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MONITORING OF GAS PRODUCTION DURING THE BIOWASTE COMPOSTING

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The aim of this paper was to monitor the production and composition of gases from the biowaste landfill in terms of the utilized composting process technology. Processing technology of biowaste in the reference sample V1 was without modification; process optimization technology – material homogenization by overturning and irrigation – was used for the second sample V2. Gas measurements (methane, carbon dioxide, ammonia, nitrous oxide) were conducted during the first and sixth weeks after their establishing. At the same time, samples were taken for laboratory determination of the dry matter content of examined materials, pH and C/N ratio. It has been statistically proved that there was a significantly higher gas production in V2, which was overturned and irrigated, than in V1. The measured CO₂ values were 2.5 times higher in V2 in comparison to V1. The mean CH₄ production in the stack V1 was 96.35 mg·m⁻³ and 235.9 mg·m⁻³ in the stack V2, which is 2.5 times more. Due to overturning and irrigation of composted material in the stack V2, the decomposition of microorganisms was faster, which also affected the amount of released gases.

Keywords: biological waste; municipal waste; landfill gases; composting

The issue of waste management is one of the biggest environmental challenges in Slovakia. Generally, municipal waste in Slovakia contains a large amount of waste suitable for sorting and recovery. It includes e.g. plastics, paper, glass, metals and biodegradable waste. Landfilling each of these components is economically disadvantageous and represents a major health risk (Hrabčák, 2013). Biodegradable waste (BDW) accounts for 40% of the mixed waste in average. It might seem that biodegradable waste does not represent a risk to the environment. However, BDW needs the optimal conditions for its decomposition, recovery and utilization of nutrients in the form of compost (Demirbas, 2011). Landfills do not provide these conditions and biowaste is compressed together with other kinds of waste in the landfill. Thereby, decomposition occurs without air and causes putrescence process. The harmful gases (such as methane) are released into the air during rotting and groundwater is polluted by landfill leachates. Numerous waste management activities are carried out in the exterior or in front of operating halls and thus they become the source of surface or fugitive emissions (Hroncová and Ladomerský, 2017). Gaseous emissions in the air represent probably the largest share of negative environmental impact of municipal waste landfilling. These are mainly methane (CH₄), nitrogen oxides, hydrogen sulphide and volatile non-methane organic compounds (Hrabčák, 2017). Biowaste can be composted either as municipal waste (35 to 70% of its total weight deposited in the Slovak Republic at landfills is currently represented by biowaste) or incinerated in

waste incinerators. Biowaste composting is considered by experts to be one of the most efficient means of CO₂ production reduction in human activities and thus also a method exploitable in fight against global warming. Due to the implementation of the European Union landfill directive to divert the biodegradable waste fraction from the municipal solid waste stream (CEC, 1999), composting has received widened interest as a means of addressing the current waste management challenges. During composting, fugitive emissions primarily depend on the compost feedstock, as well as on process and operating conditions (Amlinger et al., 2005; Amlinger et al., 2008). In addition to the composting operation, the C/N ratio, texture of the input material, humidity and temperature conditions are the essential parameters influencing the greenhouse gas production (He et al., 2001; Ekland et al., 2007; Amlinger et al., 2008). Globally, biogas production for energy use is considered to be active step towards climate protection and sustainable life technology, in which waste from animal production, livestock excrements, residues of various crops (Kažimírová et al., 2018) can be used as starting materials.

The aim of the experiment was to monitor the production and composition of landfill gases and investigate the impact of the used bio-waste recovery process on landfill gas production.

Hypotheses:

H0: There is no significant difference between gas production at stacks V1 and V2 at the start of the biodegradation process (week 1).

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H1: There is no significant difference between gas production at stacks V1 and V2 on week 6 of the biodegradation process.

H2: There are no significant differences in gas production between week 1 and 6 of the biodegradation process at each stack.

