Effect of Intermittent Negative Ventilation in Biodrying Process for Treating Pre-Shredded Waste

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Abstract. A pre-shredded waste with 49.4% of moisture content from a municipality in Thailand was treated in biodrying lysimeters with intermittent negative ventilation at the rate of 0.5 m\textsuperscript{3}/kg waste/day. Two air patterns were set with an interval of 30 min run/30 min stop (T1) and 30 min run/60 min stop (T2) and ran for seven days. The highest temperature was found in T2 at about 68.3 °C. The degradation of degradable materials was at 3.49% and 2.9% in T2 and T1, respectively. In T2, the weight could be reduced from 90 kg to 79.9 kg, corresponding to 11.2% of weight reduction. After seven days, moisture content and the heating value was acceptable requirement of Refuse Derived Fuel (RDF) for local cement plants. The highest moisture removal was presented in T2 which can reduce the moisture content of 58.24% and the heating value was increased of 42.75% from initial heating value. Based on the local RDF requirement, it could be concluded that T2 is the best performance in this study with 20.63% of final moisture content and 17,719 kJ/kg of heating value.

1. Introduction

Biodrying technology, aims at removing water from bio-wastes by adequate ventilation and high temperature resulting from organic degradation by microbial activities [1-3]. The aeration is mainly used for water evaporation and oxygen supply. Thus, the forced ventilation is usually used for biodrying process to provide an oxygen to the process and accrue the water evaporation. There are three main methods of forced ventilation; positive, negative, and combined ventilation methods [4]. The air could be more evenly distributed and the anaerobic portion is reduced with a negative ventilation method [5]. In the negative ventilation method, the higher water can be removed with lower volatile solid degradation whereas higher degradation rate of volatile solid presented in positive ventilation method [6-8]. The intermittent ventilation is more energy efficient and leads to a more homogeneous temperature and organic degradation compared to continuous ventilation in composting process [9]. Concerning with energy efficient, intermittent ventilation is reasonable for using in developing countries where the operation cost concerned.

However, there is no available data about the influent of intermittent negative ventilation modes that suitable for biodrying of Thai waste. This study investigated the effect of intermittent negative
ventilation mode on pre-shredded municipal solid waste (MSW). The evolution of temperature and the relationships between weight loss and organic degradation were discussed.

2. Methods

2.1. Experiment equipment and waste preparation
The experiments were performed in two lysimeters with 2.00 meters in height with 0.5 meters in length and width with a square shape, insulated with thermal insulator foam. The MSW was collected from the mechanical biological treatment plant in Saraburi province, Thailand. After passing through the pre-shredded process, the initial moisture content was 49.4% (wet basis) and analysed for composition by quartering method [10].

2.2. Experiment set up and operation
Two air patterns were performed during biodry process. Each lysimeter was loaded with MSW at about 90 kg (equivalent to 300 kg/m³ density). The ventilation was fixed at 0.5 m³ per kg of wet waste per day during the whole experiment for seven days. The air patterns were operated with a ventilation interval of 30 min run/30 min stop (T1) and an interval of 60 min run/60 min stop (T2).

2.3. Experiment monitoring
The processes were monitored for temperatures, weight loss, oxygen concentration, and leachate quantity. The thermocouple type K was used to monitor of temperature connected with midi Logger (Graphitec GL220) located at the middle point of lysimeter. The oxygen (O₂) concentration was monitored by using Biogas 5000 (Geo Tech) at the middle point of lysimeter. Leachate was collected and weighted.

2.4. Sampling and analytical analysis
The initial and final waste were determined for composition, water content and heating value. The water content was determined by air-drying at 105 °C for 24 h in an oven. The heating values were determined using bomb calorimeter.

3. Results and Discussions

3.1. Bio-dried characteristics
Figure 1 shown the changes in biodried product compared to raw shredded waste. The proportion of degradable materials were decreased which indicated activity of biodegradation within the lysimeter. The percentage of degradable materials could be reduced up to 3.49% in T2. The percentage of wood-based materials were increased in both experiments which was greater in T2 than T1. It can be expected that with the decreasing of degradable materials, the percentage of non-degradable materials should be increased. However, the results showed that the percentage of non-degradable materials were decreased whereas the percentage of wood-based materials were increased.

Concerning with MSW feedstock, pre-shredded waste was used as a feed-stock. The organic materials were mixed in all non-degradable materials and wood-based materials. The reduction of percentage in non-degradable materials could be explained by the organic attached in non-degradable materials were degraded. When the water in attached-organic was dehydrated, the percentage of non-degradable materials were diminished. In contrast, the composition percentage of wood-based material were increased which could be described by the water desiccated from biowaste in the process.
3.2. Evolution of temperature and oxygen during biodrying

Figure 2 presents the temperature evolution during biodrying process. Temperature was the pivotal factor affecting water evaporation and organic degradation during biodrying process. The trend of temperature was similar in T1 and T2. The temperature evolution can be divided into three stages including heating phase, high-temperature maintenance phase, and the cooling phase. The heating phase was in day 1 – day 2, with a maximum temperature of 56 °C and 68.3 °C in T1 and T2, respectively. This high temperature ensure that the final is free from pathogens because the high temperature was sufficient to kill the vast majority of enteric pathogen as presented in Table 1 [11].

