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Original Paper

Influence of biodegradation process on methane formation and composting efficiency

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ABSTRACT

In this study, the aim was to analyze the production of methane (CH_4) during the degradation process in three piles of biowaste (V1, V2, V3) and to determine the efficiency of the used biowaste treatment technology. The biowaste treatment technology in reference pile V1 was untreated. In the second pile V2, a biological preparation containing probiotic bacteria was applied and the sample V3 was treated by turning and watering once a week. Degassing shafts were installed in each pile to measure of methane concentrations during the degradation process. The Multigas Monitor 1312 gas analyzer with the Multipoint Sampler 1309 was used to measure of the methane production in the first, fourth and seventh week. The production of methane had an increasing trend throughout the process. In the V1 pile (34.60 $mg \cdot m^{-3}$, 66.25 $mg \cdot m^{-3}$ and 115.85 $mg \cdot m^{-3}$), but much more in the V3 pile (32.81 $mg \cdot m^{-3}$, 220.97 $mg \cdot m^{-3}$ and 325.89 $mg \cdot m^{-3}$). In the V2 pile with biodegradable preparation, the highest methane production was at fourth week (42.35 $mg \cdot m^{-3}$, 116.28 $mg \cdot m^{-3}$ and 72.83 $mg \cdot m^{-3}$). In the fourth and seventh week, statistically higher values of methane concentrations were recorded from the V3 pile, than from V1 and V2 piles ($P < 0.05$). Although the mechanically treated method resulted in the highest release of harmful gas, the most efficient way of biowaste treatment was shown in the V3 pile, where the percentage of sieving residues was only 18.44%, in the V2 pile it was 25.22% and up to 32.12% in the untreated V1 pile.

KEYWORDS: methane in compost, composting technology, composting process, temperature measuring

JEL CLASSIFICATION: Q15

INTRODUCTION

Biodegradable waste can be treated in different ways, but the easiest way is composting. This process is a way to treat biodegradable waste that is currently landfilled together with mixed municipal waste in most cases. Composting reduces the amount of waste and thus saves the municipalities' fees for landfill of municipal waste and in agricultural production reduces the costs of fertilization [3]. According to Favoino and Hogg (2008) [5], the use of compost can

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reduce the need for chemical fertilizers, which means reducing the greenhouse gas emissions associated with their production and use. Composting in composting plants may also contribute to the reduction of methane (CH_4) emissions, depending on the composting method [3]. Although the benefits of composting are evident, greenhouse gases can be generated and emitted to the atmosphere during this process, contributing to global warming by producing methane [11]. CH_4 is produced in large quantities in the landfills due to degradation of organic matter under anaerobic conditions [12]. Therefore, it is very important to separate biodegradable waste from mixed municipal waste and increase the efficiency of the degradation process to produce quality compost. The aim of this study was to analyze the production of methane (CH_4) in three piles of biowaste (V1, V2, V3) depending on the treatment technology used and to determine the efficiency of the used technology in terms of the final product.

MATERIAL AND METHODS

An attempt to monitor the production of methane and the efficiency of composting was carried out during eight weeks in the summer period. Three loose piles of biowaste (V1, V2, V3) were created at the same time and with the same volume of 50 m^3 (Fig. 1). The biowaste in the reference pile V1 was untreated. In the second pile V2 a biological preparation containing probiotic bacteria was used to accelerate the degradation process. The V3 pile was treated once a week by turning and watering. Degassing shafts were installed in each pile to remove landfill gas and measure of methane concentrations during the degradation process. The Multigas Monitor 1312 gas analyser, together with the Multipoint Sampler 1309 sampler was used to measure of concentrations (Innova, Denmark). The measurement system is based on Photoacoustic Infrared Detection, which delivers the ability to measure virtually any gas that is absorbed in the infrared spectrum. Measurements of methane concentrations and humidity of the composted mixture were performed in the first, fourth and seventh weeks of the degradation process. During the experiment, the temperature inside each pile was monitored daily using a Pfeuffer GT 1 injection thermometer to determine the need of turning and irrigating the waste in the V3 pile. The average temperature was determined by taking three measurements at the left, middle, and right side in each pile. Determination of compost moisture was performed in a certified laboratory. Samples were collected from left, middle, and right side of each pile at 30, 60 and 90 cm depths. These samples were combined and mixed into one composite sample. The composite samples were collected from each pile at day 7, 28 and 49. Humidity measurement was also carried out by means of an orientation test for the need of watering the V3 pile. Statistical analysis of significant differences in MATLAB environment was used to process the obtained data. We verified the hypothesis H0: there is no significant difference between the production of methane concentrations in V1, V2 and V3 heaps in weeks of composting (weeks 1, 4 and 7). The non-parametric Kruskal-Wallis test (K-W test) was used, which has less restrictive conditions [10]. In this case, the verified hypothesis is the hypothesis of equality of medians of individual samples. The efficiency of each composting process was determined after completion of the measurement. Approximately 2.5 - 3 t were taken from each pile using a loader, which was accurately weighed and then sieved on a Pezzolato L 3000 drum sieve with holes dimensions of 40 mm. The sieved material of the compost fell directly into the bucket of the loader; this was weighed on the bridge scale together with the loader. Then the drum sowing outlets were weighed and again reweighed. The weight of the loader was calculated at each weighing, which was 8.52 t with the engineer.