Material and methods

The composting plant for biodegradable waste, where the experiment was carried out, is located in the cadastral area of Výčapy-Opatovce at an altitude of 155 m. This village belongs to the area of lowland climate with slight temperature inversion. Total landfill capacity is 5,000 tonnes per year of biodegradable waste for composting. Two stacks of biowaste (V1 and V2) at the same time and with the same volume (10 m³) were needed to set up the experiment with implementation of a different technological process for composting waste at each pile. In terms of technology of biowaste processing, reference sample V1 was untreated and the second sample V2 was optimized by homogenization of material by overturning and irrigation. Each stack was equipped with a shaft for exhaustion of landfill gases. During the experiment, the temperature inside each pile was monitored daily in order to determine the need to overturn and irrigate the waste in V2. Gas production measurements (methane, carbon dioxide, ammonia, nitrous oxide) at each stack were conducted during the first and sixth weeks after their establishing. Simultaneously, samples from V1 and V2 were taken for laboratory determination of the content of dry matter, pH and C/N ratio of the materials examined. Considering the processing of collected data, programme Statistica 10 was utilized for statistical analysis of significant differences. Pfeuffer GT 1 needle thermometer was used to measure compost temperature, allowing measurements at a depth of up to 1.5 m, as well as on the surface. Determination of compost moisture, pH and C/N nutrient ratio was performed at a certified laboratory. These physical and chemical properties are important for comparison of two biowaste recovery technologies, by which the decomposition rate and the correct recovery method can be assumed for further use. Multigas Monitor

1312 gas analyser, together with the Multipoint Sampler 1309 sampler were used to measure emissions.

Measuring points:

V1 – measuring in the shaft fitted in a stack without modification of technological process;

V2 – measuring in the shaft fitted in a stack with optimization of technological processes.

Results and discussion

Table 1 shows the results of a 24-hour gas production measurement in both V1 and V2 stacks monitored on week 1 after sample creation. During the first week, mean CO₂ content reached values of 46,335.58 mg·m⁻³ in V1, and 5,2551.29 mg·m⁻³ in V2. Mean N₂O content, production of which slightly decreased in both piles during the measurement, reached value of 55.69 mg·m⁻³ in V1, and 64.00 mg·m⁻³ in V2. Recorded mean NH₃ content was 471.19 mg·m⁻³ in V1, and 436.93 mg·m⁻³ in V2. With moderate fluctuations, mean CH₄ production reached 862.19 mg·m⁻³ and 750.63 mg·m⁻³ in V1 and V2, respectively. During week 1, production of landfill gases at monitored bio-waste piles V1 and V2 did not differ significantly (Table 1) despite the fact that they contained identical material and volume of each stack and gas contents were measured immediately three days after creation of samples. Both samples were without any intervention at that time. From the material samples taken during the week 1, the same values of pH (6.13) and moisture (68.42%) were found in both V1 and V2 stacks (Table 3).

The gas production results obtained in the 24-hour measurement during the week 6 after establishing of V1 and V2 are shown in Table 2. It was statistically proven that there was recorded significantly higher gas production in V2, which was overturned and irrigated, than in V1 (Table 2). The CO₂ content was 2.5 times higher and the N₂O content was almost 3 times higher in V2 in comparison to V1. Mean NH₃ content in V1 was 12.74 mg·m⁻³; mean NH₃ content in V2 was 58.35 mg·m⁻³, making it almost 5 times higher. Mean CH₄ production was 96.35 mg·m⁻³ in V1 and 235.9 mg·m⁻³ in V2 – 2.5 times higher. The amount of gases released depends on microbial activity; therefore, it can be concluded that microorganisms decomposed the composting material in

Table 1 Gas production at measurement points V1, V2 – week 1 (mg·m⁻³)

Gas	Measurement points – stack	Number of meas.	Average ±stand. dev.	P-value
CO ₂	V1	466	46,335.58 ±3,380.66 ^a	0.06
	V2	466	52,551.29 ±3,000.82 ^a	
N ₂ O	V1	466	55.69 ±10.68 ^a	0.08
	V2	466	64.00 ±11.13 ^a	
NH ₃	V1	466	471.19 ±30.55 ^a	0.08
	V2	466	436.93 ±28.62 ^a	
CH ₄	V1	466	862.19 ±48.27 ^a	0.06
	V2	466	750.63 ±38.40 ^a	