The maintenance phase presented in day 2 to day 4. The range of temperatures in maintenance phase were at 41 °C – 49 °C and 48 °C – 62 °C in T1 and T2, respectively. The temperature was decrease in cooling phase from day 4 and remained to the end of the experiment with the range of 37 °C – 42 °C and 34 °C – 43 °C in T1 and T2, respectively.

The rise of temperature can be used as an indicator of microbial activity. The rise in temperature results from microbial respirational activities to breakdown of decomposable material on day 1 to day 4. The development of thermophilic range was indicating that there was enough carbon and nitrogen resources for metabolism of microorganism. When the degradable material has been degraded, the bioactivities were diminished and accordingly the temperature in biodrying process was dropped from day 4. This was confirmed the cessation of microbial activity by the final temperature which was in close ambient temperature at the final day of the process.
Table 1 The temperature and time necessary to destroy some pathogen in composting process.

| Organisms                  | Temperature and time                   |
|----------------------------|----------------------------------------|
| Salmonella spp             | 15 – 20 min at 60 ºC; 1 hour at 55 ºC  |
| Esherichia coli            | 15 – 20 min at 60 ºC; 1 hour at 55 ºC  |
| Entamoeba hystolitica      | 68 ºC; time not given                   |
| Taenia saginata            | 5 min at 71 ºC                         |
| Necator americanus         | 50 min at 45 ºC                        |
| Shigella spp               | 1 hour at 55 ºC                        |

The oxygen concentrations of T1 and T2 are presented in Figure 3 and could be used to describe the aeration level and bioactivities within lysimeter. It was suggested that at least 15% of oxygen concentration level in the air after biodrying process should be presented in order to ensure the sufficient oxygen level in biodrying process [12]. In this study, the oxygen concentration after ventilation was higher than 15% in both T1 and T2. Thus, negative ventilation can provide sufficient oxygen for biodrying process. The trend of oxygen level was similar in T2 when there was no ventilation (T2,0) and T1 for both on and off interval (T1,0 and T1,X) whereas a high level of oxygen was presented on the first day in T2,0. The low level of oxygen is correlated with biological activity inside biodrying lysimeter, high bioactivities were occurred in day 1 to day 4 and significantly decreased after day 4 in all biodrying lysimeter. It was found that no methane (CH4) occurred in biodrying lysimeter indicating that there was no anaerobic decomposition promoted in the process.

3.3. Weight loss during biodrying

Weight loss and moisture loss during the process can be investigated as an index of microorganism activity during the decomposition process and drives vaporization. It was found that the degradation was related to temperature profile. The initial moisture content was about 49.4% and further dropped to 33.48% and 20.63% in the T1 and T2, respectively. The same pattern was displayed in weight reduction by time (Figure 4), the highest weight loss was presented in T2, which can reduce its weight from 90 kg to 79.9 kg, corresponding to 11.21%. On the other hand, only 8.98% of the weight was reduced in T1. Weight loss in T2 was gradually decreased at day 1 to day 3 and to the rest of the experiment which is correlated to temperature profile in Figure 2. This correlation indicated that temperature was important in improving organic degradation.
Figure 4. Variation of municipal solid waste weight (a) and moisture content (b) during different sets of experiments.

The leachate production is the major problem for landfill operation and the high rate of leachate production is a critical constrain in most of solid waste treatment and waste to energy facility [13]. There was small leachate generated during biodrying process in both T1 and T2. Only small leachate was found in biodrying process with 0.11% in T1 and less than 0.01% in T2. This result contradicts with earlier research, in which leachate was generated in biodrying process [6]. However, these finding accords with the earlier researches indicating that there is no leachate generation during biodrying process [13-14].

The relative humidity could be used to confirmed the condensation of exhaust air. The relative humidity of input ventilation was recorded in hourly and it was found that the maximum relative humidity (RH) of ventilation air was presented at night time whereas the minimum RH value occurred at day time. The average of RH value was at 61.4% with the maximize value of 86.1% and the minimize value of 32.1%. The RH value of exhaust air was measured once per day and the saturated RH was observed throughout the experiment retention time. This confirmed that the air is needed for biodrying process, not only for microorganism activity but also needed to carry away water from the process. In this study, the moisture content of pre-shredded waste feedstock was removed mainly by the exhaust air.