Figure 1 Three loose piles of biowaste (V1, V2, V3)

RESULTS AND DISCUSSION

Figure 2 shows the average results of a 24-hour continuous measurement of CH_4 concentrations from the three piles V1, V2 and V3 observed in the first, fourth and seventh weeks of compost maturation.

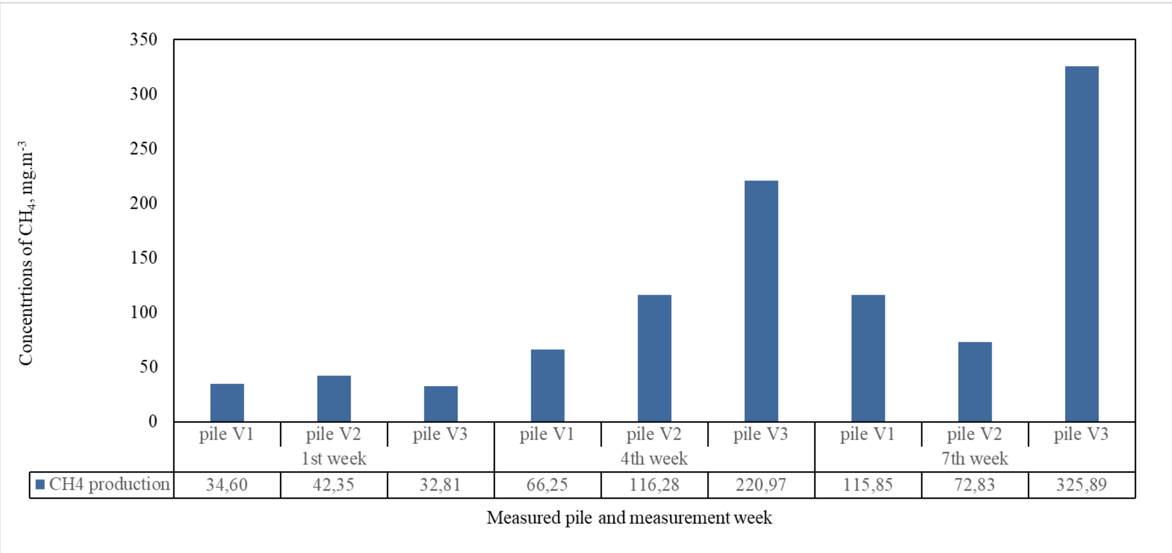

Figure 2 Average CH_4 production in V1, V2 and V3 pile in the first, fourth and seventh week after piles creation

The average CH_4 concentrations in the first week were 34.60 mg·m^{-3} (V1), 42.35 mg·m^{-3} (V2) and 32.81 mg·m^{-3} (V3). From the material samples taken were found humidity 67.42 % (h_{V1}), 67.53 % (h_{V2}) and 67.56 % (h_{V3}). These values can be considered satisfactory. In the fourth week of maturing compost, when the thermophilic phase was in progress, the mean values of CH_4 concentrations were 66.25 mg·m^{-3} (V1), 116.28 mg·m^{-3}(V2) and 220.97 mg·m^{-3}(V3).

Humidity in each pile decreased to 45.98 % (h_{V1}), 46.78 % (h_{V2}) and 48.34 % (h_{V3}). At week 7th, in the compost maturation phase, the mean values of CH_4 concentrations in the piles were 115.85 mg·m^{-3} (V1), 72.83 mg·m^{-3}(V2) and 325.89 mg·m^{-3} (V3). From samples of material from each pile, lower humidity 33.1 % (h_{V1}), 40.45 % (h_{V2}) and 43.34 % (h_{V3}) were found.

