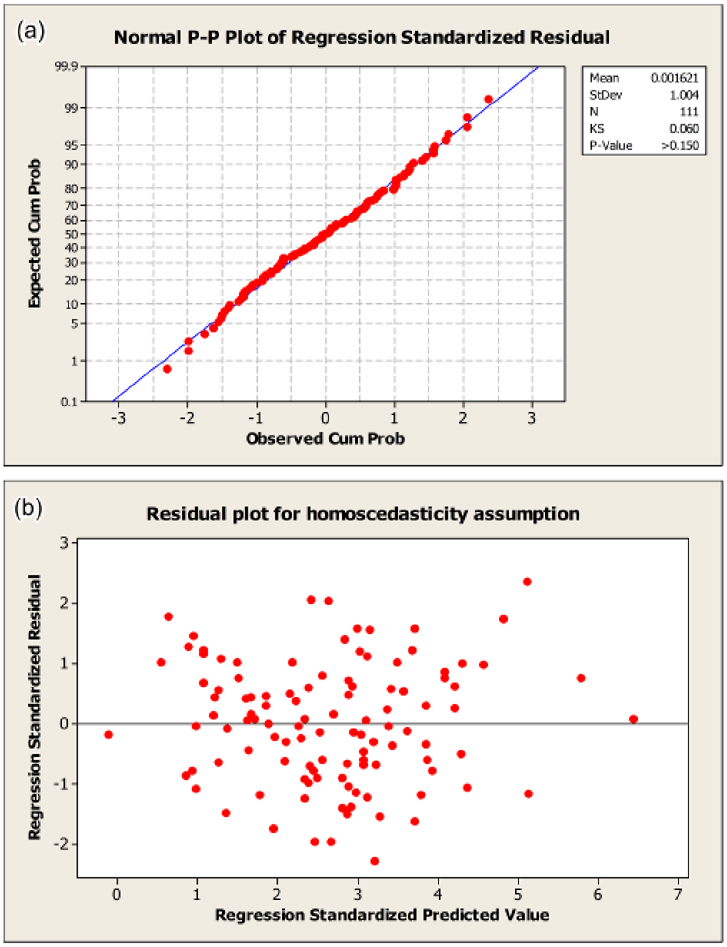

Fig. 4: Verification of model assumptions: (a) Normality of residuals, (b) Independence of residuals

On the other hand, the R^2 value of the equations in both models was 0.976, which indicates that 97.6% of the generation rate of MSW Y_{Gen} (transformed) can be explained by the explanatory variables used. It is important to note the gradual decrease of $R^2{}_{adj}$ (0.975) with respect to R^2, which is due to the adjustment by the introduction of 2 and 3 variables in models 1 and 2, respectively. The high value of R^2 and $R^2{}_{adj}$ in these models is due to the initial transformation of the explanatory variables, as well as the response variable. Additionally, the data collection carried out in this study influenced these values because they come from a census database, and not from an information survey through interviews. The internal validation of model 2 through MAPE, MAD and RMSE, showed the values of 7.70, 0.16 and 0.19, respectively, which indicates a high precision since the values of these tests are close to 0 (zero). The external validation by $R^2 jackknife$ presented a value of 97.44%. Therefore, model 2 also has a high forecasting capacity.

Non-significant variables

The analysis of the 8 explanatory variables using the VIF test produced the initial elimination of the variables X_{As}, ln-X_{Hgs}, ln-X_{Ces} and ln-X_{Dpi}, since their value was higher than the cut-off of 4. The variables X_{As} and ln-X_{Dpi} have been used mainly in studies at household or locality levels (Khan *et al*, 2016; Ojeda *et al.,* 2008), but in this paper they were used at district level, and the effect of these variables seems not to be important (low correlation with the response variable ln-Y_{Gen}). The variables ln-X_{Hgs} and ln-X_{Ces} were eliminated because they are highly correlated with X_{Mi}, since the latter is a multidimensional indicator that measures deprivation in a population, through variables similar to those eliminated. Finally, through the *r* test, only X_{Mi} was eliminated, since it was highly correlated with ln-X_{Pbam}, with a coefficient of -0.695, i.e., much higher than the cut-off value of 0.6 (positive or negative); additionally, this variable was less correlated with the ln-Y_{Gen} response variable (Table 4).

Table 4: Correlation matrix of variables

Pearson's correlation	*ln*-Y_{Gen}	*ln*-X_{Pop}	*ln*- X_{Pd}	*ln*- X_{Pbam}
ln-X_{Pop}	0.985	---	---	---
ln- X_{Pd}	0.161	0.169	---	---
ln- X_{Pbam}	0.638	0.573	-0.059	---
X_{Mi}	-0.355	-0.271	-0.097	-0.695

Significant variables

The transformed variables X_{Pop}, X_{Pd} and X_{Pbam} were used in the search for the best model, since their VIF and r values were below the cut-off values. $\boldsymbol{X_{Pop}}$ has been used in the studies of Azadi and karimí (2016) and Abdoli *et al.* (2011), as the most important explanatory variable. In this study, Pearson's correlation *r*-value was 0.985, which indicates that it is also the variable most related to the generation of waste, particularly in a positive way, i.e., to a larger population corresponds a greater quantity of MSW. The variable $\boldsymbol{X_{Pd}}$ has been used in few publications. Bel and Mur (2009) use this variable also to obtain the costs associated with waste management. In this study, *r*-value of 0.161 was obtained, which indicates a poor correlation with the response variable. The analysis of the forecast model 1 indicated that this variable is not statistically significant, and its use must be taken with caution. The $\boldsymbol{X_{Pbam}}$ variable is positively related to the response variable. Its Pearson's correlation coefficient was 0.638. This variable is important in the study area, since it can be concluded that people who move from one municipality to another have different consumption patterns that modify the amounts of MSW. Other explanatory variables mentioned in Kolekar *et al.* (2016), for instance age, employment status, level of urbanization and environmental variables such as precipitation or temperature, were not used in this study since it is difficult to find a database with information on these variables.

Other generated models

Eqs. 13, 14 and 15 show other models generated with the variables initially raised (models 3, 4 and 5 respectively). All these models are statistically significant and are also useful for forecasting purposes, but incorporate explanatory variables that are not significant; therefore, their results are not accurate (Table 5). Additionally, they have low parsimony because they incorporate more than 2 or 3 explanatory variables. Table 6 shows the statistical behavior of the predictors. The p-value and the VIF must be analyzed because they indicate multicollinearity between the variables and also their possible interpretation within the generated model.

$$lnY_{Gen} = -8.48 + 1.13\ ln_{X_{Pop}} - 0.0019\ ln_{X_{Pd}} + \ 0.0315\ ln_{X_{Pbam}} - \ 0.0111X_{Mi} \qquad (13)$$

$$lnY_{Gen} = -8.42 + 1.13\, ln_{X_{Pop}} - 0.0008\, ln_{X_{Pd}} + 0.0324\, ln_{X_{Pbam}} - 0.0070X_{As} - 0.0119X_{Mi} \quad (14)$$

$$lnY_{Gen} = -8.22 + 0.995\, ln_{X_{Pop}} + 0.0039\, ln_{X_{Pd}} + 0.0261\, ln_{X_{Pbam}} - 0.0006X_{As} + 0.133\, ln_{X_{Hgs}} - 0.00525X_{Mi} \quad (15)$$

Table 5: Analysis of variance of other generated models

Model	Source	Degree of freedom (df)	Sum of Squares	Mean square	F	Sig.	$R^2{}_{adj}$
3	Regression	4	150.900	37.725	1,177.44	0.000	0.977
	Residual	106	3.396	0.032			
	Total	110	154.297				
4	Regression	5	150.902	30.180	933.42	0.000	0.977
	Residual	105	3.395	0.032			
	Total	110	154.297				
5	Regression	6	151.397	25.233	905.01	0.000	0.980
	Residual	104	2.900	0.028			
	Total	110	154.297				

Table 6: Statistical behavior of predictors in models 3, 4 and 5

Model	Predictor	Coefficient	p-value	VIF	Comments
3	Constant	-8.48	0.000	-------	There is no multicollinearity among predictors, but some of them are not statistically significant (p-value> 0.05).
	$ln_{X_{Pop}}$	1.13	0.000	1.947	
	$ln_{X_{Pd}}$	-0.0019	0.937	1.300	
	$ln_{X_{Pbam}}$	0.0315	0.053	3.556	
	X_{Mi}	-0.0111	0.002	2.405	
4	Constant	-8.42	0.000	-------	There is multicollinearity between predictors (VIF> 5) and some of them are not statistically significant (p-value> 0.05).
	$ln_{X_{Pop}}$	1.13	0.000	1.948	
	$ln_{X_{Pd}}$	-0.0008	0.975	1.374	
	$ln_{X_{Pbam}}$	0.0324	0.055	3.789	
	X_{As}	-0.0070	0.844	5.373	
	X_{Mi}	-0.0119	0.026	5.177	
5	Constant	-8.22	0.000	-------	
	$ln_{X_{Pop}}$	0.995	0.000	5.634	
	$ln_{X_{Pd}}$	0.0039	0.869	1.377	
	$ln_{X_{Pbam}}$	0.0261	0.096	3.824	
	X_{As}	-0.0006	0.986	5.384	
	$ln_{X_{Hgs}}$	0.133	0.000	6.180	
	X_{Mi}	-0.0525	0.309	5.710	

Inferences about the municipalities of the study area

Based on model 2 and its statistical analysis, inferences were made to forecast the generation rate of MSW in the municipalities of the CCS. The forecast was made with the most current data of the variables X_{Pop} and X_{Pbam}, corresponding to the year 2015. Fig. 5 shows MSW generation forecast and its comparison with the original database. In most of the municipalities of the CCS, the generation rate of MSW presented a gradual increase with respect to population growth (variable X_{Pop}), except in Arriaga, Chiapilla, Osumacinta, Suchiapa, Teopisca, Tonalá, Venustiano Carranza and Villaflores, due to the fact that the population of these municipalities did not increase in the 2010-2015 period.

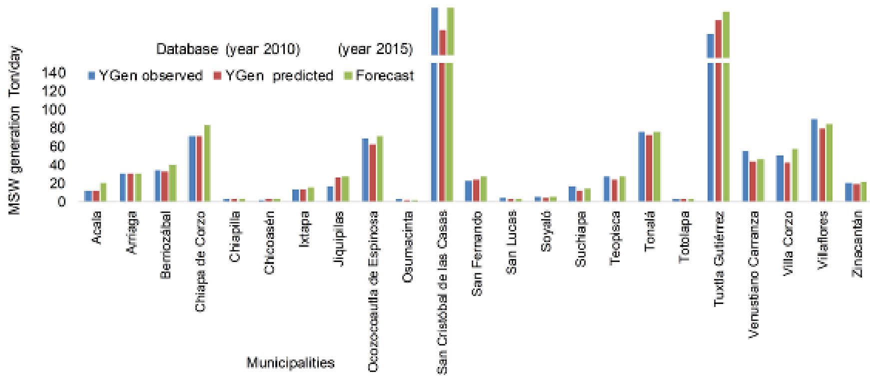

Fig. 5: Forecast of MSW generation rates in the municipalities of the study area

Currently, the study area generates 1,600 tons of MSW/day, of which 74% comes from the regional heads such as Berriozábal, Ocozocoautla de Espinosa, San Cristóbal de las Casas, Tuxtla Gutiérrez and Villaflores.

CONCLUSION

In this study, a forecast model was developed to determine the generation of MSW in the municipalities of the CCS, Chiapas State, Mexico. A MLR was used to obtain the forecast model with social and demographic explanatory variables. Two forecast models were presented and analyzed, with variables that met the multicollinearity test. The most important variables to predict the rate of MSW generation in the study area were the population of each municipality (X_{Pop}), the population born in another municipality (X_{Pbam}) and the population density (X_{Pd}). X_{Pop} is the most influential explanatory variable of waste generation, particularly it is related in a positive way. X_{Pbam} is less related to waste generation. X_{Pd} is the variable that least influences waste generation prediction; in addition, it can present problems of correlation with other explanatory variables. Although other variables, such as daily per capita income (X_{Dpi}) and average schooling (X_{As}), are very important, they do not seem to have an effect on the response variable in this study. The user of this forecast model should use model 2, since it is the one with the highest parsimony (it uses fewer variables); $R^2{}_{adj}$, MAPE, MAD and RMSE values indicated high influence on the explained phenomenon and high forecasting capacity. Additionally, it is important to mention that when using the models proposed for forecasting purposes, it is necessary to make a transformation in the explanatory and response variables (use inverse of natural logarithm). The inferences made on the municipalities of the study area showed that, except in some municipalities, the MSW generation rate usually presented a gradual increase with respect to population growth and with respect to the number of inhabitants that were born in another entity (migration). Finally, this study can be a solid basis for comparison for future research in the area of study. It is possible to use different mathematical models such as artificial neural network, principal component analysis, time-series analysis, etc., and compare the response variable or the predictors.

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AUTHOR CONTRIBUTIONS

Example:

M. Asadi performed the literature review, experimental design, analyzed and interpreted the data, prepared the manuscript text, and manuscript edition. R. Mostafaloo performed the experiments and literature review, compiled the data and manuscript preparation. H. Izanloo helped in the literature review and manuscript preparation. A. Zayadi performed some of the remained experiments…………

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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 (NOMENCLATURE)

Commented [Mw13]: A list of manuscript abbreviations and chemical symbols which are used throughout the text must be included at the abbreviations table. The abbreviations should be defined in the text at first use and then placed at the abbreviations table. The provided abbreviations list must be arranged alphabetically according to the left column.

$\propto$	Level of significance
A_t	Observed value
β_i (1,2,3 ... k)	Regression coefficients
CCS	Cuenca del Cañón del Sumidero
d	Durbin-Watson test
Eq.	Equation
F	Fisher test
F_t	Predicted value
H_0	Null hypothesis
k	Number of explanatory variables included in the model
$ln\text{-}Y_{Gen}$	Natural logarithm of MSW generation
$ln\text{-}X_{Pop}$	Natural logarithm of population
$ln\text{-}X_{Pd}$	Natural logarithm of population density
$ln\text{-}X_{Pbam}$	Natural logarithm of population born in another municipality
$ln\text{-}X_{Hgs}$	Natural logarithm of household with goods and services
$ln\text{-}X_{Ces}$	Natural logarithm of commercial establishments and services
$ln\text{-}X_{Dpi}$	Natural logarithm of daily per capita income
MAD	Mean Absolute Deviation
MAPE	Mean absolute percentage error
MLR	Multiple Linear Regression
MSW	Municipal Solid Waste
n	Sample size
p-p plot	Probability-probability plot
p-value	Probability value
r	Pearson correlation coefficient
r-value	Pearson correlation coefficient
R^2	Coefficient of determination

$R^2{}_{adj}$	Adjusted coefficient of determination
$R^2 jackknife$	Jackknife coefficient of determination
RMSE	Root Mean Square Error
SSE	Sum of Squared Errors
SS_{YY}	Sum of the squares of the difference of (Y_i) and the $(\bar{Y})$
VIF	Variance Inflation Factor
X_i (1,2,3 ... k)	Explanatory variables
X_{As}	Average schooling
X_{Ces}	Commercial establishments and services
X_{Dpi}	Daily per capita income
X_{Hgs}	Household with goods and services
X_{Mi}	Marginalization index
X_{Pbam}	Population born in another municipality
X_{Pd}	Population density
X_{Pop}	Population
$\bar{Y}$	Average of observed data
Y_{Gen}	MSW generation
Y_i	Value of each individual observation
$\hat{Y}_i$	Predicted value

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Notice:

1- All references must be formatted according to the below references

2- All references hyperlinks must be taken and included at under each references (DOI is not accepted)

3- All journals in the references must be formatted in abbreviation. In order you find the journals title abbreviations, refer to the link below:

https://woodward.library.ubc.ca/research-help/journal-abbreviations/

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GRAPHICAL ABSTRACT

A **Graphical Abstract** must be produced according to the main findings of the manuscript research story summarizes visually and pictorially. Providing some selected manuscript graphs, tables, images, diagram or text cannot be assumed as Graphical Abstract!
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HIGHLIGHTS

The provided HIGHLIGHTS must be written scientifically according to your research output and **NOVELTY** not as your research aims and methodology into **3 to 4 HIGHLIGHTS** statements:

- The predictive model developed was constructed using multiple linear regression, with explanatory social and demographic variables that met the multicollinearity test;
- The results of this work show that the variables most influential on waste generation are directly related to the number of inhabitants; such as population, population density and population born in another entity;
- The suggested predictive model has a high parsimony, in addition, the adjusted coefficient of determination and the accuracy coefficients indicated high influence on the explained phenomenon and a high forecasting capacity.