^a the same upper indices indicate – there is no significant difference in gas production between V1 and V2 at $p < 0.05$

Table 2 Gas production at measurement points V1, V2 – week 6 ($\text{mg}\cdot\text{m}^{-3}$)

Gast	Measurement point – stack	Number of meas.	Average $\pm$ stand. dev.	P-value
CO_2	V1	462	$6,481.49 \pm 802.72^a$	0.00009
	V2	462	$16,135.51 \pm 1,852.36^b$	
N_2O	V1	462	4.45 ± 0.50^a	0.00008
	V2	462	13.00 ± 1.57^b	
NH_3	V1	462	12.74 ± 1.10^a	0.00008
	V2	462	58.35 ± 5.45^b	
CH_4	V1	462	96.35 ± 15.33^a	0.00009
	V2	462	235.90 ± 35.00^b	

^{a,b} different upper indices indicate significant difference in gas production in V1 and V2 at $p < 0.05$

Table 3 Analysis of material samples from stacks V1 and V2

Time of sampling	V1			V2		
	pH	moisture (%)	C : N	pH	moisture (%)	C : N
Week 1	6.13	68.42	9.12 : 1	6.13	68.42	9.12 : 1
Week 6	7.29	27.45	23.59 : 1	8.22	46.9	12.7 : 1

V2 more rapidly thanks to overturning and irrigation. As reported by other authors (Sundberg and Jonsson, 2007), it is possible to shorten the time needed for production of a stable compost product and thus to increase the efficiency of composting plants by increasing the aeration and adding water to compensate for drying. The same results were achieved by Hrad et al. (2014), who reported that emissions were higher during the overturning and thus the frequency of shovelling

appears to be a key factor in regulation of emissions during biowaste composting.

There were also observed different pH values in V1 and V2 – namely 7.29 and 8.22, respectively – different moisture contents in material samples taken from V1 (27.45%) and V2 (46.9%) on week 6 (Table 3).

From the initial values of the gas concentrations measured at week 1, the gas concentrations at week 6 in each stack decreased to significantly

lower levels (Figs. 1 and 2). However, in V2, this decrease was smaller since the decomposition process taking place inside the stack was supported by aeration as a result of overturning, making the composting an aerobic process. However, aeration caused the compost drying. Therefore, irrigating was needed in order to increase the temperature, allowing thus the faster degradation of composted material, since moisture facilitates the movement of microorganisms and serves as a medium for chemical reactions.

The maximum CO_2 concentrations observed during the week 1 correspond to the maximum temperatures recorded during the first days of composting; as the temperatures gradually dropped, the amount of CO_2 produced also decreased. These results are consistent with the findings of several other authors (Plíva et al., 2006; Jiang, 2011), who reported that the amount of released CO_2 decreases with compost maturation time; furthermore, they observed that material temperature, pH and C/N nutrient ratio have also significant impacts on CO_2 compost production. Fig. 3 shows the course of temperature during the entire process, indicating the time of overturning and irrigating the stack V2. The temperature rose rapidly at the start of the experiment, a maximum temperature of 70 °C was

Fig. 1 Comparison of gas production on weeks 1 and 6 – stack V1 ($\text{mg}\cdot\text{m}^{-3}$)
Wilks lambda = 0.00760, $F(4, 124) = 4,050.2$, $p = 0.0000$

Fig. 2 Comparison of gas production on weeks 1 and 6 – stack V2 (mg·m⁻³)
Wilks lambda = 0.00822, F (4, 124) = 3,738.4, *p* = 0.0000

Fig. 3 Temperature profile of samples in V1 and V2

observed on the third day, causing a short mesophilic phase followed by a slight decrease in temperature to 45 °C. After adjusting by means of overturning and irrigating, the temperature rose close to 70 °C. However, the temperature inside the pile is also affected by the external temperature, which varied from 7 to 27 °C. Hellmann et al. (1997) and Osada et al. (2010) observed similar results in a system of composting in rows. These temperature variations were caused by the degradation of partially decomposed materials that were transferred from anaerobic to aerobic areas (Jiang, 2011).