In the first week, CH_4 production did not meet the assumption of equality of medians of each sample. The amount of CH_4 produced in the V2 pile was statistically significantly higher ($P < 0.05$) (Tab. 1). As reported by Tiqua et al. (2000) [14] the windrows can be exposed to several external environmental variables, and this may create variability in windrows with the same composting material at the beginning of the process, even in windrows with the same treatment. In our experiment, a biological preparation containing probiotic bacteria was applied to this V2 pile at the beginning of experiment to accelerate the degradation process, which could cause higher CH_4 production.

Table 1 CH_4 production from piles V1, V2, V3 in the first, fourth and seventh week

Meas. in week	Meas. piles	Number of meas.	Average + stand. dev.	Median	P-value		
1	V1	43	34.60 ± 9.76	34.36 [a]	(12) 0.0171		
	V2	43	42.35 ± 14.77	41.82 [b]		(23) 0.0035	
	V3	43	32.81 ± 7.77	32.62 [a]			(13) 0.4319
4	V1	43	66.25 ± 9.02	63.69[a]	(12) 0.0000		
	V2	43	116.28 ± 14.41	119.87[b]		(23) 0.0000	
	V3	43	220,97 ± 56.56	217.30[c]			(13) 0.0000
7	V1	36	115.85 ± 19.94	112.18[a]	(12) 0.0000		
	V2	36	72.83 ± 17.10	68.20[b]		(23) 0.0000	
	V3	36	325.89 ± 123.24	306.90[c]			(13) 0.0000

[abc] different upper indices indicate significant difference in CH_4 concentrations in V1, V2 and V3 at $P < 0.05$

In the fourth week from the V3 pile, which was turned, and irrigated, statistically significantly higher CH_4 production values were recorded than from a pile of V1 and V2 ($P < 0.05$). Methane production was 3.3 times higher from V3 pile than V1 and 2 times higher than V2 pile (Tab.1). In the seventh week it was statistically proven that from the V3 pile statistically significantly higher values of CH_4 production ($P < 0.05$) were recorded, it was almost 3 times more than V1, and nearly 5 times more than V2.

Production of CH_4 concentrations in both the untreated V1 pile and the turned and watering V3 pile had a growing trend throughout the process. Conversely, in the V2 pile with the addition of the biopreparation, it was increased shortly after the pile formation and the highest CH_4 concertation's production was already in the fourth week, which was in accordance with rapid decomposition of compost materials because rapid aerobic decomposition leads to suitable anaerobic conditions for CH_4 emission production [12]. In the seventh week, readily available carbon compounds were depleted, which reduced the activity of microbes in the composting material, thereby reducing the production of CH_4. This model was similar to research of Fukumoto et al. (2003) [6] and Szanto et al. (2007) [13].

As reported Michel, et al. (2013) [9], Illmer and Schinner (1997) [7] windrow turning is one of the composting strategies that affect the degree of decomposition, and quality of the composted product. Szanto et al. (2007) [13] observed lower CH_4 emissions in turned piles than in static systems. Several authors reported that even in well-aerated process CH_4 was emitted [2] while [1] observed a rapid decrease when the oxygen supply was increased.