ORIGINAL RESEARCH PAPER (11%)

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

ABSTRACT:

BACKGROUND AND OBJECTIVES: Urban intensity and activities produce a lot of biodegradable municipal solid waste. In this research, the biodrying process is used to process municipal solid waste into Refuse Derived Fuel and evaluation of greenhouse gases.

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

FINDINGS: The result showed that variation in airflow effect on cellulose content and the calorific value. Optimum airflow based on cellulose content and calorific value is 6 L/min.kgin.kg with a decrease of cellulose content by 10.05% and an increase of calorific value 38.17%. The biodrying process was also able to reduce water content from 69% to 40%. On day 0, the CH_4 concentration between control and biodrying was very different by 2.65 ppm and 1.51 ppm respectively at the beginning of the research and the peak temperature. The concentrations of N_2O in each control was about 534.69 ppb and 175.48 ppb. The lowest level of N_2O was when the biodrying process used 2 L/min.kg airflow.

CONCLUSION: The calorific value of MSW after the biodrying process (refuse derived fuel) has a range of about 4,713 cal/g – 6,265 cal/g. It can be classified in the low energy coal (brown coal) category, that is equal to <7,000 cal/g. The biodrying process is proven to be an alternative MSW processing that can produce RDF and low GHG emissions.

KEYWORDS: *Biodrying; Greenhouse gas; MSW; Refuse derived fuel; Temperature*

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
43	10	3

RUNNING TITLE: Calorific and greenhouse gas emission in MSW.

INTRODUCTION

Urban intensity and activities produce much biodegradable solid waste. It must be managed to avoid a negative impact on the environment, such as odors and pollutant emissions, soil, water, gas, etc. Current methods of processing solid waste by burning or landfill is not optimal. The space available for final processing (TPA) is critical, and finding alternative new space (TPA area) is difficult and expensive, especially in big cities. Waste to Energy (WTE) technology has the potential to reduce the volume of the original waste by 90%, depending on the composition by recovering the energy (Patil *et al.,* 2014). The water level in urban solid waste is an essential factor because it affects the efficiency of combustion and converting the process of solid waste into energy (Suksankraisorn *et al.,* 2010). Among the methods that are developing, mechanical biological treatment (MBT) becomes a potential choice because of its environmental-friendly waste treatment system (Egan *et al.,* 2005). Natural drying, often called biodrying, is one of the critical components of the MBT processes. Solid waste will be through mechanical-biological bioconversions (Rada and Ragazzi, 2015; Velis *et al.,* 2009). In practice, the solid waste that has been chopped and has high water content put into the reactor. By the biodrying processes, solid waste produces dry solid waste (bio-dried) which undergoes a further mechanical process. This process combines the heat that generated from the aerobic decomposition process of organic compounds, and excess air which serves as a reliable waste dryer (Velis *et al.,* 2009). The dried solid waste can be considered to be Refused Derived Fuel (RDF). It is a fuel material produced from various types of waste, such as urban waste, industrial waste, or commercial waste (Scheutz *et al.,* 2014). RDF can be used as a substitute for coal (Rada and Ragazzi, 2015). Most of the biodrying processes can reduce water content in solid waste which is about between 30% and 80% of the initial water content (Li *et al.,* 2015; Zhang *et al.,* 2008; Zhao *et al.,* 2010). Water removal varies between 3.1 to 10.7 g water/g volatile solid consumed depending on the composition of first waste and operating conditions (Frei *et al.,* 2004; Ma *et al.,* 2016). Wastes that have been processed using biodrying include manure, pulp mill sludge, food waste, MSW, and sewage sludge. The biodrying process is carried out in batch conditions with 20 days of maximum duration. The final result of biodrying is RDF that can be used as co-fuel in the cement industry and boiler unit (Garg *et al.,* 2007; Wagland *et al.,* 2011). Colomer-Mendoza *et al.,* (2013) conducted gardening waste using 10 reactors with air volume obtained from 0.88 to 6.42 L / (min · kg dry weight) and added 5% of bulking agents. the bulking agent led to greater weight loss. However, important aspects, such as greenhouse gas emissions have not been studied. Most research discusses greenhouse gas emissions from the composting process of solid waste such as solid sludge. For example, González *et al.,* (2019) discusses greenhouse gases, volatile organic compounds and odor emissions in sewage sludge but does not discuss the degradation process of the biodrying process. Even though biodrying and composting have different purposes; composting requires rapid degradation while biodrying experiences partial degradation (Goyal *et al.,* 2005). Characterization of greenhouse gas (GHG) and odor compounds of solid sludge compost making at standard scale has been widely published (Maulini-duran *et al.,* 2013; Rincón *et al.,* 2019), while several studies have been carried out at full scale (González *et al.,* 2019; Shen *et al.,* 2012). Emissions from the biodrying process need advanced studied because of their impacts on global warming (Pan *et al.,* 2018). Biodrying is an alternative approach to evaluate MSW, and the GHG emissions from this process deserve to be investigated. This study aims to increase the calorific value and evaluate the MSW degradation process using biodrying. Greenhouse gas emissions are also evaluated in depth. This study has been conducted in 2019 in the greenhouse to avoid disturbing animals and manipulating the desired environmental conditions.

MATERIALS AND METHODS

In this study, MSW was manually collected from The KORPRI housing complex, Tembalang, Semarang, Central Java, Indonesia with coordinates -7.061131, 110.446709. The characteristics of the sample at this location are almost the same as MSW produced by the majority people of Semarang city. MSW needs to sort out to determine the percentage of each component (%). The MSW component, percent by weight, consists of 64% leaves, 12% paper, 16% plastic, 6% uneaten vegetables, 1,73% uneaten of meals, and 0, 27% fruit peels. Then, MSW was chopped using a chopper with dimensions of 15-20 mm, while the plastic MSW was manually cut by scissor. All MSW components were mixed and measured in volume, then put into a biodrying reactor. MSW volume is 0.051 m3 (85% of total volume) and 0.009 m3 (15% of total volume) is bulking agent. The bulking agent is mature and stable compost with dimensions of ± 10 mm. MSW volume calculation is based on the maximum reactor capacity of 60 liters (body diameter: 38 cm; total height: 65 cm; weight: 3 kg). The biodrying reactor is made of polyethylene plastic equipped with a heat sink (Thermoshield Universal) to minimize heat loss. The bottom of the reactor is installed a stainless-steel pipe (Ø3 mm) to ensure uniform air distribution. Variations of airflow (0, 2, 3, 4, 5, 6 l/ min) use an aquarium pump (Resun LP-100). Each reactor has sampling holes with a diameter of 7 cm at 20 cm, 40 cm, and 60 cm height from the bottom of the reactor. The holes were tightly closed when they were not used. Temperature sensor probes were placed at the top, middle, and bottom of the reactor, and the average rate was noted down. Temperature measurement used a stainless steel temperature sensor that is waterproof to the nearest 0,01 °C. Temperature parameters were recorded automatically every 15 minutes. The recording data would be saved in an SD card in *xlsx* format. The range of temperature probe is -50 ° C to 200 ° C. Leachate that was produced by the reactor, was collected and measured the volume (if incurred). The biodrying reactor scheme is shown in Fig. 1.

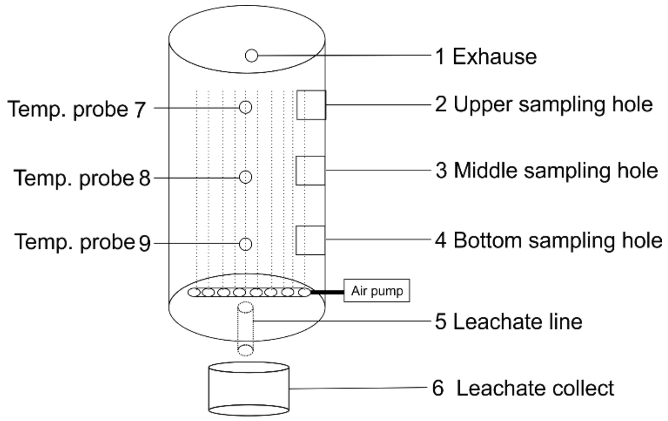

Fig. 1: The biodrying reactor scheme

During the biodrying process, parameters of water content are analyzed every day. The water content was measured using the gravimetric method. 20 g of samples were collected from three different levels of depths (top, middle, and bottom), and mixed to analyze water content in triplicate ways with a deviation standard set on <5%. The neutral detergent fiber of each sample was determined and used to calculate the cellulose contents (Goering and van Soest, 1970). C-Organic was tested using the Walkey-Black method that is a rapid and effective means for determining the organic carbon. Nitrogen content was analyzed using the Kjeldahl method. Organic carbon and nitrogen testing were done in triplicate ways. Caloric/heat content testing was performed using Bomb Calorimeter. Greenhouse Gas (GHG) sampling was carried out at the highest temperature for CO_2, CH_4, and N_2O. The Greenhouse Gas Analysis used 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. Flowchart of this research is show in Fig. 2.

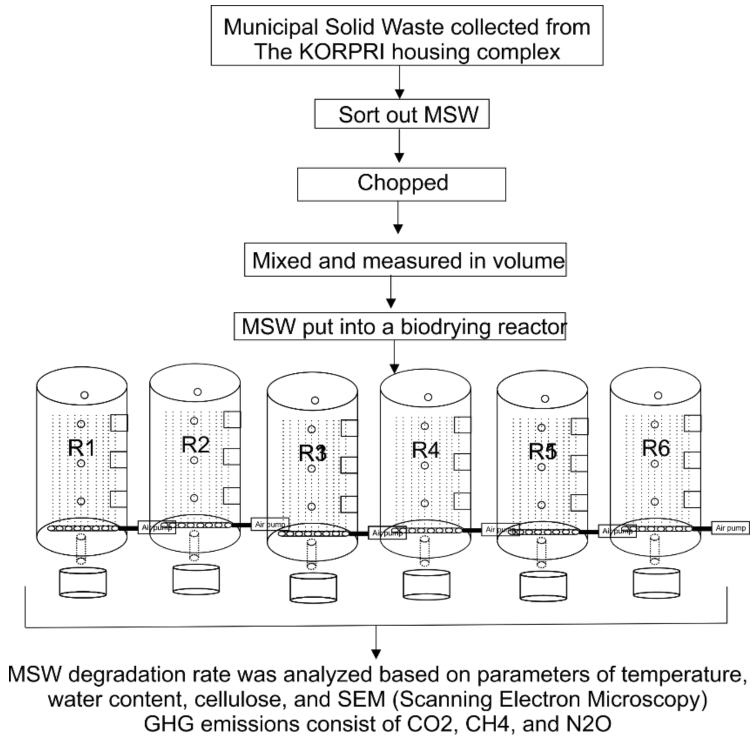

Fig. 2: Flowchart research about calorific and greenhouse gas emission in municipal solid waste treatment using biodrying

RESULTS AND DISCUSSION

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

Temperature Profile

Biodrying is an exothermic process, where an aerobic process requires oxygen for microbial activity. Temperature is a parameter for the exothermic process and a crucial factor that influence the process of water evaporation and organic degradation (Fadlilah and Yudihanto, 2013; Sen and Annachhatre, 2015; Zhang *et al.,* 2008). Temperatures that are too high and too low can slow down the drying process because decomposer microorganisms are inactive, so there is an incomplete drying process (Sudrajat, 2006). Temperature data that occur with the variation of air flow are shown in Fig. 3.

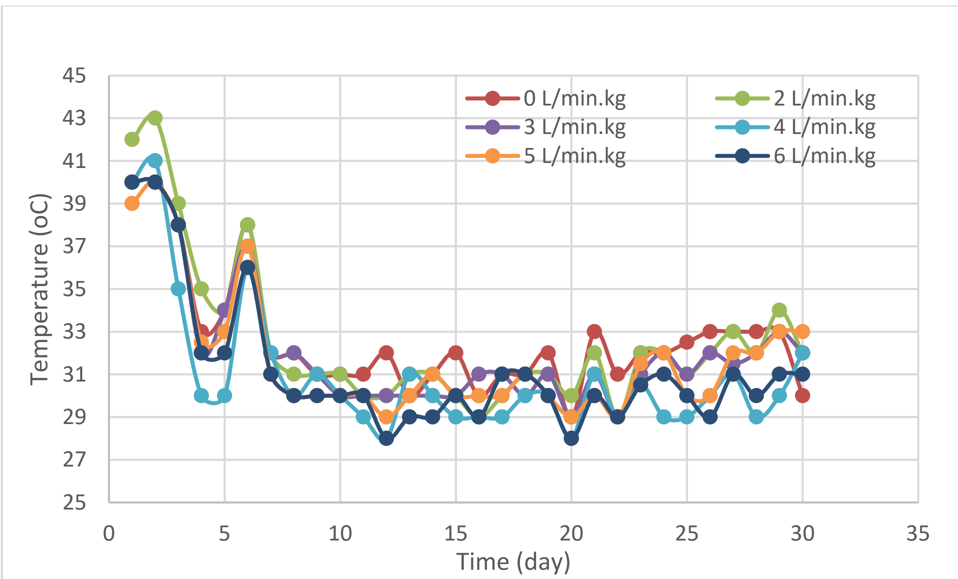

Fig. 3: Temperature profile graph in the biodrying process for 30 days

Temperature was monitored every day for 30 days to see the activities of microorganisms during the biodrying process (Jalil *et al.,* 2016). Fig.3 shows the temperature of matrix in each variation. Each reactor produces different temperatures due to differences in MSW decomposition speed. Airflow rate causes aerobic conditions (Velis *et al.,* 2009). In biodrying reactor, the amount of air in reactor 6 is more than reactor 2, as a result the speed of decomposition of solid waste is different. The highest temperature mencapai 43 ^{o}C resulting from reactor 2 (airflow 2 L/min.kg) on the 2nd day, then the temperature decreased to 39 ^{o}C on 3rd day and was stable in the mesophilic phase until 8th day. Furthermore, the temperature gradually reduced until it reached 29 ^{o}C. The result of this research is compatible with the study of Sadaka *et al.,* (2011). They state that there was a temperature escalation of about 37.7 ^{o}C – 48.8 ^{o}C in the biodrying temperature on day 2 to day 3. These temperatures indicate a high biodegradation process due to the high metabolism of microorganisms (Fadlilah and Yudihanto, 2013; Jalil *et al.,* 2016). According to Jalil *et al.,* (2016) the temperature rises due to microorganism activities in a biodrying reactor. For the biodrying method, "mesophilic" temperature and moderately "thermophilic" temperature are more applicable than "thermophilic" temperature. Mesophilic temperatures are about 35 ^{o}C and 40 ^{o}C. Moderately thermophilic temperatures are about 40 ^{o}C to 45 ^{o}C. Thermophilic temperatures, which is about 55˚C to 70˚C. Specifically, Jokiniemi and Ahokas, (2014) states that the combination of high temperature and low airflow can slow down the drying process. This condition corresponds to Sadaka *et al.,* (2011). The temperature rises on the second day and then returns to ambient temperature. During this biodrying process, the phase of the moderately thermophilic temperature developed on the second day, while the mesophilic phase was on until day six. On day 7 to day 30, there was an increase and decrease in temperature, which was relatively uniform (stable) with temperature ranging from 28 ^{o}C – 34 ^{o}C. This condition indicates that the large enough activity of microorganisms does not occur to create biological stability after the biodrying process takes place (Adani *et al.,* 2002). Jalil *et al.,* (2016) in their research, using solid waste samples such as food scraps, papers, plastics, and woods, find a similar condition.

Water content

Water content is an essential parameter in determining the success of the biodrying process. Water content affects the chemical reaction associated with microbial growth and the biodegradation process of organic substances (Tom *et al.,* 2016; Velis *et al.,* 2009). At the beginning of the biodrying process, initial levels are generally set in the range of 50%-75%. If the initial water content is too low, then microbial activities are too small, because the microbial metabolic needs water to processes. Whereas high water content creates anaerobic conditions. Water is more dominant in filling pores than air, so oxygen availability is limited (Colomer-Mendoza *et al.,* 2013; Fadlilah and Yudihanto, 2013; Sadaka *et al.,* 2011). The results of measurements of water content in each reactor at different aeration airflows are shown in Fig. 4.