Considering the measurement results recorded during the week 6,

it is obvious that the production of the monitored gases was higher in V2 compared to V1. During the first week, the C/N ratio of samples V1 and V2 was equal, 9.12 : 1. During the week 6, the C/N ratio of samples V1 and V2 was 23.59 : 1 and 12.7 : 1, respectively. Table 3 shows that the observed gas concentrations in sample V2 were higher. The C/N ratio is an important factor in controlling microbiological metabolism (Godwin et al., 2017). As reported by Amlinger et al. (2008), the amount of CO₂ released also depends on the C/N ratio. CO₂ emissions are lower when the C/N ratio of processed raw materials is higher. However, a low C/N ratio is responsible for higher NH₃ emissions, especially at good aeration

and high compost temperatures. Therefore, a C/N ratio >25 will help to minimize NH₃ and N₂O emissions. However, a C/N ratio >35 may result in the available nitrogen pool limiting the proper decomposition and humification process (Amlinger, 2008). Jiang (2011) states in his study that a lower C/N ratio resulted in a higher production of methane emissions by reduction in the air spaces. High aeration rate can reduce the CH₄ emissions, whereas the emissions of N₂O and NH₃ increase. As the author further states, the moisture content can affect the methane and ammonia emissions during the composting period. However, he does not consider the moisture impacts significant.

For the purpose of reference, monitoring report of gas measurement emitted from the body of municipal solid waste mixed with biodegradable waste using degassing shafts is provided (Potyš, 2018). The author observed the average CO₂ content of 15.6 vol. %, which is 28,668.1.2 mg·m⁻³, and average CH₄ content of 21.4 vol. %, which is 142,257.6 mg·m⁻³. Although these data are not comparable with experiment presented, because the amounts and compositions of gaseous emissions depend on moisture, temperature, etc., by application of anaerobic decomposition stage, it can be assumed that the municipal waste mixed with biowaste produces higher amounts of harmful gases than biodegradable waste composted separately. However, this will be the subject of further investigation.

Conclusion

Gaseous emissions (especially methane) from composting can be a significant source of anthropogenic greenhouse gases emissions and air pollution. An experiment was conducted to estimate the effects of aeration by means of overturning and moisture content on the gas production during composting. A 24-hour measurement method was used and the gas production was compared in two open stacks located at two waste piles with different processing technology of composted material. Results showed that the production of all monitored gases was the highest at the beginning of composting process and the amount

of gases gradually decreased during the process. By comparing the two technological compost treatments, it has been shown that the higher gas production and faster decomposition of microorganisms occur when compost material is overturned and irrigated, resulting in reduction of time necessary for achieving of a stable compost product and increasing compost efficiency. On the basis of the evaluated data in the first week, the H0 hypothesis can be accepted, since the production of landfill gases in the monitored biowaste stacks V1 and V2 did not differ significantly at the beginning of the process. Hypothesis H1 proved to be false, because statistical analysis of significant differences has shown that the gas production in V2, which was overturned and irrigated, was significantly higher than in V1 in the sixth week. Furthermore, this is also true for H2 hypothesis, since by analysing significant differences in gas amounts produced during the first and sixth weeks, it was statistically proven that landfill gas production differs significantly at the significance level $\alpha = 0.05$. Directive of the European Parliament and Council 2008/98/EC on waste, as well as Council Directive 1999/31/EC on the landfill of waste, clearly prioritize the use of biodegradable waste according to the waste hierarchy – material recovery before energy recovery and waste disposal (Jensen et al., 2017). Consequently, all biowaste that is not contaminated with foreign substances and other unsuitable ingredients should be used primary for compost production.

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