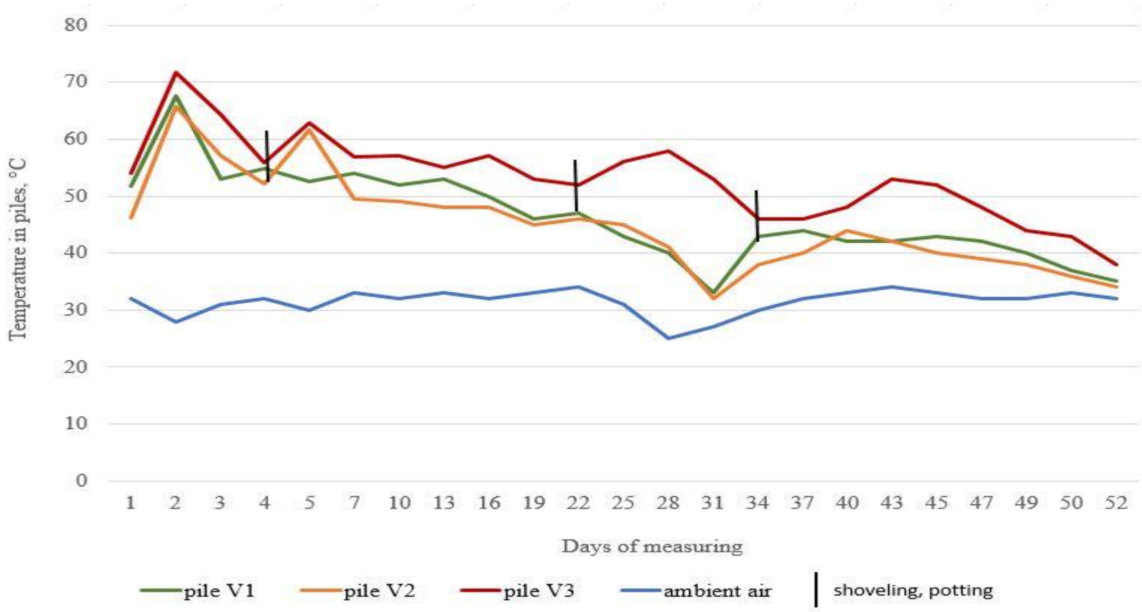

Fig. 3 Temperature profile in pile V1, V2, V3 and ambient air during the composting process

The temperature of the compost in each pile increased rapidly after the start of the experiment (Fig. 3), the maximum temperatures (68 °C, 66 °C and 72 °C) were observed on day 2. Then the temperature decreased gradually during the process between 40 °C and 60 °C and the degradation process took place in the thermophilic phase. The thermophilic phase of all treatments was long enough to satisfy the requirement for sanitation eff ect. Watering was carried out whenever it was evident that the temperature would fall below the desired 45 °C. Since the piles were of a smaller size, their temperature was also influenced by the outside temperature, as can be seen in Figure 3. At the inverted V3 pile, the highest temperatures were observed even when the ambient air temperature dropped. After 50 days, which is enough time for the entire composting process to take place, the temperature began to drop and reached below 40 °C. At the end of the degradation process, each pile was sieved and weighed to determine the efficiency of the processing technology used. It was found that turning and irrigation in the V3 pile had a significant effect on the amount of compost produced. The proportion of sieving residue in V3 was the smallest and only 18.44% and the remaining 81.56 % was quality compost. In the case of V2, the proportion of sieving was up to 25.22 % and in the case of V1, it was 32.12 %. The compost was only 74.78 % in V2 and 67.88 % in V1. From the given results it is evident that by treatment we achieved the highest rate of waste degradation and reached the highest percentage of the final product in the form of compost. In unturned piles, aerobic conditions prevail mostly at the outer surface of the piles, while anaerobic conditions dominate inside [8]. According to the results, it is clear that controlled composting process is financially efficient because it reduces the time degradation process, as well as space composting facilities, thereby reducing the overall operating costs of the composting plant.

CONCLUSIONS

Based on the measured and evaluated data in the first week, the hypothesis H0 can´t be accepted, CH_4 production did not meet the assumption of median equality. The amount of CH_4 produced in the V2 pile was statistically significantly higher ($P < 0.05$). Statistically significantly higher values of the methane production were recorded from the V3 pile, which was turned and irrigated, than from the unturned piles V1 and V2 in the fourth week. Analysis of significant differences in the amount of concentrations in the seventh week showed that statistically significantly higher values of methane production were recorded from the V3 pile than from V1 and V2 ($P < 0.05$). Turning affected not only the temperature but also the resulting amount of product. Understanding the effects of different composting strategies is important because the composted product will eventually be used as a supplement to the soil. Based on the results from the measurement, it was shown that turning and irrigating resulted to the highest release of CH_4 into the air, but also faster decomposition of microorganisms, which can reduce the time required to achieve a stable compost product and increase the efficiency of the composting plant. These results of measurements can be used in other research activities that will deal with the formation of gases during landfilling or composting. From a life-cycle assessment perspective, it is necessary to have experimental data both on greenhouse gas emissions and process efficiency to have a fair evaluation of the environmental impacts of composting.

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REFERENCES

[1] Beck-Friis, B., Pell, M., Sonesson, U., Jönsson, H. & Kirchmann, H. (2000). Formation and emission of N_2O and CH_4 from compost heaps of organic household waste. *Environmental Monitoring and Assessment*, vol. 62, pp. 317-331.