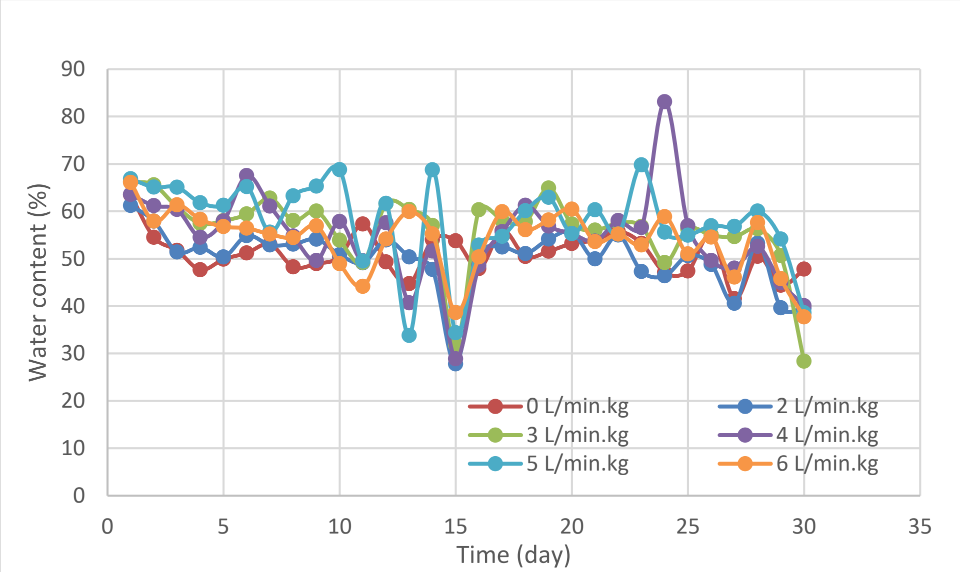

Fig. 4: Graph of water content profile in the biodrying process for 30 days

At the beginning of the biodrying process, water content did not decrease significantly. On the day 15 there was a significant decreasing of water content compared to the first day, which is in reactor 1 (0 L/min.kg) 63,47% to 23,75%, reactor 2 (2 L/min.kg) 61,22% to 27,77%, reactor 3 (3 L/min.kg) 66,26% to 31,84%, reactor 4 (4 L/min.kg) 63,54% to 28,87%, reactor 5 (5 L/min.kg) 66,09% to 38,60%. This reduction shows that the biodrying process was working effectively according to the literature, which ranges between days 7–15 (Velis *et al.*, 2009). The degradation condition of water content is compatible with the research of Jalil *et al.*, (2016), on the day 14 there was a degradation of water content from 67 ± 0,24% to 33,91 ± 2,24%. According to Adani *et al.*, (2002), the water content can reduce the decomposition level of solid waste. On day 20, the water level on solid waste increased in all reactors. This escalation is due to the addition of water from the condensation process inside the reactor (Widarti *et al.*, 2015). Water will be evaporated because of the decomposition process of solid waste. Then, it turns into dew on the surface of the reactor due to the absence of a steam trap. The dew turns to be saturated steam and falls back into the pile of solid waste so that the water content increases again. On day 30, solid waste in reactor 1 had a water content of 47,78%. This value is higher than other reactors. It is because the reactor 1 had a configuration without aeration. This condition means that solid waste did not undergo a biodrying process, where the process of reducing water content in solid waste was only through a biological process (Perazzini *et al.*, 2016). On the other hand, reactor 2,3,4,5 and 6 L/min.kg had aeration, which helped them in drying process physically and biological process (Perazzini *et al.*, 2016; Sen and Annachhatre, 2015). Water content in the biodrying process can be reduced due to the evaporation of water molecules of the solid waste surface. In this process, a changed phase occurred changes the liquid into gas, and aeration accelerates the transfer of steam from inside material to the outside air (Bilgin and Tulun, 2015; Velis *et al.*, 2009). This statement is consistent with Sen and Annachhatre (2015). They also states that the higher air flow, the solid waste will dry up physically only, not due to the heat generated by aerobic degradation. The final results of the research produced solid waste with the lowest water content in reactor 3 (3 L/min.kg) of 28,37%. Based on this research, biodrying succeeded in reducing water content in solid waste higher than 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 another way with composting, the nutritions or organic substances such as C-Organic and total nitrogen in biodrying are not fully degraded. However, C-Organic and nitrogen levels are preserved as fuel (Fadlilah and Yudihanto, 2013). Eq. 1 is a diagram of degradation aerobic process reaction that produces carbon and nitrogen (Sen and Annachhatre, 2015).

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

C-Organic and Total Nitrogen (dry matter) in this research is shown in Table 1. Based on Table 1, C-Organic at the beginning of the biodrying process ranged from 50.96% - 64.82%. During 30 days of research, kadar C-Organic berkisar antara 47,30%-60,35%. The decrease of C-Organic was not significant. This decrease shows that low consumption of carbon is useful to increase the calorific value (Colomer-Mendoza *et al.,* 2013). However, on the 6 L/min.kg airflow, it had an escalation of carbon content. This escalation occurs due to high aeration airflow, which can stop the microbial activity until it is unable to degrade organic compounds properly (Colomer-Mendoza *et al.,* 2013; Sadaka *et al.,* 2011).

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

Total Nitrogen decreased during the process of 30 days of research. Initial Total Nitrogen ranged between 1.07% - 1.63%. While on the day 30 was ranged about 0.62% - 1.45%. Total Nitrogen are volatile and the less nitrogen content, the slower organic matter decomposes (Widarti *et al.,* 2015). The slower decomposition of organic matter will lead to no overall degradation of the research sample, which can be used as fuel (Fadlilah and Yudihanto, 2013). This research is corresponding with the research of Colomer-Mendoza *et al.,* (2013) by using a sample garden solid waste without additional bulking agents and variations in airflow.

Cellulose

In aerobic conditions, microbes in the biodrying process can degrade semi-biodegradable organics and are challenging to be degraded like cellulose (Wardhani *et al.,* 2017). Cellulose is one of the first growing cells of polysaccharides (carbohydrates), which are attacked by microorganisms in the early stages of decomposition (Evangelou, 1998). The source of cellulose in this research derived from solid waste samples used that were leaf litter, paper, and food scraps. The cellulose content in leaves is about 15-20% and paper about 85-99% (Howard *et al.,* 2003). While cellulose level of food scraps is about 13% (Astuti, 2016). However, in general, the cellulose level in the dry-weight of solid waste is various from 15-60% of its dry-weight (Evangelou, 1998). One of the potentials that can be used by cellulose materials is as necessary materials for fuel (Anindyawati, 2010). Fig. 5 shows the graph of measurements of cellulose levels for 30 days.

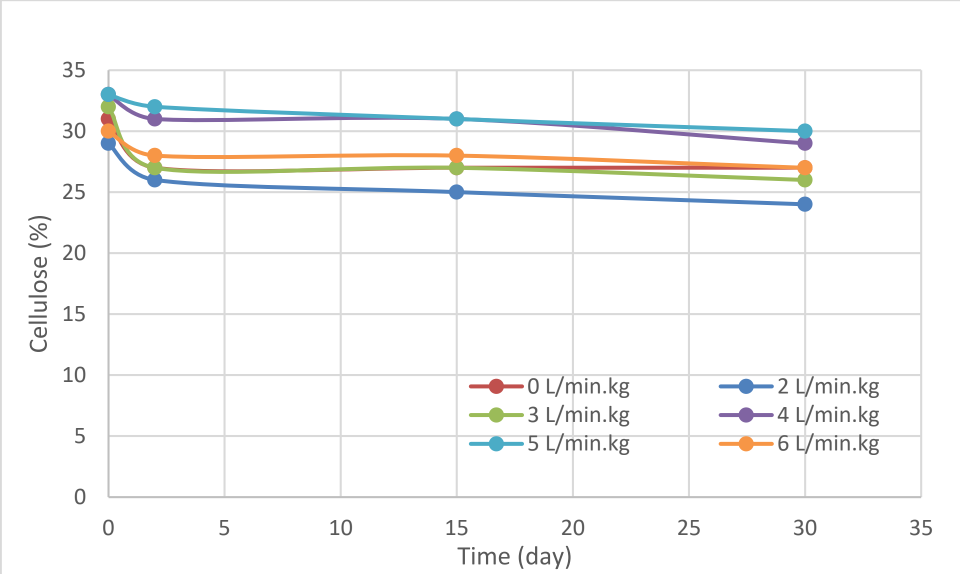

Fig. 5: The cellulose content based on variations in airflow (flow rate)

Fig. 5 is the level of cellulose produced for 30 days. On day 0, during the process, the level of cellulose in each reactor ranged about 29%-30%. On day two there was the highest degradation cellulose level until 26-32% with the lowest level of cellulose at aeration flow of 2 liters/minute. The highest temperature followed on day 2 with a range of about 40 °C – 43 °C. This temperature is included in the thermophilic phase. In that phase occurs the most considerable degradation of cellulose (Huang, 2010). It can happen because the activity of the carboxymethyl enzyme of cellulose is indicated to be active in the thermophilic phase. After the thermophilic period, there is a temperature derivation of organic matter that has been metabolized, so that the degradation of cellulose continues to occur until the day 30 but not as much as in the thermophilic phase (Huang, 2010). This research is consistent with the Huang (2010) research, where the highest degradation of cellulose comes on day three up to 15 at the time of the thermophilic phase. Whereas, rapid decomposition happens in the thermophilic phase. The derivation in cellulose content during 30 days research in each reactor is shown in Fig. 6.

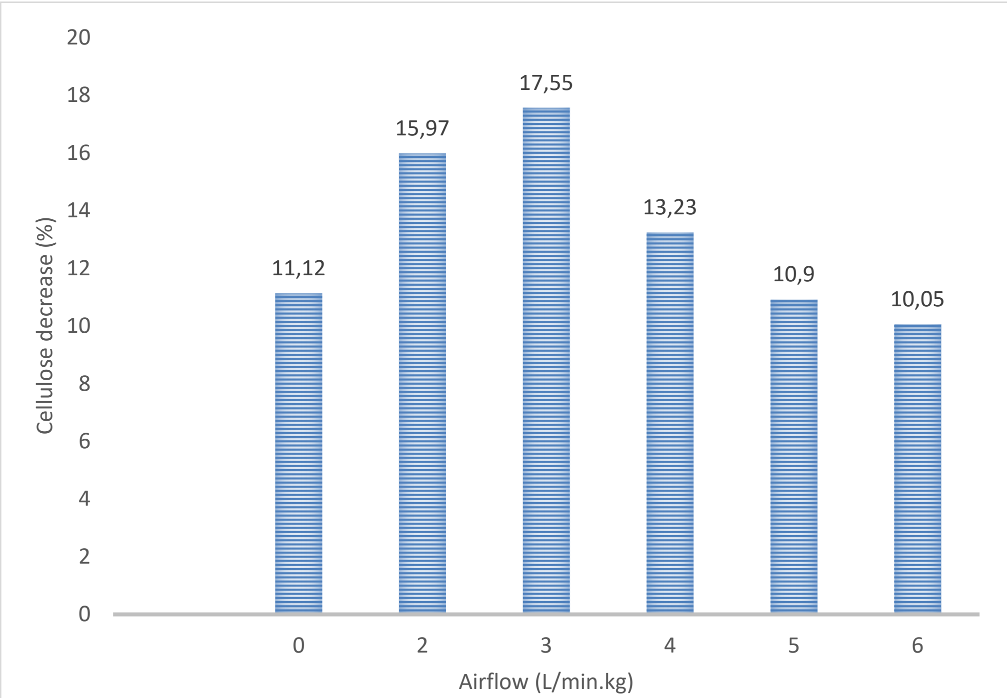

Fig. 6: Derivation cellulose levels (%) at various flow rate variations

Based on Fig. 6, there is a derivation of the cellulose level in each reactor. It shows that there was a degradation of cellulose during the biodrying process. Based on the statistical test, the significance result obtained is 0,032 (sig < 0,05), which means that there is a significant effect due to variations in air flow on cellulose level. Degradation of cellulose breakdown occurs due to the presence of microbial enzymes into oligosaccharides subsequently into glucose. These microbial enzymes are cellulose enzymes which are extracellular (enzymes produced in cells and released into the media) that can hydrolyze macromolecules, one of which is cellulose. Cellulose degradation produces CO_2 and water. The most significant deterioration comes up in aeration 3 L/min.kg, which is 15,97% while the smallest decreased is in aeration 6 L/min.kg, which is 10,05%. This phenomenon indicates that higher airflow can stop the activity of microbes. Then makes it unable to degrade organic compounds properly and also the consumption of nutrients is low (Colomer-Mendoza *et al.,* 2013; Sadaka *et al.,* 2011). Thus, variations in airflow affect cellulose degradation in the biodrying process.

Calorific

Calor value is an indicator of energy content possessed by a substance, including in solid waste. Reliable waste treatment using the biodrying method is expected to function to increase energy content by drying solid waste to produce RDF products (Fadlilah and Yudihanto, 2013). In the first two days of the biodrying process, each reactor in range 4,575.07 – 4,777.91 cal/g. This condition is influenced by the high activities of microorganisms which are shown by the moderately thermophilic temperature phase (40 ^{o}C to 50 ^{o}C). By the increase in microorganisms' activity, the consumption of nutrients needed by microorganisms is significant, so that effects on the calorific value produced. A significant escalation in calorific value is occurred on day 15 to be 4,643.70 – 6,175.22 cal/g and became stable until day 30 with a range between 4,713.36 – 6,265.37 cal/g. This escalation is because of the decrease in water content. On day 15, a significant reduction in water content becomes 23.75%-38.60% compared to day 2, where the water content ranged about 54.51%-65.56%. It is because on day two, the water content was still high, and the calorific value is low. It is because some of the heat is used to evaporate the water at the beginning of the process. Whereas on day 15, water content was lower, so the heat in water evaporation was not as much as when the water content is still high. Thus, when the water content is lower than the calorific value increases. This escalation is also because of the derivation of microorganisms activity, which is characterized by a decrease in temperature (Fig.3), so that nutrient consumption is low (Colomer-Mendoza *et al.,* 2013). This condition is compatible with research by Fadlilah and Yudihanto (2013) and Sen and Annachhatre (2015) the most massive increase in calorific value occurred between days 12 and 16. Based on the statistical test, the significant result is 0.032 (sig<0.05), which means there is a significant effect due to the variation of airflow on calorific value. The increase in calorific value during 30 days study in each reactor is shown in Fig. 7.

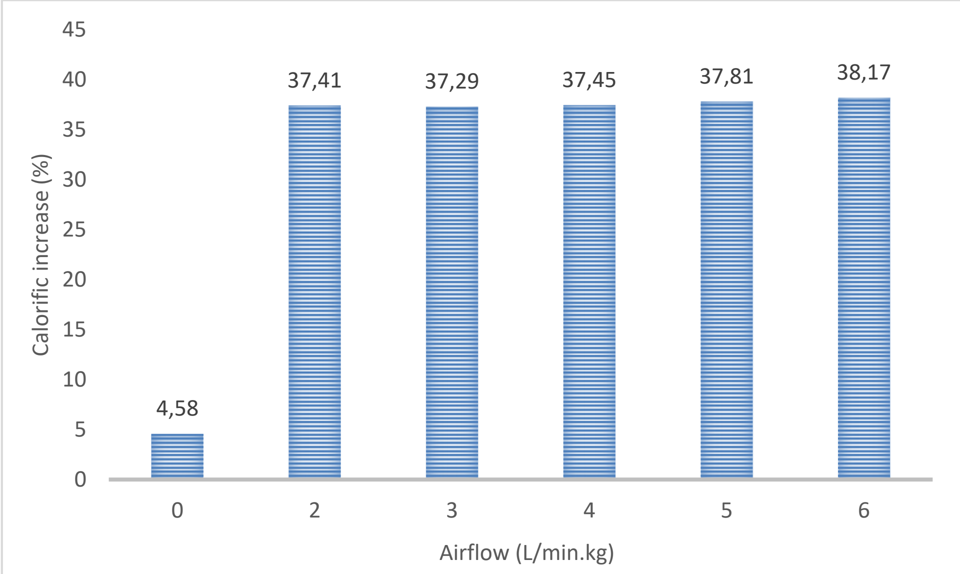

Fig. 7: Percentage increase in calorific value due to variations in flow rate (aeration)

Based on Fig. 7 for 30 days of research, there was a difference between the control reactor (without the addition of flowrate) and the biodrying reactor. In the reactor without additional flow 0 L/min.kg, the calorific value did not significantly increase. It was only 4,58% with an initial calorific value of 4,507.46 cal/g and the final value of 4,713.36 cal/g. While in the reactor with additional flow rate, calorific value increased about 37.29% - 38.19%. The minimal calorific value enhancement was at the rate 3 L/min.kg with an initial calorific value of 4,520.98 cal/g and final calorific value of 6,206.78 cal/g. The maximum calorific value enhancement was at the rate 6 L/min.kg with initial calorific value 4,534.51 cal/g and the final calorific value is about 6,265.37 cal/g. These conditions indicate that airflow rate influence the enhancement of calorific value in the bio drying. This research is compatible with Fadlilah and Yudihanto (2013). Where the biodrying process at solid food waste produces the calorific value of about 4,952 cal/g for flow rate 6 L/min.kg and 4,064 cal/g for 4 L/min.kg. The calorific value of the biodrying process has a range of about 4,713 cal/g - 6,265 cal/g. Also, according to SNI 13-6011-1999 concerning the classification of resources and coal reserves, the calorific value of the biodrying process can be classified in the low energy coal (brown coal) category, which is equal to <7,000 cal/g. The increase in calorific value is influenced by the degradation of organic substances, one of which is cellulose. In this research, when the flow rate experienced maximum degradation of cellulose, then it produced the lowest calorific value in its final result. Conversely, the maximum escalation of calorific value when the flow rate experiences the lowest cellulose degradation. It is consistent with Sugni *et al.* (2005), which explains that the maximum degradation of organic matter produces a low energy content.