3.4. Moisture content and heating value of bio-dried product

According to Figure 5, the percentage increase of low heating value (LHV) varied with the corresponding to the water reduction percentage. The increasing of LHV was 42.75% in T2, greater than in T1 at 29.93%, which corresponds to 17,719 kJ/kg and 16,125 kCal/kg, respectively. This value is in an acceptable quality of RDF standard of the European Association of Waste Treatment Companies for Stabilized Wastes that is higher than 15,000 kJ/kg [15] and RDF requirement needed of cement plant in Thailand.

The reduction of moisture content occurred by the metabolic heat produced by microorganisms in waste with ventilation supplied to the process. A similar trend occurred with water reduction percentage, where the water can be reduced by 58.24% in T2, while only 32.23% of water can be reduced in T1. The water content of final product should be quite low (about30%) in order to prevent any further biological activity in the final material [16]. The final moisture content of T2 was at 20.63% which is in the acceptable RDF requirement for cement plant, whereas the final moisture content in T1 is not in the acceptable requirement.
4. Conclusions
In conclusion, the basic biodry phenomena were promoted by the degradation of microorganisms to produce heat through the aerobic decomposition and the performance of water removal corresponded to the temperature inside lysimeter. The different negative ventilation mode effected to biodry process significantly. The intermittent negative ventilation with an interval of 30 min run/60 min stop was shown better performance than the lysimeter operated with an interval of 30 min run/30 min stop. The highest LHV was obtained from a lysimeter with the interval of 30 min run/60 min stop. Based on the market-based RDF requirement for cement plant in Thailand, it could be concluded that the lysimeter with the interval of 30 min run/60 min stop is the best performance in this study. There is a need to study another negative ventilation pattern in order to find an optimization mode for treating the moist MSW.

5. References
[1] Zhang DQ, He PJ and Shao LM 2009. Sorting efficiency and combustion properties of municipal solid waste during bio-drying. Waste Management, 29(11), pp.2816–23
[2] Adani F 2002. The influence of biomass temperature on biostabilization–biodrying of municipal solid waste. Bioresource Technology, 83(3), pp.173–9
[3] Sugni M, Calcacerta E and Adani F 2005. Biostabilization-biodrying of municipal solid waste by inverting air-flow. Bioresource Technology, 96(12), pp.1331–7
[4] Haug RT 1993. The Practical Handbook of Compost Engineering. Boca Raton: Lewis Publishers. 752 p
[5] Chiumenti A, Chiumenti R, Diaz LF, Savage GM, Eggerth LL and Goldstein N 2005. Modern composting technologies. The JG Press, Inc. Emmaus: Pennsylvania, USA
[6] Shao LM, He X, Yang N, Fang JJ, Lu F and He PJ 2012. Biodrying of municipal solid waste under different ventilation modes: drying efficiency and aqueous pollution. Waste Management & Research, 30(12), pp.1272–80
[7] Zhang DQ, He PJ, Shao LM, Jin TF and Han JY 2008. Biodrying of municipal solid waste with high water content by combined hydrolytic-aerobic technology. Journal of Environmental Sciences, 20(12), pp.1534–40
[8] Zhang DQ, He PJ, Yu LZ and Shao LM 2009. Effect of inoculation time on the bio-drying performance of combined hydrolytic–aerobic process. Bioresource Technology, 100(3), pp.1087–93
[9] Ekinci K, Keener HM, Elwell DL and Michel C 2004. Effects of four aeration strategies on the composting process: Part I - Experimental studies. Transactions of the American society of Agricultural Engineers, 47, pp.1697-708
[10] ASTM D5231-92 2016, Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste, ASTM International, West Conshohocken, PA, 2016, DOI: 10.1520/D5231-92R16, www.astm.org

[11] Déportes I, Benoit Guyod JL, Zmirou D 1995. Hazard to man and the environment posed by the use of urban waste compost: a review. *Science of The Total Environment*. 172(2-3), pp.197–222

[12] Rada EC, Franzinelli A, Taiss M, Ragazzi M, Panaitescu V and Apostol T 2007. Lower heating value dynamics during municipal solid waste bio-drying. *Environmental Technology*. 28(4), pp.463-9

[13] Tom AP, Pawels R and Haridas A 2016. Biodrying process: A sustainable technology for treatment of municipal solid waste with high moisture content. *Waste Management*. 49, pp.64-72

[14] Zhao SQ, Huang WX, Yin R, Yuan S, Huang DD, Liu C 2014. The effect of bio-drying on heating values of municipal solid waste. *Advance Material Research*. 1010–1012, pp.537–46

[15] European commission – directorate general environment 2003. *Refuse derived fuel, current practice and perspectives (B4-3040/2000/306517/MAR/E3)*. WRc Ref: CO5087-4

[16] Diaz LF, Savage GM 2007. Factors that affect the process. In: Diaz LF et al (Eds). *Compost science and technology*. Elsevier, Chapter 4 pp 49-65

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