[2] Clemens, J. & Cuhls, C. (2003). Greenhouse gas emissions from mechanical and biological waste treatment of municipal waste. *Environmental Technology*, vol. 24, no. 6, pp. 745-754. doi: https://doi.org/10.1080/09593330309385611

[3] Colón, J., Cadena, E., Pognani, M., Barrena, R., Sánchez, A., Font X. & Artola, A. (2012). Determination of the energy and environmental burdens associated to the biological treatment of source-separated municipal solid wastes. *Energy & Environmental Science*, vol. 5, no. 2, pp. 5731–5741. doi: https://doi.org/10.1039/C2EE01085B

[4] Colón, J., Martinéz-Blanco, J., Gabarell, X., Artola, A., Sánchez, A., Rieradevall, J. & Font, X. (2010). Enviromental assessment of home composting. *Resources, Conservation and Recycling*, v. 54, n. 11, p. 893-904. doi: http://dx.doi.org/10.1016/j.resconrec.2010.01.008

[5] Favoino, E. & Hogg, D. (2008). The potential role of compost in reducing greenhouse gases. *Waste Management & Research*, vol. 26, no.1, pp. 61-69. doi: https://doi.org/10.1177/0734242X08088584

[6] Fukumoto, Y., Osada, T., Hanajima, D. & Haga, K. (2003). Patterns and quantities of NH_3, N_2O and CH_4 emissions during swine manure composting without forced aeration- effect of compost pile scale. *Bioresource Technology*, vol. 89, no. 2, pp. 109-114. doi: https://doi.org/10.1016/S0960-8524(03)00060-9

[7] Illmer, P. & Schinner, F. (1997). Compost turning a central factor for rapid and high quality degradation in household composting. *Bioresource Technology*, vol. 59, no. 2-3, pp. 157-162. doi: https://doi.org/10.1016/S0960-8524(96)00156-3

[8] Jiang, T., Schuchardt, F., Li, G., Guo, R. & Zhao, Y. (2011). Effect of C/N ratio, aeration rate and moisture content on ammonia and greenhouse gas emission during the composting. *Journal of Environmental Sciences*, vol. 23, no.10, pp. 1754-1760. doi: https://doi.org/10.1016/S1001-0742(10)60591-8

[9] Michel, F.C. JR., Forney, L.J., Huang, A.J.F., Drew, S., Czuprenzski, M., Lindeberg, J.D. & Reddy, A. (2013). Effects of turning frequency, leaves to grass mix ratio and windrow vs. pile configuration on the composting of yard trimmings. *Compost Science & Utilization*, vol. 4, no. 1, pp. 26-43. doi: https://doi.org/10.1080/1065657X.1996.10701816

[10] Ostertágová, E., Ostertág, O. & Kováč, J. 2014. Methodology and application of the Kruskal-Wallis Test. *Applied Mechanics and Materials*, vol. 611, pp. 115-120. doi: https://doi.org/10.4028/www.scientific.net/AMM.611.115

[11] Sánchez, A., Artola, A., Font, X., Gea, T., Barrena, R., Gabriel, D., Sánchez Monedero, M.A., Roig, A., Cayuela, M.L. & Mondini, C. (2015). Greenhouse gas emissions from organic waste composting. *Environmental Chemistry Letters*, vol. 13, pp. 223–238. doi: https://doi.org/10.1007/s10311-015-0507-5

[12] Seo, Y. & Kim, S. (2013). Estimation of greenhouse gas emissions from road traffic: a case study in Korea. *Renewable and Sustainable Energy Reviews,* vol. 28, pp. 777-787. doi: https://doi.org/10.1016/j.rser.2013.08.016

[13] Szanto, G.L., Hanekers, H.V.M., Rulkens, W.H. & Veeken, A.H.M. (2007). NH_3, N_2O and CH_4 emissions during passively aerated composting of straw-rich pig manure. *Bioresource Technology*, vol. 98, no. 14, pp. 2659-2670. doi: https://doi.org/10.1016/j.biortech.2006.09.021

[14] Tiquia, S. M., Richard, T. L. & Honeyman, M. S. (2000). Effect of windrow turning and seasonal temperatures on composting of hog manure from hoop structures. *Environmental Technology (United Kingdom)*, vol. *21*, *no.* 9, pp. 1037-1046. doi: https://doi.org/10.1080/09593332108618048