SEM analysis (Scanning electron microscopy)
SEM analysis is one analysis to determine the morphology of the surface of a sample. SEM shows physical changes that occur during the degradation process of solid waste by microbes (Sharma *et al.*, 2019). Fig. 8 is the result of the SEM test from a solid waste sample of one of the reactors, which is reactor 2 with a airflow of 2 L/min.kg.

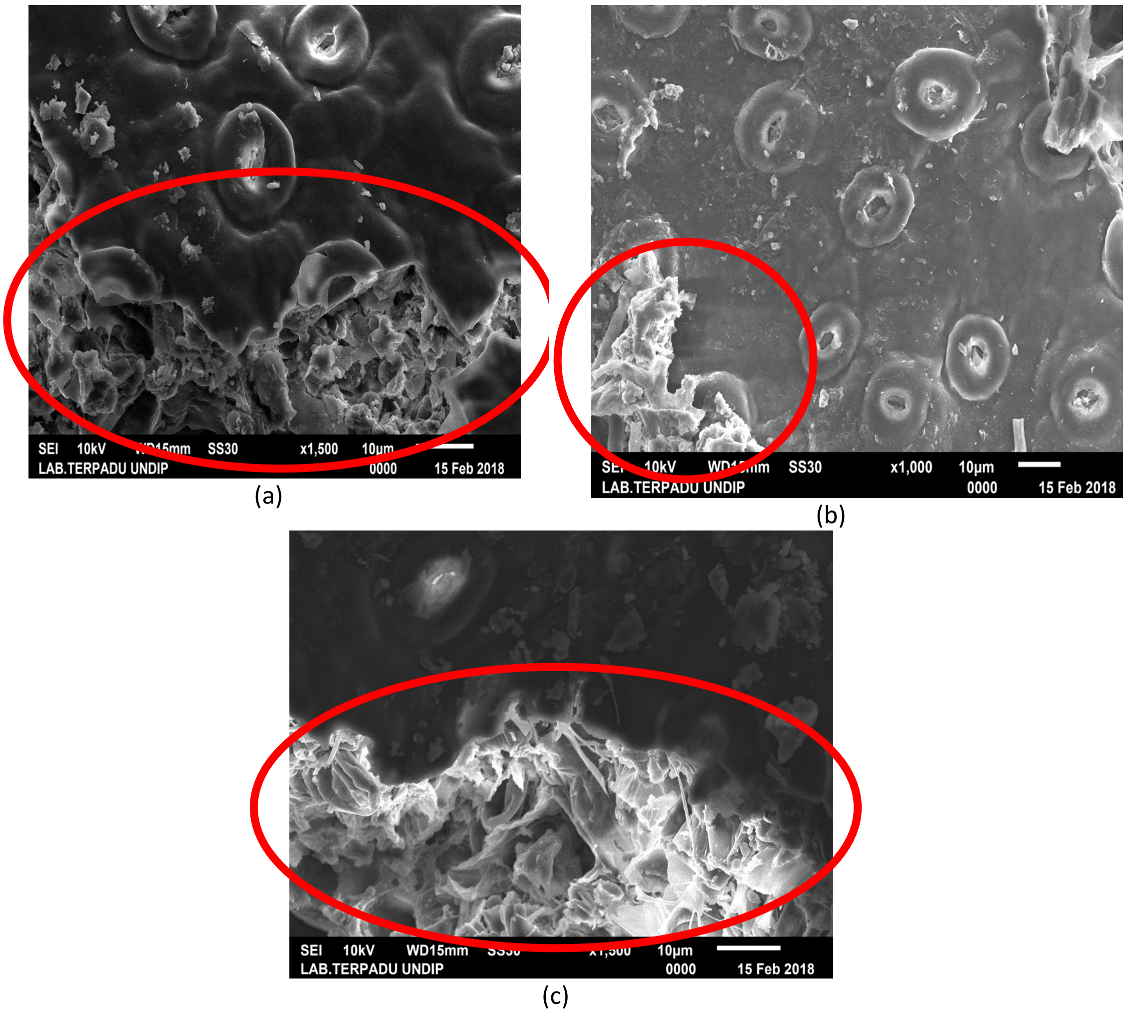

Fig. 8: SEM test result from solid waste sample with flow rate 2 L/min.kg (a) day 0 magnification 1,000x , (b) day 15 magnification 1,500x, (c) day 30 magnification 1,500x

Fig. 8 is SEM results on solid waste samples on day 0, 15, and 30 with aeration flow 2 L/min.kg. The surface morphology of solid waste on day 0 shows a larger size with smaller cavities/pores. By the time in research (day 15 to 30), there is a degradation process that causes a shrinkage of particle size and escalation of cavities on the surface. SEM results are in line with Sharma *et al.,* (2019) research, which states that the size of solid waste cavities is getting bigger due to the degradation process. It indicates there was a degradation process in the biodrying process that lasts for 30 days.

Greenhouse emission (GHG)

Air emissions are measured to determine the effects of the biodrying process in solid waste toward gasses that cause the greenhouse effect consisting of CH_4, CO_2, and N_2O. The gas measurement is done at day 0 and at the time when the temperature reaches its peak (42.5 °C). Research on greenhouse gas emissions using the same solid waste for 30 days. The result of the greenhouse gas is shown in Table 3. CH_4, CO_2, and N_2O gases are produced from the decomposition of biodegradable organic matter in MSW. In this study, biodegradable organic waste were leaves (64%), paper (12%), uneaten vegetables (6%), uneaten of meals (1.73%), and fruit peels (0.27%), while plastic (16%) is non biodegradable.

Table 3: 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 (L/min.kg)	CH_4 (ppm)		CO_2 (ppm)		N_2O (ppb)	
	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

CH_4 emissions during the biodrying process

The results of the CH_4 concentration test in the biodrying process are shown in Fig.9. On day 0, CH_4 concentration was very different between the control (without aeration) and solid waste with biodrying treatment, respectively 2.65 ppm (1,34 mg/kg) and 1.51 ppm (0,73 mg/kg). The conversion of ppm to mg/kg of CH_4, CO_2, and N_2O is based on the calculation of fluxes that were used to calculate the experimental data by second order polynomial equation (gas concentration vs. time) (Hao *et al.,* 2002). CH_4 emissions are very low when compared with the research of Wang, *et al.,* (2018) using biochar, zeolite and wood vinegar combining for composting of pig manure resulting CH_4 emissions of 8.83 g/kg. Methane emission was quite high during the decomposition process of solid waste, but the presence of aeration in the biodrying process was able to reduce methane emissions. Hellebrand (1998) states that methane emissions increase during a decomposition of grass and green waste. He is also observed an increase in methane emissions for 30 days during the decomposition process of urban waste. They noted that methane emissions were reduced drastically by adding aeration. Yusuf et al. (2012) calculated methane emissions 28% higher during anaerobic decomposition than during a windrow composting.

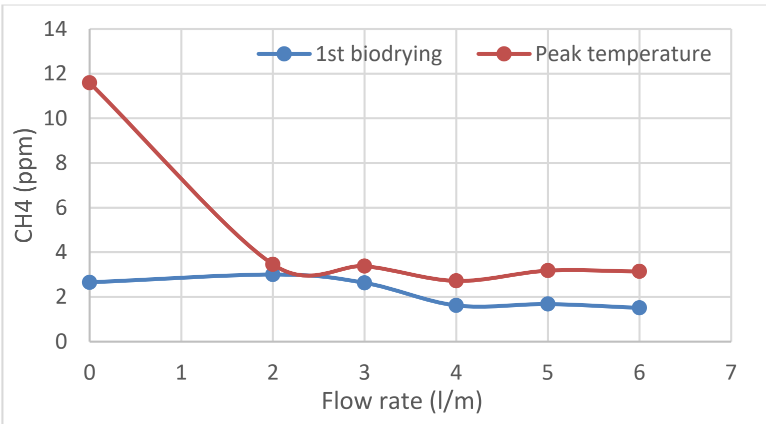

Fig. 9: The CH_4 levels (ppm) at 0 days and at the time the temperature reaches its peak.

CO_2 emissions during the biodrying process

The results of the CO_2 concentrations test during the biodrying process are shown in Fig. 10. The graph describes that CO_2 levels using biodrying are lower than without-bio drying. On day 0 the difference of CO_2 concentration between control (without aeration) and solid waste with biodrying treatment was very significant, respectively 68.888,95 ppm (2,75 g/kg) and 5.153,67 ppm (0,27 g/kg) (13:1 in comparison). Awasi *et al.,* (2016) stated that CO_2 emissions of 10 g C $m^{-2}d^{-1}$ on the 22nd day resulted from composting sewage sludge. Meanwhile, research conducted by Wang, *et al.,* (2018) using combining biochar, zeolite and wood vinegar for composting of pig manure produced CO_2 of 116.5 g $kg^{-1}d^{-1}$.

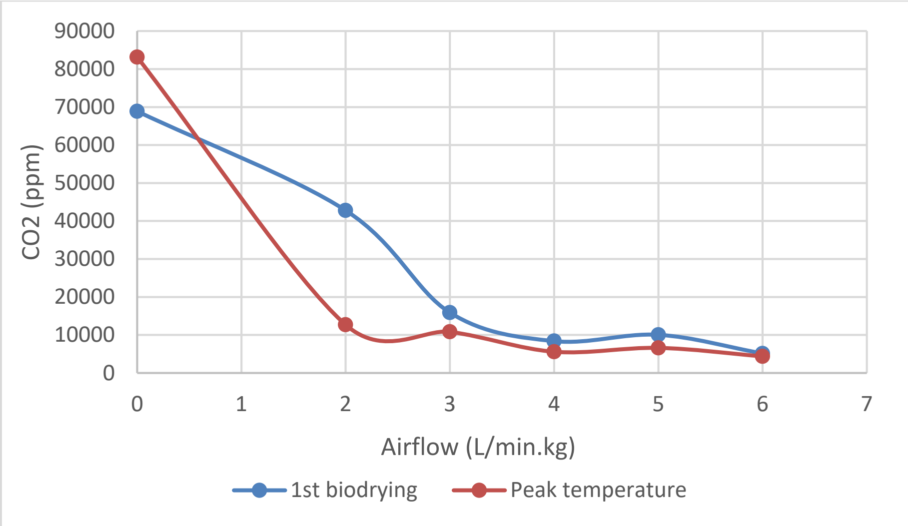

Fig. 10: Graph of CO_2 levels (ppm) at 0 days and when the temperature reaches its peak

N_2O emissions during the biodrying process

The results of N_2O concentration testing during the biodrying process are shown in Fig. 11. The biodrying process produces N_2O emission higher at the time of the temperature reached its peak (Thermophilic). Research conducted by Wang, *et al.,* (2018) using a combination of biochar, zeolite and wood vinegar for composting pig produced N_2O emissions of 47.29 mg kg^{-1}. According to Paul (2001), nitric oxide emissions are generally higher during thermophilic composting. Nitrous oxide emissions are as a side product from nitrification and denitrification. Nitrification involves the oxidation of ammonium into nitrate. The heterotrophic nitrification process contributes to N_2O emissions.

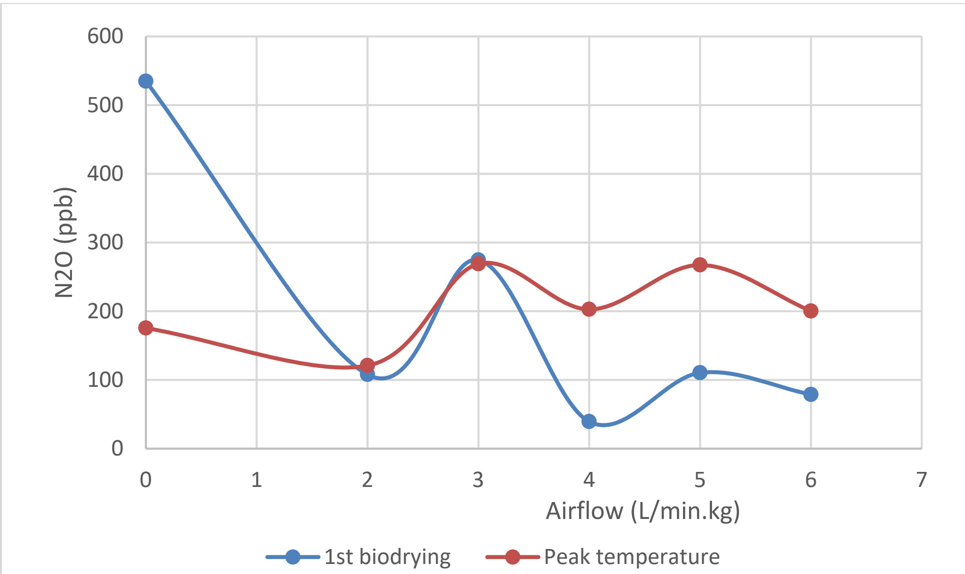

Fig. 11: Graphs of N_2O levels (ppm) at day 0 and when they reach their peak temperature

CONCLUSION

This research aims to increase the calorific value, evaluate the degradation process, and greenhouse gas emissions from MSW using biodrying. The results showed that the biodrying process can increase calorific value of MSW (refuse derived fuel) about 37.29% - 38.19%. The calorific value of RDF has a range of about 4,713 cal/g - 6,265 cal/g can be classified in the low energy coal (brown coal) category, which is equal to <7,000 cal/g. ~~MSW degradation process is~~

known from the parameters of temperature, water content, cellulose, C-Organic, and Total Nitrogen. The highest temperature reaches 43 oC resulting from reactor 2 (airflow 2 L/min.kg) on second day. , then decreased to 39 ºC on day three and was stable in the mesophilic phase until day 8. The biodrying process can achieve moderately thermophilic temperatures are between 40 ºC to 45 ºC. The final results of the research produced solid waste with the lowest water content in reactor 3 (airflow 3 L/min.kg) of 28.37%. Based on this research, biodrying succeeded in reducing water content in solid waste higher than control (without bio drying). Meanwhile, the lowest cellulose reduction resulted from the reactor 6 (6 L/min.kg) of 10.05%. This phenomenon indicates that higher airflow can slow the activity of microorganisms. The decrease in C-Organic and Total Nitrogen were not significant. The slower decomposition of C-Organic and Total Nitrogen will lead to no overall degradation of samples, which can be used as fuel. MSW morphology based on SEM results on day 0 shows a larger size with smaller cavities/pores. By the time in research (days 15 to 30), there is a degradation process that causes shrinkage of particle size and escalation of cavities on the surface. Overall, the biodrying process results in lower GHG emissions than without biodrying. The highest CH_4 emissions are at its peak temperature (43 °C) with levels of 11.59 ppm. CO_2 concentration between control (without aeration) and solid waste with the biodrying treatment is 68,888.95 ppm and 5,153.67 ppm, respectively (13: 1 ratio). N_2O concentration each control is about 534.69 ppb and 175.48 ppb at the beginning of research and its peak temperature. The lowest level of N_2O is when the biodrying process uses a rate of 2 L/min.kg. We find that MSW biodrying process can increase the calorific value and reduce greenhouse gas emissions. The biodrying process allows MSW not to be discharged into final processing. Appropriate strategy needs to be done so that other factors that affect the heat value and GHG emissions are known.

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 research. 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

ºC	Celsius
cal/g	Calorie/gram
CH_4	Methane
CO_2	Carbon dioxide
FTD	Flame Thermionic Detector
GHG	Greenhouse gas
MBT	Mechanical biological treatment
MSW	Municipal Solid Waste

N_2O	Nitrous oxide
L/min.kg	Liters per minute.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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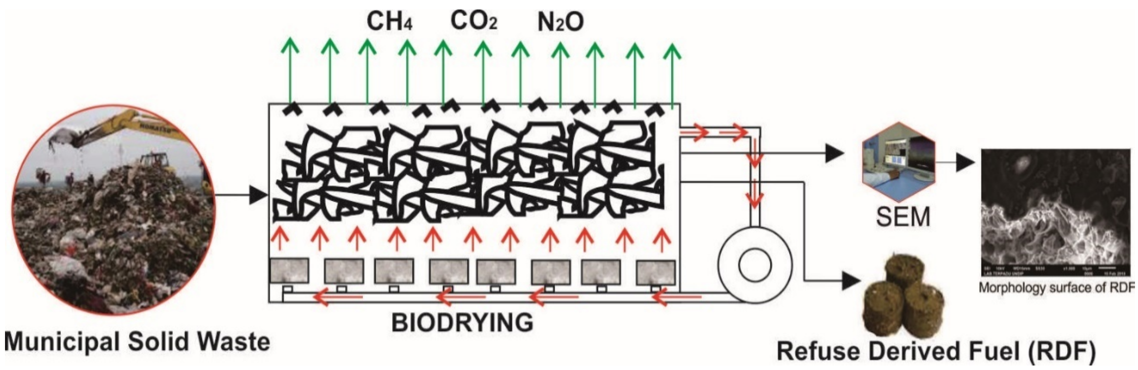
GRAPHICAL ABSTRACT



HIGHLIGHTS

- The biodrying process can increase calorific value of Municipal Solid Waste and reduce greenhouse gas emissions;
- The calorific value of Refuse Derived Fuel can be classified in brown coal category, which is equal to <7,000 cal/g;
- Biodrying process can reduce CO_2 emissions by 13 times compared to without biodrying.

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Reviewer # 1:

Query	Review Details Required	Author's Response (Author **MUST** show the place of performed corrections in the revised manuscript)
1.	Greenhouse using six biodrying reactors made from acrylic material equipped with digital temperature recording, blower, and flow meters. – Photographs of the experimental setup should be included.	Photographs is shown in Fig. 1 in **materials and methods**
2.	What type of solid waste is used for generation of green house gas? - need Explanation.	We explain in **Greenhouse emission (GHG).** Research on greenhouse gas emissions using the same solid waste for 30 days. The result of the greenhouse gas is shown in Table 3. CH4, CO2, and N2O gases are produced from the decomposition of biodegradable organic matter in MSW. In this study, biodegradable organic waste were leaves (64%), paper (12%), uneaten vegetables (6%), uneaten of meals (1.73%), and fruit peels (0.27%), while plastic (16%) is non biodegradable.
3.	There was no information on carbon monoxide generation from the solid waste.	We are not discussing CO (carbon monoxide) gas because we argue that CO gas is not emitted during aerobic decomposition of solid waste.
4.	How much quantity of solid waste is used for the study and for the production of green house gases?	We explain in **materials and methods.** All MSW components were mixed and measured in volume, then put into a biodrying reactor. MSW volume is 0.051 m3 (85% of total volume) and 0.009 m3 (15% of total volume) is bulking agent. The bulking agent is mature and stable compost with dimensions of ± 10 mm. MSW volume calculation is based on the maximum reactor capacity of 60 liters (body diameter: 38 cm; total height: 65 cm; weight: 3 kg).
5.	Every day the solid waste is	We explain in **Temperature profile.** Each reactor

	drying, then definitely temperature on the solid waste is getting reduced. But, this study has different variation. – need justification.	produces different temperatures due to differences in MSW decomposition speed. Airflow rate causes aerobic conditions (Velis et al., 2009). In biodrying reactor, the amount of air in reactor 6 is more than reactor 2, as a result the speed of decomposition of solid waste is different.
6.	Are the authors used either same solid waste for 30 days for the production of green house gas or different solid waste? Need justification.	We explain in **Greenhouse emission (GHG).** Research on greenhouse gas emissions using the same solid waste for 30 days.
7.	There was no comparison study made between this study and the previous studies.	We explain in **CH4 emissions during the biodrying process.** On day 0, CH_4 concentration was very different between the control (without aeration) and solid waste with biodrying treatment, respectively 2.65 ppm (1,34 mg/kg) and 1.51 ppm (0,73 mg/kg). The conversion of ppm to mg/kg of CH_4, CO_2, and N_2O is based on the calculation of fluxes that were used to calculate the experimental data by second order polynomial equation (gas concentration vs. time) (Hao *et al.,* 2001). CH_4 emissions are very low when compared with the research of Wang, *et al.,* (2018) using biochar, zeolite and wood vinegar combining for composting of pig manure resulting CH_4 emissions of 8.83 g/kg. **CO2 emissions during the biodrying process** On day 0 the difference of CO_2 concentration between control (without aeration) and solid waste with biodrying treatment was very significant, respectively 68.888,95 ppm (2,75 g/kg) and 5.153,67 ppm (0,27 g/kg) (13:1 in comparison). Awasi *et al.,* (2016) stated that CO_2 emissions of 10 g C $m^{-2}d^{-1}$ on the 22^{nd} day resulted from composting sewage sludge. Meanwhile, research conducted by Wang, *et al.,* (2018) using combining biochar, zeolite and wood vinegar for composting of pig manure produced CO_2 of 116.5 g $kg^{-1}d^{-1}$. **N2O emissions during the biodrying process** Research conducted by Wang, et al., (2018) using a combination of biochar, zeolite and wood vinegar for composting pig produced N2O emissions of 47.29 mg kg-1.
8.	Conclusion chapter is too lengthy, move some portion to the results and discussion	We have delete sentences: 1. MSW degradation process is known from the parameters of temperature, water content,

	chapter.	cellulose, C-Organic, and Total Nitrogen. 2. Then decreased to 39 ^{o}C on day three and was stable in the mesophilic phase until day 8. The biodrying process can achieve moderately thermophilic temperatures are between 40 ^{o}C to 45 ^{o}C. 3. This phenomenon indicates that higher airflow can slow the activity of microorganisms. 4. By the time in research (days 15 to 30), there is a degradation process that causes shrinkage of particle size and escalation of cavities on the surface.
9.	How long this green house gas generated from this experimental setup from what quantity?	We just measure at day 0 and at the time when the temperature reaches its peak (42.5 ^{o}C). Based on Awasi et al., (2016) stated CO_2 gas emissions are still produced from the composting sewage sludge process even though the compost is already mature and stable.

Reviewer # 2:

Query	Details reviewing required	Author's response
1.	In the abstract, the word FINDING must be changed to Findings.	We already change the word FINDING must be changed to FINDINGS
2.	Introduction: The introduction presents the general issues. Some specific information related to this study should be reviewed.	We explain **in the introduction.** Colomer-Mendoza et al., (2013) conducted gardening waste using 10 reactors with air volume obtained from 0.88 to 6.42 L / (min · kg dry weight) and added 5% of bulking agents. the bulking agent led to greater weight loss. However, important aspects, such as greenhouse gas emissions have not been studied. Most research discusses greenhouse gas emissions from the composting process of solid waste such as solid sludge. For example, González et al., (2019) discusses greenhouse gases, volatile organic compounds and odor emissions in sewage sludge but does not discuss the degradation process of the biodrying process.
3.	In the materials and methods, it would have been better if you provided a flow chart on how did	We explain in **materials and methods.**
4.	Improve the grammatical and syntactical structure of the paper as a whole; some sentences are	Sentences already proofread again by Victorie Language School (VLS)
5.	The conclusion should be presented clearly with specific results. Using these key points: - Revisit the aim of the study; - Include what the findings of your study addresses; and - Provide a summary of your study	We explain **in the conclusion.** - This research aims to increase the calorific value, evaluate the degradation process, and greenhouse gas emissions from MSW using biodrying. - We find that MSW biodrying process can increase the calorific value and reduce greenhouse gas emissions. The biodrying process allows MSW not to be discharged into final processing.
6.	Please ensure that all abbreviations are matched and are all written in the abbreviation section.	We already revise
7.	Check all the references it matches in the body of the manuscript	We already revise

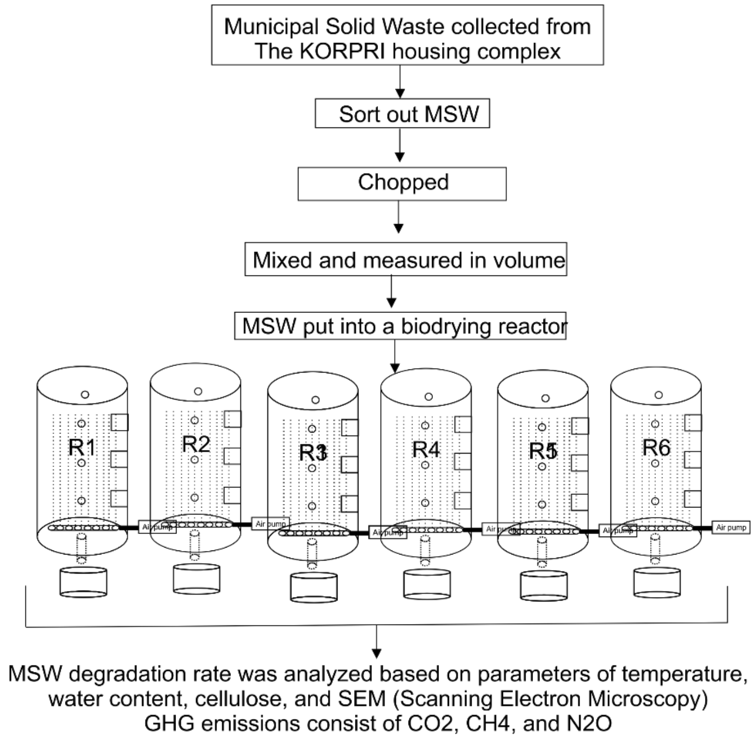

Fig. 2: Flowchart research about calorific and greenhouse gas emission in municipal solid waste treatment using biodrying

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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~~lot~~ of biodegradable municipal solid waste. Therefore~~In this research~~, ~~the~~ biodrying processing was~~is~~ adopted~~used to process municipal solid waste~~ to ensure the conversion into Refuse Derived Fuel and ~~evaluation of~~ greenhouse gases.

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

FINDINGS: The result showed ~~that~~ significant effect of~~variation in~~ airflow variation~~effect~~ on cellulose content and ~~the~~ calorific value. Furthermore, the o~~O~~ptimum value~~airflow based on cellulose content and calorific value i~~was 6 L/min/kg, producing a~~with a~~ 10.05% decline ~~inrease of~~ cellulose content ~~by, 10.05%~~ and a~~n~~ 38.17% increase in~~of~~ calorific value ~~38.17%~~. Also~~T,he biodrying process was also able to~~ the~~reduce~~ water content reduced from 69% to 40%. ~~On day 0, t~~The CH_4 concentration between control and biodrying ~~was~~ substantially~~very~~ varied~~different~~ at~~by~~ 2.65 ppm and 1.51 ppm respectively on day 0~~at the beginning of the research~~ and at~~nd the~~ peak temperature. Morever,~~The concentrations of~~ the value of N_2O in each control was about 534.69 ppb and 175.48 ppb~~.~~, while ~~T~~the lowest level was recorded~~of N_2O was when~~ after~~the~~ biodrying ~~process~~ with~~used~~ 2 L/min/kg airflow.

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

KEYWORDS: *Biodrying; Greenhouse gas; MSW; Refuse derived fuel; Temperature*

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NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
43	10	3

RUNNING TITLE: Calorific and greenhouse gas emission in MSW.

INTRODUCTION

Urban intensity and activities instigate the immense production ofe much biodegradable solid waste. ThereforeIt must be, proper management is requiredd to avoid a negative impacts on the environment, throughsuch as odorouss and pollutant emissions in, soil, water, gas, and othersetc. The Ccurrent methods of processing methodsolid waste involvingby burning or landfill is not optimal., and Tthe space availability of spacele for final processing (TPA) is critical. Also, and identifyingfinding an alternative new space location (TPA area) is difficult and expensive, especially in big cities. Moreover, Wwaste to Energy (WTE) technologiesy hass the potential to reduce the volume of the original waste volumeby (up to 90%) by recovering the energy, depending on the composition by recovering the energy (Patil *et al.,* 2014). The water level content in urban solid waste is an essential factor in urban solid waste, due tobecause ithe aeffects on the efficiency of combustion and conversionting the process of solid waste into energy (Suksankraisorn *et al.,* 2010). Among the methods that are developingHowever, mechanical biological treatment (MBT) isbecomes thea potential prospective choice amongst the methods being developed, because of theits environmental-friendly characteristicswaste treatment system (Egan *et al.,* 2005). The phenomenon of Nnatural drying, also known asoften called biodrying, is aone of the critical components of the MBT processes., involving the treatment of Ssolid waste will be through mechanical-biological bioconversions (Rada and Ragazzi, 2015; Velis *et al.,* 2009). In practice, During practice,the solid waste that has been chopped materials withand has high water content are placedut into the reactor. SubsequentlyBy the biodrying processes, solid waste produces dry solid waste (bio-dried) are produced through a biodrying processes, beforewhich undergoes a subjectingfurther to mechanical treatmentprocess. Thereforeis process, combines the heat that generated from the aerobic decomposition process of organic compounds, and excess air are combined towhich serves as a reliable waste dryer (Velis *et al.,* 2009). Moreover, Tthe dried solid waste productscan are alsobe considered to asbe Refused Derived Fuel (RDF). It is a fuel material produced from various types of waste, derived fromsuch as urban waste, industrial waste, or commercial waste sources (Scheutz *et al.,* 2014). The RDF iscan be possibly adoptedused as a substitute for coal (Rada and Ragazzi, 2015)., and Mmost of the biodrying processes is capablen of reducinge the water content in solid waste towhich is about between 30% and 80% of the initial valuewater content (Li *et al.,* 2015; Zhang *et al.,* 2008; Zhao *et al.,* 2010). Furthermore, Water the quantity removedal varies between 3.1 to 10.7 g water/g volatile solid consumed, depending on the preliminary composition of first waste 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 materialsWastes that have been previously treatedprocessed using biodrying include manure, pulp mill sludge, food waste, MSW, and sewage sludge. The biodrying process is carried out in batch conditions with 20 days of maximum duration. The final outcomeresult of biodrying is RDF, which is oftenthat can be used as co-fuel in the cement industry and boiler unit (Garg *et al.,* 2007; Wagland *et al.,* 2011). Colomer-Mendoza *et al.,* (2013) treatedconducted gardening waste withusing 10 reactors, characterized bywith an air volume obtained offrom 0.88 to 6.42 L/min/kg (dry weight) and added 5% of bulking agents. the bulking agent led to implicated in increasedgreater weight loss. However, some important aspects, includingsuch as greenhouse gas emissions have not been studied., as Mmost studiesresearch approach thisdiscusses greenhouse gas emissions phenomenon from the composting process of solid waste, e.g.,such as solid sludge. For example, González *et al.,* (2019) discussedds greenhouse gases, volatile organic compounds and odor emissions in sewage sludge, without consideringbut does not discuss possiblethe degradations process duringof the biodrying process. In addition,Even though biodrying and composting have different purposes; composting and biodrying serve varied purposes, which requires rapid anddegradation while biodrying experiences partial degradation, respectively (Goyal *et al.,* 2005). The Ccharacterization of greenhouse gas (GHG) and odorous compounds inof solid sludge compost are compiled

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MATERIALS AND METHODS

~~In this study,~~ MSW was manually collected from ~~T~~the KORPRI housing complex, Tembalang, Semarang, Central Java, Indonesia, with coordinates -7.061131, 110.446709. The sample characteristics~~ of the sample at this location~~ wa~~e~~re ~~almost~~ highly~~the~~ similar~~ame~~ to~~as~~ those~~MSW~~ produced by ~~the~~ most~~ajority~~ people in~~of~~ Semarang city~~.~~, which~~MSW~~ were further~~needs~~ ~~to~~ sorted ~~out~~ to determine the percentage of each component (%). In addition, t~~T~~he~~ MSW component,~~ percent by weight of the MSW component~~,~~ comprises~~nsists of~~ 64% leaves, 12% paper, 16% plastic, 6% uneaten vegetables, 1,73% uneaten of meals, and 0~~,~~.27% fruit peels. This~~en,~~ material~~MSW~~ was chopped using a chopper ~~with~~ measuring~~dimensions of~~ 15-20 mm, while the plastic variety~~MSW~~ was manually cut with~~by~~ a scissors. Subsequently, ~~A~~all MSW components were mixed and measured in terms of volume, before~~then~~ placing~~ut~~ into a biodrying reactor. The bulking agent is mature and stable compost measuring ± 10 mm, and comprising~~MSW volume is~~ 0.051 m^3 of MSW (85% of total volume) and 0.009 m^3 of bulking agent (15% of total volume)~~ is bulking agent. The bulking agent is mature and stable compost with dimensions of ± 10 mm~~. Therefore, the MSW volume calculation ~~i~~was based on the maximum reactor capacity of 60 liters (body diameter: 38 cm; total height: 65 cm; weight: 3 kg)~~.~~, while t~~T~~he biodrying reactor ~~i~~was constructed~~made~~ using~~of~~ polyethylene plastic, and equipped with a heat sink (Thermoshield Universal) to minimize heat loss. ~~The bottom of t~~The reactor base is installed a stainless-steel pipe (Ø3 mm) to ensure uniform air distribution~~.~~, while~~Variations of~~ airflow variations (0, 2, 3, 4, 5, 6 l/ min/kg) was achieved~~use~~ using an aquarium pump (Resun LP-100). Furthermore, e~~E~~ach reactor comprise~~has~~ of sampling holes, measuring~~with~~ a diameter of 7 cm, at a height of 20 cm, 40 cm, and 60 cm ~~height~~ from the ~~bottom of the~~base~~ reactor~~. These~~ holes~~ orifice were tightly closed when ~~they were~~ not in use~~d~~. The temperature sensor probes were placed at the top, middle, and bottom area~~of the reactor~~, and the average rate was noted ~~down~~. Moreover, ~~T~~temperature measurements required~~used a~~ stainless steel ~~temperature~~ sensors~~ that is~~, with waterproof characteristics against~~to~~ the nearest 0~~,~~.01 °C. The degree of heat~~emperature parameters~~ was~~ere~~ ~~recorded~~ automatically recorded every 15 minutes~~.~~, and ~~T~~the ~~recording~~ data is~~would be~~ saved as *xlsx* format in an SD card~~ in *xlsx* format~~. The ~~range of~~ temperature probe range was~~is~~ -50 ° C to 200 ° C~~.~~, while the ~~L~~leachate ~~that was~~ produced by the reactor~~,~~ was collected, and ~~measured~~ the volume was measured (if incurred). Fig. 1 shows ~~T~~the biodrying reactor scheme~~ is shown in Fig. 1~~.

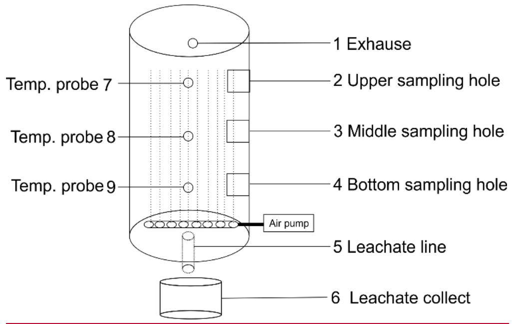

Fig. 1: The biodrying reactor scheme

~~During the biodrying process,~~The ~~parameters of~~ water content parameter was~~are~~ measured using the gravimetric method and the analysis~~zed~~ was performed every day, during the biodrying process. ~~The water content was measured using the gravimetric method.~~ This involved measuring and mixing a total of 20 g ~~of~~ samples ~~were collect~~obtained ~~ed~~ from three different levels of depths (top, middle, and bottom)~~, and mixed to analyze water content~~ in triplicate ways, with ~~a~~ deviation standard set on <5%. The respective neutral detergent fiber ~~of each sample~~ was determined and used to calculate the cellulose content~~s~~ (Goering and van Soest, 1970)~~.~~. In addition, C-Organic was evaluated~~tested~~ using the rapid and effective Walkey-Black method ~~that is a rapid and effective means for determining the organic carbon.~~, while Nitrogen content was analyzed using the Kjeldahl method~~.~~, where both~~Organic carbon and~~ assessments~~nitrogen testing~~ were performed~~done~~ in triplicate~~s ways~~. Specifically, ~~C~~caloric/heat content was tested~~ing was performed~~ using Bomb Calorimeter~~.~~, while Greenhouse Gas (GHG) sampling was performed~~carried out~~ at the highest temperature for CO_2, CH_4, and N_2O~~. The Greenhouse Gas Analysis~~, using~~ed~~ 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 ~~F~~flowchart ~~of the study is show in Fig. 2~~.

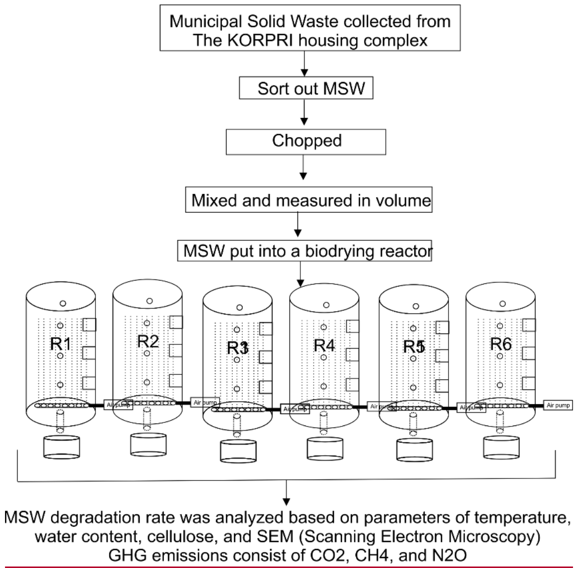

Fig. 2: Flowchart research on~~about~~ calorific and greenhouse gas emission in municipal solid waste treatment using biodrying

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~~process~~, where ~~an~~ aerobic processes utilize~~requires~~ oxygen for microbial activity. In addition, ~~T~~temperature is a significant parameter ~~for the exothermic process~~, which serves as~~and~~ a crucial factor ~~that~~ influencing~~e the process of~~ water evaporation and organic degradation (Fadlilah and Yudihanto, 2013; Sen and Annachhatre, 2015; Zhang *et al.*, 2008). Moreover~~Tempe,ratures that are~~ too high or~~and~~ ~~too~~ significantly low values have the potential~~can~~ to slow-~~ ~~down the drying process, due to the~~because~~ inactivity of decomposer microorganisms ~~are inactive~~, subsequently leading to~~so there is~~ an incomplete course of action~~drying process~~ (Sudrajat, 2006). Fig. 3 shows the~~T~~ temperature data recorded~~that occur~~ in relation to~~with the~~ varied~~ation of~~ air- flow ~~are shown in Fig. 3~~.

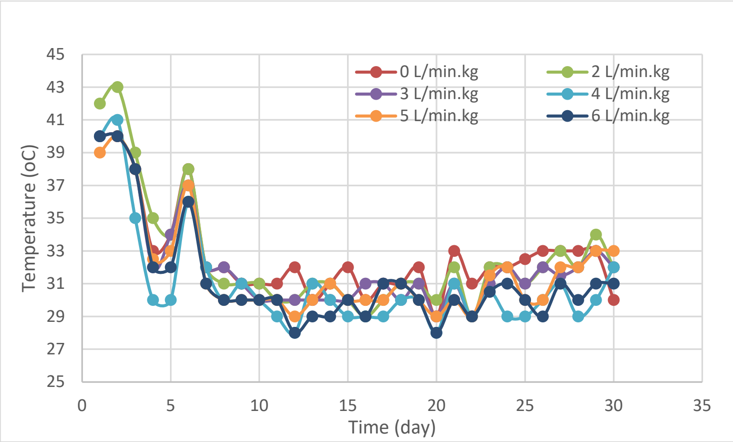

Fig. 3: Temperature profile graph in the biodrying -process for 30 days

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

Furthermore, ~~E~~each reactor produces different temperatures, in relation~~due~~ to the ~~differences~~ distinct~~in~~ MSW decomposition speed~~.~~, while the ~~A~~airflow rate influences~~causes~~ aerobic conditions (Velis *et al.*, 2009). ~~In biodrying reactor, t~~The amount of air in reactor 6 ~~i~~was more than the quantity in reactor 2, hence~~as a result~~ the variation in speed ~~of decomposition of solid waste is different~~. Moreover, ~~t~~The highest temperature ~~mencapai 43 °C resulting~~ from reactor 2 (airflow 2 ~~L/min.kg~~L/min/kg) was 43 °C on the 2nd day, followed by~~then the temperature~~ a decline~~reased~~ to 39 °C on the 3rd day, ~~-~~and ~~was~~ stablility was~~e~~ consequently achieved in the mesophilic phase up to the~~until~~ 8th day. Therefore~~Furthermore~~, the temperature was gradually reduced to~~until it reached~~ 29 °C~~.~~, and ~~t~~The ~~result of this~~ research outcome was~~is~~ compatible with the study of -Sadaka *et al.*, (2011). This~~ey~~ stated that~~at~~ presence of~~there was~~ a temperature escalation from~~of~~ about 37.7 °C to~~–~~ 48.8 °C during~~in the~~ biodrying ~~temperature~~ on day 2 to day 3~~.~~, ~~These temperatures~~ indicating~~e~~ a high biodegradation process resulting~~due to~~ from~~the high~~ substantial~~metabolism of~~ microorganism metabolism~~s~~ (Fadlilah and Yudihanto, 2013; Jalil *et al.*, 2016). This is congruent with the~~According report by to~~ Jalil *et al.*, (2016) ~~the temperature rises due to microorganism activities in a biodrying rea~~, based on a study performed using a reactor~~tor~~. Also~~For the biodrying method~~, "mesophilic" ~~temperature~~ (35 °C and 40 °C) and

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moderately "thermophilic" temperatures (40 °C to 45 °C) are more applicable compared tothan the "thermophilic" typetemperature. Mesophilic temperatures are about 35 °C and 40 °C. Moderately thermophilic temperatures are about 40 °C to 45 °C. Thermophilic temperatures, which is about (55˚C to 70˚C). Specifically, Jokiniemi and Ahokas, (2014) reported on thestates that ability forthe a combination of high temperature and low airflow tocan slow down the drying process. This condition corresponds to Sadaka *et al.,* (2011). In addition, Tthere is a rise in temperature rises on the second day, followed byand athen retractionurns to ambient leveltemperature. AlsoDuring this biodrying process, the phase of the moderately thermophilic as well as the mesophilic phasestemperature developed on the second and sixth day, respectivelywhile the mesophilic phase was on until day six. MoreoverOn day 7 to day 30, relatively uniform (stable) but fluctuatingthere was an increase and decrease in temperature values were recorded from day 7 to 30, which was relatively uniform (stable) with temperature ranging from 28 °C – 34 °C. This condition indicates that the absence of adequately large enough activity of microorganism activitys does not occur required to create biological stability after the biodrying process takes place (Adani *et al.,* 2002). Jalil *et al.,* (2016) recognized a similar condition, inin thetheir studyresearch, using solid waste samples, includingsuch as food scraps, papers, plastics, and woods, find a similar condition.

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Water content

Water content is an essential parameter in determining the success of athe biodrying process. ThisWater content constraint influencesaffects the chemical reactions associated with microbial growth and the biodegradation process of organic substances (Tom *et al.,* 2016; Velis *et al.,* 2009). At tThe beginning of the biodrying process, initial levels at the onset are generally set in the range of 50%-75%. Furthermore,If the initial extremelywater content is too low values, lead tothen reduced microbial activities are too small, because the microbial metabolic needs water to processes. whileWhereas higher water content amount creates anaerobic conditions. Moreover, Wwater is more dominant in filling pores compared tothan air, thusso limiting the oxygen availability is limited (Colomer-Mendoza *et al.,* 2013; Fadlilah and Yudihanto, 2013; Sadaka *et al.,* 2011). Fig. 4 show tThe results of measurement resultss of water content in each reactor at different aeration airflows are shown in Fig. 4.

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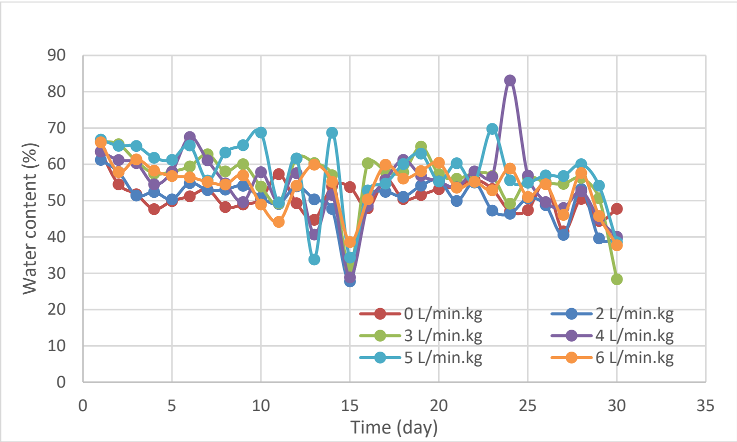

Fig. 4: Graph of water content profile in the biodrying process for 30 days

Water content Aat the inceptionbeginning of the biodrying process, water content did not is not decrease substantiallyignificantly low. Comparably,On a significant decline wasthe recorded on day 15 there was a significant decreasing of water content compared to the first day,, at 63,47% to 23,75% which is in reactor 1 (0 L/min.kgL/min/kg) 63,47% to 23,75%, 61,22% to 27,77% for reactor 2 (2 L/min.kgL/min/kg) 61,22% to 27,77%, reactor 3 (3 L/min.kgL/min/kg) was 66,26% to 31,84%, reactor 4 (4 L/min.kgL/min/kg) 63,54% to 28,87%, while 66,09% to 38,60% was observed in reactor 5 (5 L/min.kgL/min/kg) 66,09% to 38,60%. This reduction indicatesshows that the biodrying process was working effectivenessly, according to the literature, which ranges between days 7–15 (Velis *et al.,* 2009). The degradation characteristicsondition of water content is compatible with the research of Jalil *et al.,* (2016), as observed on the day 14 there was a degradation of water content from (67 ± 0,24% to 33,91 ± 2,24%). According to Adani *et al.,* (2002), it is possible forthe water content tocan reduce the decomposition level of solid waste. On day 20, tThe water level recorded oin solid waste increased on day 20 forin all reactors. This escalation is due to, resulting from the addition of water from the condensation process inside the reactor (Widarti *et al.,* 2015). Subsequently,Water will be evaporationed is performed because of the decomposition process of solid waste. Then, andit turns converted into dew on the reactor surface of the reactor, due to the absence of a steam trap. Thise dew isturns furtherto be converted into saturated steam, and falls back into the pile of solid waste for another cycle ofso that the water content increases again. On day 30Moreover, the solid waste in reactor 1 compriseshad a relatively higher water content value of 47,.78%. This, value comparedis tohigher than others reactors. ThisIt is due tobecause the reactor 1 had a configuration without aeration. This condition means that solid waste did, thus thenot absence ofundergo a biodrying process.. Therefore,where the process of reducing water content was reducedin solid waste was only through a biological approachprocess (Perazzini *et al.,* 2016). ConverselyOn the other hand, reactor 2,3,4,5 and 6 L/min.kgL/min/kg were equipped withhad aeration, which helped them in drying process physically and biological dryingprocess (Perazzini *et al.,* 2016; Sen and Annachhatre, 2015). Water content in the biodrying process can be reduced due to the , by evaporation of water molecules of the solid waste surface. In additionthis process, a change ind phase occursred andchanges the liquid is converted into to gas, asnd 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)., whereThey also states that the higher air flow was assumed to influence, the physically dry up of solid waste will dry up physically only, and not due to the heat generated by aerobic degradation. The final results of the research comprise the production ofed solid waste, with the lowest water content of 28.37% recorded in reactor 3 (3 L/min.kgL/min/kg) of 28,37%. Based on this research, biodrying successfullyeded in reduceding the moisture levelwater content in solid waste, compared tohigher thean control (without bio drying).

C-Organic and Total Nitrogen

C-Organic is a source of energy for the process of decomposition and cell formation., Wwhile nitrogen is an element needed by microorganisms for protein synthesis (Siswanto, M. Hamzah, Mahendra, 2012). In additionIn another way with composting, boththe nutritions or organic constituentssubstances such as C-Organic and total nitrogen in biodrying are not fully degraded in biodrying, after development with composting. However, henceC-Organic and nitrogen the levels are preserved as fuel (Fadlilah and Yudihanto, 2013). Eq. 1 showsis a thediagram of degradation reaction of aerobic process reaction responsible for theat production ofes 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 and Total Nitrogen (dry matter) in this studyin this research is shown in Table 1. Based on Table 1, and an insignificant declineC-Organic was recorded from 50.96% - 64.82% at the beginning of the biodrying process to 47,30%-60,35%ranged from 50.96% - 64.82%. afterDuring 30 days of research, kadar C-Organic berkisar antara 47,30%-60,35%. The decrease of C-Organic was not significant. This reductiondecrease indicatesshows theat usefulness of low carbon consumption of carbon is useful into increasinge the calorific value (Colomer-Mendoza *et al.,* 2013). However, the carbon content escalated on the 6

L/min.kgL/min/kg airflow, it had an escalation of carbon content. This escalation occurs, due to high level of aeration airflow., This iswhich assumed tocan inhibitstop the microbial activity to the extentuntil it whereis unable to degrade proper organic compounds degradationproperly is impossible (Colomer-Mendoza *et al.*, 2013; Sadaka *et al.*, 2011).

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

Table 1 also shows the decline in total Nitrogen (dry matter)decreased during the process of 30 days period of research., from an Iinitial Total Nitrogen ranged value range ofbetween 1.07% - 1.63%. While on the day 30 was ranged to about 0.62% - 1.45%. This constituentTotal Nitrogen isare volatile and lowerthe less levelsnitrogen content, have been implicated inthe slower organic matter decompositiones (Widarti *et al.*, 2015),. The slower decomposition ,therefore of organic matter will leading tolead theo absence of anyno overall degradation of the research sample degradation, and forwhich can furtherbe applicationused as fuel (Fadlilah and Yudihanto, 2013). This research is correspondsing with the studyresearch of Colomer-Mendoza *et al.*, (2013), whereby using a sample garden solid waste was used in the absence of anywithout additional bulking agents, and treated with variedations in airflow.

Cellulose

UnderIn aerobic conditions, the microbes in the biodrying -process have thecan ability to degrade semi-biodegradable organics, which isand are challenging to be degraded like as observed with cellulose (Wardhani *et al.*, 2017). ThisCellulose is one of the first growing cells of polysaccharides (carbohydrates), frequentlywhich are attacked by microorganisms in the early stages of decomposition (Evangelou, 1998). The , sourced of cellulose in this research derived from solid waste samples, includingused that were leaf litter, paper, and food scraps. The respective cellulose content in leaves is about 15-20%, and paper about 85-99% (Howard *et al.*, 2003). While cellulose level, andof food scraps is about 13% (Astuti, 2016). However, althoughin general, the cellulose level in the dry-weight of solid waste is generally variesous from 15-60% of its dry-weight (Evangelou, 1998). Furthermore, Oone of the potential applications that can be used by cellulose materials is as a necessary materials for fuel (Anindyawati, 2010)., and Fig. 5 shows the graph of measurements of cellulose levels overfor a 30 day periods.

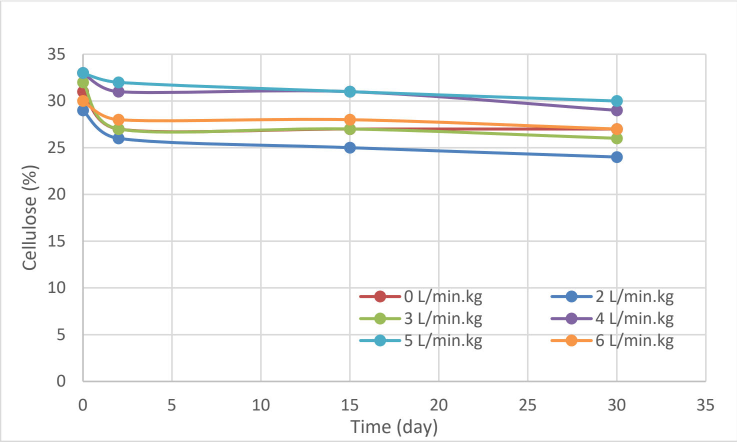

Fig. 5: The cellulose content based on variations in airflow (flow rate)

Fig. 5 showsis the level of cellulose produced for 30 days. On day 0, during the process, the level of cellulose ,in each reactor and a rangeed of about 29%-30% was reported in each reactor at the inception. SubsequentlyOn day two there was the highest degradation cellulose level was recorded on day twountil at 26-32%, in treatments with the lowest level of cellulose at aeration flow of 2 liters/minute. Th, followed bye those with the highest temperature followed on day 2, inwith a range of about 40 °C – 43 °C. This temperature is, included asin the thermophilic phase. ThisIn that phase facilitatesoccurs the the most considerable degradation of cellulose (Huang, 2010)., It can happen duebecause to the optimized activity of the carboxymethyl enzyme of cellulose is indicated to be active in the thermophilic phase. HenceAfter the thermophilic period, the subsequent period is characterized byre is a temperature derivation of metabolized organic matter that has been metabolized, allowing forso that relatively lowerthe degradation of cellulose continues to occur up tountil the day 30, which is continuousbut not as much as in the thermophilic phase (Huang, 2010). This research is consistent with the Huang (2010) research, where the most significanthighest cellulose degradation of cellulose was observedcomes fromn day three up to 15, whereat the time of the thermophilic phase occurred. HoweverWhereas, rapid decomposition was also recordedhappens in the thermophilic phase., and Fig. 6 shows tThe derivation in cellulose content during 30 days research in each reactor over the study periodis shown in Fig. 6.

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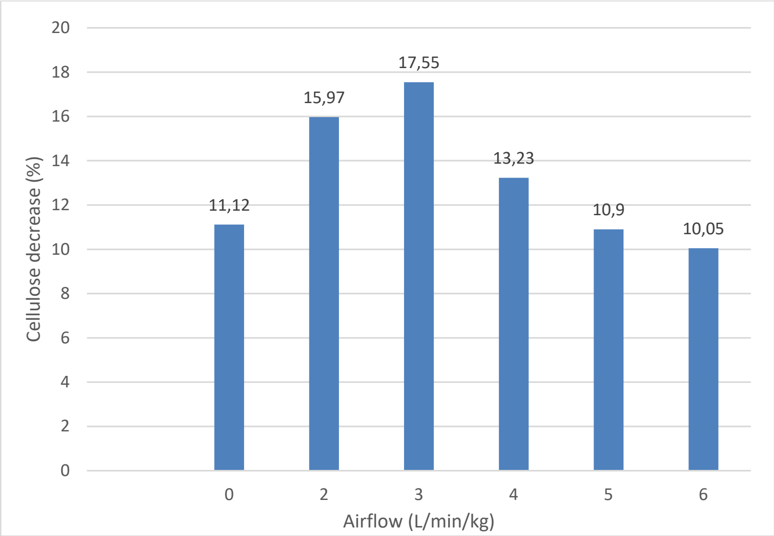

Fig. 6: Derivation cellulose levels (%) at various flow rate variations

Based on Fig. 6, ~~there is~~ a derivation of ~~the~~ cellulose level was observed in each reactor~~.~~, confirming the occurrence of~~It shows that there was a~~ degradation~~ of cellulose~~ during the biodrying process. ~~Based on t~~The statistical test~~,~~ shows a~~the~~ significance result~~ obtained~~ at~~is~~ 0~~,~~.032 (sig < 0~~,~~.05), ~~which~~ indicating~~means that~~ the~~re is a~~ substantial~~ignificant~~ effect on cellulose level, at~~due to~~ varied~~ations in~~ air flow~~ on cellulose level~~. In addition,~~Degradation of~~ cellulose is broken~~eak~~down ~~occurs~~ to oligosaccharides and subsequently into glucose, due to the presence of extracellular microbial enzymes~~ into oligosaccharides subsequently into glucose. These microbial enzymes are cellulose enzymes which are extracellula.r~~ This form of~~(enzymes~~ enzyme is produced in cells,~~ and~~ and released into the media~~)~~, with the~~that~~ ability~~can~~ to hydrolyze macromolecules~~, one of which is cellulose~~. Therefore,~~Cellulose degradation produces~~ CO_2 and water is produced. The most significant deterioration of 15.97% was observed~~comes up~~ in aeration 3 ~~L/min.kg~~L/min/kg~~, which is 15,97%~~, while the least~~smallest~~ ~~decreased~~ was~~is~~ recorded in aeration 6 ~~L/min.kg~~L/min/kg, at~~which is~~ 10~~,~~.05%. This phenomenon indicates th~~e~~at ability for higher airflow to~~can~~ stop ~~the activity of~~ microbial activity~~es.~~, and inhibits~~Then makes~~ proper~~it unable to degrade~~ organic compound~~s~~ degradation~~properly~~, as~~nd~~ well as~~also~~ nutrient~~the~~ consumption~~ of nutrients is low~~ (Colomer-Mendoza *et al.*, 2013; Sadaka *et al.*, 2011). Hence~~Thus~~, ~~variations in~~ airflow variation affects cellulose degradation in the biodrying process.

Calorific

Calor value is an indicator of energy content in~~possessed by~~ a substance, including in solid waste. In addition,~~R~~ reliable ~~waste~~ treatment through~~using the~~ biodrying method is expected to ~~function to~~ increase energy content by drying the solid waste, in order to produce RDF products (Fadlilah and Yudihanto, 2013). ~~In the first two days of the biodrying process~~Meanwhile, each reactor produced a~~in~~ range 4,575.07 – 4,777.91 cal/g within the first two days. This condition ~~i~~was influenced by the high activities of microorganisms, ~~which are~~ shown by the moderately thermophilic temperature phase (40 °C to 50 °C). Based~~y~~ on the increased~~ in~~ microorganisms' activity, there was significant consumption of nutrients needed by microorganisms~~ is significant~~, which~~so that~~ influenced~~effects~~ ~~on~~ the calorific value~~ produced~~. Furthermore, ~~A~~a significant escalation ~~in calorific value~~ was~~is~~ observed~~occurred~~ on day 15, at~~to be~~ 4,643.70 – 6,175.22 cal/g, which~~and became~~ was stable~~le~~ up to~~until~~ day 30, ~~with~~in a range of~~between~~ 4,713.36 – 6,265.37 cal/g. This escalation results from~~is because of~~ a~~the~~ decline~~rease~~ in water content. Also~~On day 15~~, there was a significant reduction ~~in water content~~ on day 15 to~~becomes~~ 23.75%-38.60%, compared to 54.51%-65.56% reported on day 2~~, where the water content ranged about 54.51%-65.56%~~. This~~It~~ ~~i~~was due~~because on day two,~~ to the markedly high water content~~ was still high,~~ and low~~the~~ calorific value on the second day~~is low.~~, resulting~~It is because some of~~ from the use of heat~~ is used~~ during~~to~~ evaporation~~e~~ at~~the water at~~ the ~~beginning of the~~ process inception. However~~Whereas on day 15~~, the~~water content was~~ lower value observed on day 15~~,~~ was due to~~so~~ the relatively lower heat during~~in water~~ evaporation~~ was not as much as when the water content is still high. Thus~~, hence~~when the~~ reduced water content~~ is lower~~ is directly proportional to~~than the~~ increased calorific value~~ increases~~. The~~is~~ escalation ~~is~~ also occurs because of the derivation of microorganisms activity, ~~which is characterized by a~~ and declining~~rease~~ ~~in~~ temperature (Fig. 3), resulting in~~so that~~ low nutrient consumption~~ is low~~ (Colomer-Mendoza *et al.,* 2013). This condition is congruent~~compatible~~ with the study~~research~~ by Fadlilah and Yudihanto (2013); Sen and Annachhatre (2015), where the most massive increase in calorific value was observed~~occurred~~ between days 12 and 16. Based on the statistical test, a~~the~~ significant result of~~is~~ 0.032 (sig<0.05)~~,~~ indicates~~which means~~ there~~re is a~~ significant effect ~~due to~~ of~~the variation of~~ airflow variation on calorific value~~. The increase in calorific value during 30 days study in each reactor~~, a~~i~~s shown in Fig. 7.

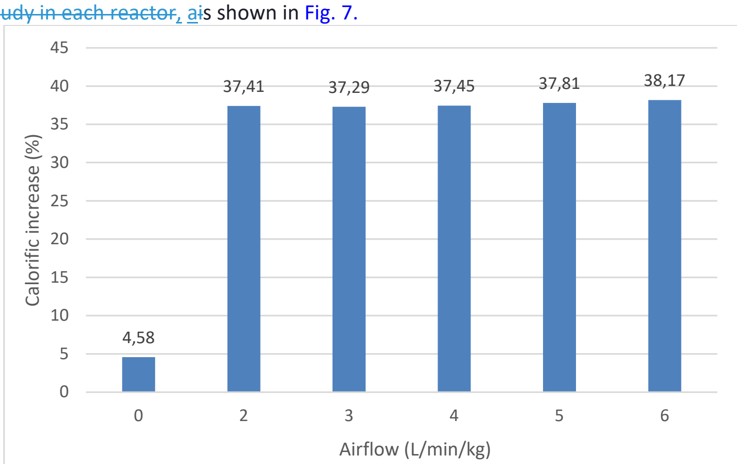

Fig. 7: Percentage increase in calorific value due to variations in flow rate (aeration)

Based on Fig. 7~~ for 30 days of research~~, there was a difference between the control ~~reactor~~ (without the addition of flowrate) and the biodrying reactor. This is evidenced by~~In~~ the insignificant increase in~~reactor~~ calorific observed in treatments without additional flow 0 ~~L/min.kg~~L/min/kg~~, the calorific value did not significantly increase. It was~~, at only 4~~,~~.58%, with an initial ~~calorific value of 4,507.46 cal/g~~ and ~~the~~ final value of 4,507.46 and 4,713.36 cal/g, respectively. Conversely,~~While in~~ the treatment reactor~~ with additional flow rate, calorific~~ had an increased value by~~increased~~ about 37.29% - 38.19%~~.~~, where~~T~~ the minimal ~~calorific value~~ enhancement was recorded at the rate 3 ~~L/min.kg~~L/min/kg, with an initial and~~calorific value of 4,520.98 cal/g and~~ final ~~calorific~~ value of 4,520.98 and 6,206.78 cal/g, respectively. Meanwhile, ~~T~~the maximum change~~calorific value enhancement~~ was recognized in~~at~~ the reactor~~the rate~~ of 6 ~~L/min.kg~~L/min/kg, with corresponding initial ~~calorific value 4,534.51 cal/g~~ and ~~the~~ final ~~calorific~~ value of~~is~~ ~~about~~ 4,534.51 and 6,265.37 cal/g. These conditions indicate the~~at~~ ~~airflow rate~~ influence of airflow rate on~~the enhancement of~~ calorific value during~~in~~ the bio drying. This research is compatible with Fadlilah and Yudihanto (2013)~~.~~, w~~W~~here the biodrying ~~-~~process performed on~~at~~ solid food waste generated~~produces the calorific value of~~ about 4,952 cal/g in~~for~~ flow rate of 6 ~~L/min.kg~~L/min/kg and 4,064 cal/g ~~-~~for 4 ~~L/min.kg~~L/min/kg. In addition, ~~T~~the calorific value of the biodrying ~~-~~process was~~has~~ within a range of ~~about~~ 4,713 cal/g - 6,265 cal/g~~. Also~~, and is further classified in the low energy (brown) coal category, according to SNI 13-6011-1999 concerning the classification of resources and coal reserves~~, the calorific value of the~~

biodrying process can be classified in the low energy coal (brown coal) category, which is equivalental to <7,000 cal/g. The increase in calorific value is influenced by the degradation of organic substance degradations, includingone of which is cellulose. In tThis research, showed the least final calorific value inwhen treatments withthe flow rate experienced maximum raw material deteriorationgradation of cellulose, then it produced the lowest calorific value in its final result. Conversely, and vice versathe maximum escalation of calorific value when the flow rate experiences the lowest cellulose degradation. ThisIt finding is consistent with Sugni *et al.* (2005), whereeich explains that the maximum degradation of organic matter degradation produceds a lower energy content.

SEM analysis (Scanning electron microscopy)

SEM analysis is one analysis used to determine the surface morphology of the surface of a sample. ThisSEM shows the physical changes that occur caused byduring the microbial degradation process of solid waste by microbes (Sharma *et al.,* 2019). Fig. 8 demonstratesis the test result of the SEM test from a solid waste sample fromof one of the reactors, which is reactor 2, with an airflow of 2 L/min.kgL/min/kg.

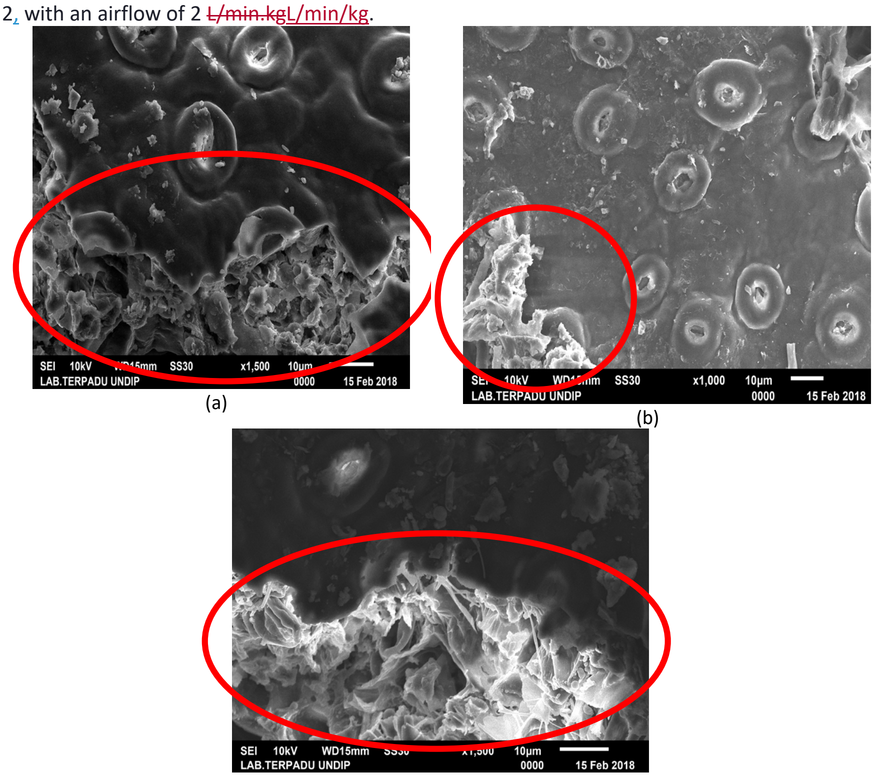

Fig. 8: SEM test result from solid waste sample with flow rate 2 L/min.kgL/min/kg (a) day 0 magnification 1,000x , (b) day 15 magnification 1,500x, (c) day 30 magnification 1,500x

Fig. 8 showsis the SEM results ofn solid waste samples on day 0, 15, and 30 with aeration flow 2 L/min.kgL/min/kg. The surface morphology of solid waste on day 0 s.hows This features a relatively larger size, with smaller cavities/pores, compared to, 15, and 30. By the time in research (day 15 to 30), there is a degradation process that withcauses characteristica shrinkage of particle size and escalation of cavities on the surface cavities. TheSEM findingsresults are in line with Sharma *et al.,* (2019) research, wherewhich states that the size of solid waste cavityies size~~is~~ was~~getting~~ bigger after~~due to~~ the degradation process. This~~It~~ indicates the~~re~~ occurrence of~~was a~~ degradation ~~process~~ during the 30 days of biodrying~~ process that lasts for 30 days~~.

Greenhouse emission (GHG)

Air emissions are measured to determine the effects of ~~the~~ biodrying ~~process~~ ~~i~~on solid waste toward the gasses responsible for~~that cause the~~ greenhouse effect, comprising~~consisting of~~ CH_4, CO_2, and N_2O. The ~~gas~~ measurements are~~is~~ collected~~done~~ on~~at~~ day 0 and at the time when a peak~~the~~ temperature of~~reaches its peak~~ ~~(~~42.5 °C~~)~~ is reached. ~~Research on greenhouse gas emissions using the same solid waste for 30 days.~~ Table 3 shows the result of ~~the~~ greenhouse gas ~~is~~ emmitted~~shown in Table 3. CH_4, CO_2, and N_2O gases are produced~~ from the decomposition of biodegradable organic matter in MSW, comprising CH_4, CO_2, and N_2O. The~~In this~~ sources~~study, biodegradable organic waste were~~ include leaves (64%), paper (12%), uneaten vegetables (6%), uneaten of meals (1.73%), and fruit peels (0.27%), while plastic waste (16%) are~~is~~ non biodegradable.

Table 3: 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 (~~L/min.kg~~L/min/kg)	CH_4 (ppm)		CO_2 (ppm)		N_2O (ppb)	
	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

CH_4 emissions during the biodrying process

Fig. 9 shows ~~T~~the result~~s~~ of the CH_4 concentration test in the biodrying process~~ are shown in Fig.9. O~~, and the output on day 0~~, CH_4 concentration~~ was very different between the control (without aeration) at 2.65 ppm (1.34 mg/kg) and solid waste with biodrying treatment~~, respectively 2.65 ppm (1.34 mg/kg)~~ a~~t~~nd 1.51 ppm (0.73 mg/kg). The conversion of ppm to mg/kg ~~o~~for CH_4, CO_2, and N_2O ~~i~~was based on the calculation of fluxes ~~that were~~ used to evaluate~~calculate~~ the experimental data, through~~by~~ second order polynomial equation (gas concentration vs. time) (Hao *et al.*, 2002). In addition, the CH_4 emissions ~~a~~were very low ~~when~~ compared to~~with~~ the research of Wang, *et al.,* (2018), which was performed using the combination of biochar, zeolite and wood vinegar ~~combining~~ for composting ~~of~~ pig manure ~~resulting CH_4 emissions of~~ where 8.83 g/kg gas was produced. This current research shows a~~Methane emission was quite high during the decomposition process of solid waste, but the~~ reduced methane yield with the presence of aeration during the biodrying process~~ was able to reduce methane emissions~~. Hellebrand (1998) reported~~states~~ higher~~that methane emissions~~ values~~increase~~ during a decomposition of grass and green waste~~. He is also observed an~~, and also a more significant~~increase~~ output~~in methane emissions~~ after~~for~~ 30 days~~s~~ ~~during the decomposition process~~ of urban waste decomposition. This escalation was considerably~~They noted that methane emissions were~~ reduced ~~drastically~~ by ~~adding~~ aeration. Yusuf *et al.* (2012) calculated a 28% higher methane emission~~s 28% higher~~ during anaerobic decomposition, compared to~~than during a~~ windrow composting.

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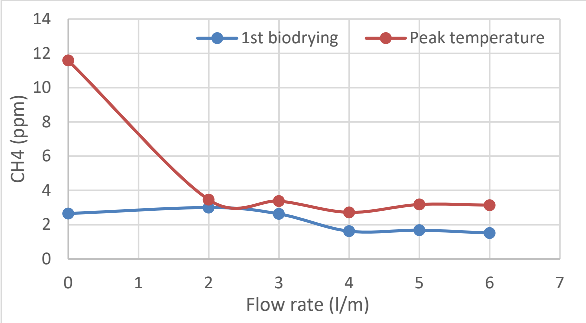

Fig. 9: The CH_4 levels (ppm) at 0 days and at the time the temperature reaches its peak.

CO_2 emissions during the biodrying process

Fig. 10 shows tThe results of the CO_2 concentrations test during the biodrying process are shown in Fig. 10., and tThe graph describes lowerthat CO_2 levels using biodrying are lower than compared to the treatments without- bio--drying. On day 0 Furthermore, tthe differences in valueof CO_2 concentration between control (without aeration) and solid waste with biodrying treatment was very significant on day 0, atrespectively 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 astated that CO_2 emissions of 10 g C /m^2/d on the 22nd day resulted offrom composting sewage sludge composting. Moreovereanwhile, the studyresearch conducted by Wang, *et al.*, (2018), using a combination ofing biochar, zeolite and wood vinegar for the composting of pig manure yieldedproduced CO_2 of 116.5 g/kg/d.

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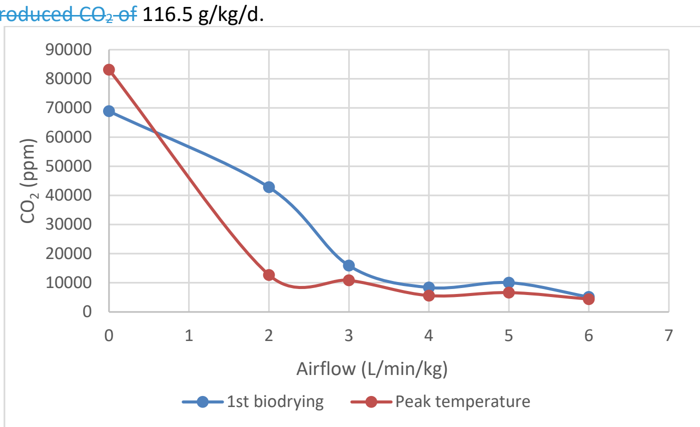

Fig. 10: Graph of CO_2 levels (ppm) at 0 days and when the temperature reaches its peak

N_2O emissions during the biodrying process

Fig. 11 shows Tthe results of N_2O concentration testing during the biodrying process are shown in Fig. 11. The biodrying process produces N_2O emission , and a higher value was recorded at the time of the peak temperature reached its peak (Thermophilic). A studyResearch conducted by Wang, *et al.*, (2018), using a combination of biochar, zeolite and wood vinegar for composting pig yieldedproduced 47.29 mg/kg of N_2O emissions of 47.29 mg/kg. According to Paul (2001), the nitric oxide emissions releasedare generally higher during thermophilic composting is generally higher. This often occursNitrous oxide emissions are as a side product ofrom nitrification and denitrification. Nitrification, involvinges the oxidation of ammonium into nitrate and denitrification. In addition,The heterotrophic nitrification processes also play a major contributory rolees duringto N_2O productionemissions.

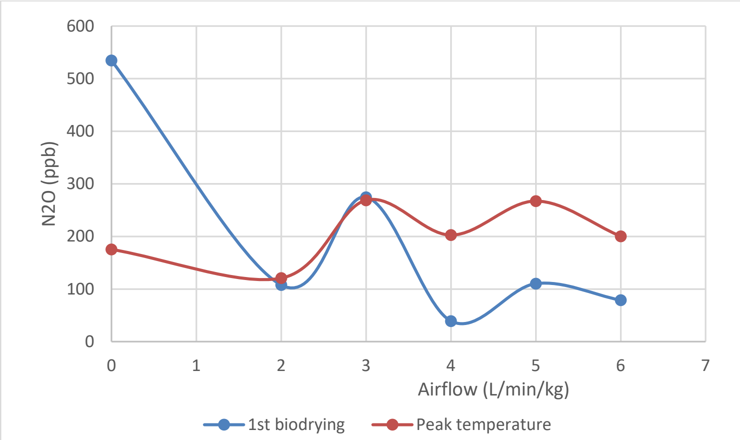

Fig. 11: Graphs of N_2O levels (ppm) at day 0 and when they reach their peak temperature

CONCLUSION

This research ~~aims to~~ aims to evaluate the increase in~~the~~ calorific value, ~~evaluate~~ as well as the degradation process, and greenhouse gas emissions from MSW (refuse derived fuel), using biodrying. The results showed a~~that~~ higher~~the biodrying process can increase~~ calorific value to ~~of MSW (refuse derived fuel)~~ about 37.29% - 38.19%~~. The calorific value of RDF has a range of about~~ or 4,713 cal/g - 6,265 cal/g, which ~~can~~ is~~be~~ classified in the low energy coal (brown coal) category, being~~which is equal to~~ <7,000 cal/g. Furthermore, ~~T~~ the most significant~~highest~~ temperature reache~~ds~~ was 43 °C on second day, as observed~~resulting~~ in~~from~~ reactor 2 (airflow 2 ~~L/min.kg~~L/min/kg) ~~on second day~~. The lowest water content of 28.37% was~~final results of the research~~ produced by the solid waste ~~with the lowest water content~~ in reactor 3 (airflow 3 ~~L/min.kg~~L/min/kg) ~~of 28.37%~~. Therefore~~Based on this research~~, the biodrying process ensured a successful~~eded in~~ reduction~~ing~~ in sample moisture~~water content in solid waste higher~~ compared to the~~an~~ control ~~(without bio drying)~~. ~~Meanwhile, t~~The lowest cellulose reduction of 10.05% was observed in~~resulted from the~~ reactor 6 (6 ~~L/min.kg~~L/min/kg) ~~of 10.05%. T~~ In addition, ~~he~~ degradation of~~crease in~~ C-Organic and Total Nitrogen was~~ere~~ slow and not significant~~. The slower decomposition of C-Organic and Total Nitrogen will lead to no overall degradation of samples~~, hence~~which~~ the~~can be~~ potential for~~used~~ application as fuel. Based on SEM, MSW morphology ~~based on SEM results~~ on day 0 showed~~s~~ ~~a~~ larger sized molecules with smaller cavities/pores. ~~Overall, t~~The treatment~~biodrying~~ process results in lower GHG emissions compared to~~than~~ the control~~without biodrying~~. Furthermore, ~~T~~the highest CH_4 emissions, measuring 11.59 ppm was~~are~~ observed at the~~its~~ peak temperature of ~~(~~43 °C~~) with levels of 11.59 ppm.~~, while the CO_2 concentration of~~between~~ control (without aeration) and solid waste exposed~~with~~ to~~the~~ biodrying ~~treatment~~ was~~is~~ 68,888.95 ppm and 5,153.67 ppm, respectively (13: 1 ratio). Meanwhile, the N_2O concentration was~~each control is about~~ 534.69 ppb and 175.48 ppb at the inception~~beginning~~ of research and during~~its~~ the peak temperature. The lowest level ~~of N_2O i~~was recorded~~when the biodrying process uses~~ in reactor with air flow rate of 2 L/min/kg. The~~We find that~~ MSW biodrying ~~process can~~ was confirmed to increase the calorific value and reduce greenhouse gas emissions. This~~e biodrying process~~ inhibits~~allows~~ the~~MSW not to be~~ possibility of sample discharging~~ed~~ into the final processing. Appropriate Therefore, proper strategy is needed~~s~~ to ~~be done so that other factors that~~ understand~~affect~~ other factors influencing the heat value and GHG emissions ~~are known~~.

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
$g\ C/m^2/d$	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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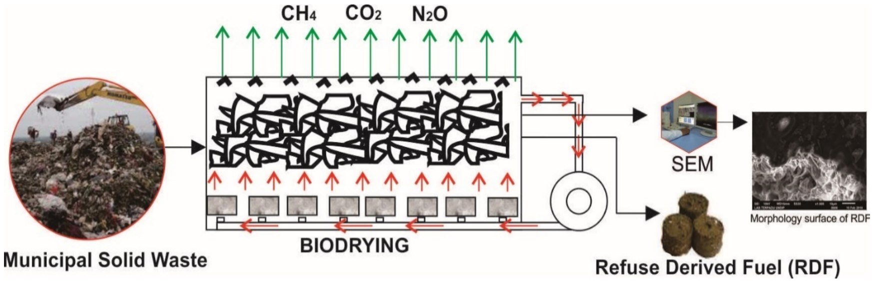
GRAPHICAL ABSTRACT



HIGHLIGHTS

- The biodrying process can increase calorific value of Municipal Solid Waste and reduce greenhouse gas emissions;
- The calorific value of Refuse Derived Fuel can be classified in brown coal category, which is equal to <7,000 cal/g;
- Biodrying process can reduce CO_2 emissions by 13 times compared to without biodrying.

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Manuscript Title: **Calorific and greenhouse gas emission in municipal solid waste treatment using biodrying**

Authors: Badrus Zaman,Wiharyanto Oktiawan,Mochtar Hadiwidodo,Endro Sutrisno,Purwono Purwono

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