LANDFILLING OF BIODEGRADABLE WASTE AND GENERATION OF LANDFILL GAS

Jan ŠONSKÝ[1], Shuran ZHAO[2], Petr VACULÍK[1], Vlastimil ALTMANN[2]

[1]Department of Technological Equipment of Buildings, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, 165 21 Prague, Czech Republic
[2]Department of Machinery Utilization, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, Prague 6, 165 21, Czech Republic

Abstract
Landfilling of organic waste generates landfill gas. Landfill gas is primarily made up of greenhouse gases and its release into the atmosphere is undesirable. Despite the obligation to capture landfill gas from the landfill, emissions to air may occur. With this in mind, since 2015, legislation has restricted which organic waste can be landfilled. Therefore, instead of landfilling, organic waste is diverted to facilities for its further use, such as composting facilities. Despite this pressure to reduce landfilling, the organic component is increasing. This is mainly due to the increasing amount of mixed municipal waste being landfilled, which, according to regular analyses by EKOKOM, a.s., contains up to 25 % organic content. Despite the increasing share of the organic component within the landfill body, the amount of landfill gas has been decreasing year by year. It appears that the amount and production of landfill gas is therefore dependent on more than just the quantity of waste, but mainly on the moisture content and composition of the organic material.

Key words: *waste, waste management, landfill, landfill gas, emissions.*

INTRODUCTION

Landfill gas is produced by the decomposition of organic materials inside the landfill body. Its formation is conditioned by a sufficient content of organic material. Important factors are the moisture content of the waste, the volume of the landfill body, the degree of compaction, and most importantly, the overall composition of the disposed waste (*Kumar & Sharma, 2014*). Landfill gas must be extracted from the landfill body and its utilization must be ensured, e.g., in cogeneration units. With respect to environmental protection, there is a gradual pressure to reduce landfilling of biodegradable wastes and hence less generation of landfill gas, which has an impact on global warming (*Sanjuan-Delmas et al. 2021*).

Landfill gas is mainly composed of methane (CH_4) and carbon dioxide (CO_2). Other gases are minor (*Cáb and Šeděnková, 2019*). Landfill gas is produced in 2 phases - aerobic and anaerobic. During the aerobic phase, which lasts only a few days, growth of organisms and exothermic reactions occur. During the aerobic phase, mainly O_2 is consumed, and CO_2 is the main product of this phase and anaerobic environment is gradually formed. The anaerobic phase occurs in 3 successive phases (*Williams, 2005*). In the first phase, acetogenesis, there is a complete transition between the aerobic and anaerobic environment. Gradual hydrolysis results in microbial conversion of biodegradable matter to produce volatile organic acids, hydrogen, ammonia nitrogen and carbon dioxide. The electron acceptor oxygen is displaced by carbon dioxide and the electron acceptors become nitrates and sulphates. The second anaerobic phase is the methanogenic unsterilized phase. The acids formed from the acetogenesis phase are consumed by methanogenic bacteria to form methane and carbon dioxide (*Obersky et al., 2018*). The electron acceptors nitrate and sulfate are reduced to sulfide and ammonia. The third anaerobic phase is the methanogenic stabilized phase. The final phase of landfill stabilization. Gradually, the remaining substrate and nutrients are utilized causing a dampening of biological activity (*Sel et al., 2016*).

Landfill gas is extracted from the landfill body using a degasification system. This is composed of 2 parts - a collection and a conveyance network. The collection network collects the gas from the landfill body. The intake network diverts the gas from the collection network inside the landfill body to the landfill gas recovery facility (*Zheng et al., 2018*). The degasification system is either active or passive. The active method involves the collection of gas by means of a vacuum created by an external device. The passive method uses the pressurized gas inside the landfill body. The landfill gas is used as a fuel

due to its energy properties. It is most often burned in cogeneration units where electricity and heat are produced (*Friesenhan et al., 2017*).
According to the above information, it is evident that the abundance of organic material in the landfill has a great influence on the generation of landfill gas. Due to the pressure to reduce the landfilling of biodegradable waste according to Decree No. 273/2021 on the details of waste management, it can be assumed that the amount of organic material in the landfill and the amount of landfill gas should decrease. The Decree allows the disposal of biodegradable waste only if it is a component of mixed municipal waste (MSW). The organic component in MSW accounts for 17 to 26% of the total amount of MSW (*Najfus, 2021*). Considering the composition of MSW, it can be concluded that the amount of organic component in landfill will increase if more MSW is landfilled (*Sel et al., 2016*). The main objective of this work is to analyze the amount of organic material in MSW landfill and its effect on landfill gas generation.

MATERIALS AND METHODS

The analysis of the amount of landfilled organic material and its impact on the amount of landfill gas was carried out at a landfill in the Central Bohemia Region, where 93 000 tons of municipal waste have been landfilled on average since 2014. The landfill has separate sections from industrial and municipal waste. Data on the amount of municipal waste disposed between 2014 and 2021, by individual catalogue numbers according to the internal records of the company operating the landfill, were used. Data from cogeneration units that burn landfill gas were also used. The cogeneration units measure continuously the amount of electricity produced and the consumption of landfill gas. The data were processed using MS Excel.
The amount of landfilled organic material and its percentage in the total amount of landfilled waste is evaluated. This quantity is then related to the consumption of landfill gas in the cogeneration unit.

RESULTS AND DISCUSSION

Ríos and Picazo-Tadeo (2021) state that landfilling is an undesirable method of waste disposal compared to waste utilization. Despite this fact, and legislative pressure, the amount of landfilled waste in the country is increasing. The amount of municipal waste landfilled between 2014 and 2021 is shown in Table 1.

Tab. 1 Quantity and composition of landfilled waste

Type of waste / Year / Weight	2014	2015	2016	2017	2018	2019	2020	2021
					kt			
Organic component	0.101	0.397	0.025	0.034	0.025	0.032	0.021	0.013
Packaging (plastic, tetra-pak, metals, glass)	0.325	0.237	0.265	0.333	0.392	0.356	0.243	0.281
Hazardous waste	0.037	0.028	0.002	0.003	0.002	0.008	0.019	0.223
Other materials	0.169	0.120	0.109	0.186	0.221	0.257	0.230	0.202
Inert waste	18.876	24.425	24.888	26.615	30.659	27.462	31.170	31.759
MSW	52.640	54.458	61.552	68.159	69.622	73.969	72.220	77.182
Total	72.148	79.664	86.841	95.330	100.921	102.084	103.903	109.660

Table 1 and Figs. 1 and 2 show the total production of the monitored waste components disposed in landfill. The total amount of waste disposed to landfill showed an increasing trend between 2014 and 2021. Fig. 2 shows that the amount of directly landfilled biodegradable waste that must be reduced according to the waste ordinance is decreasing. These are mainly catalogue numbers (according to Decree No. 8/2021, on the Waste Catalogue and the Assessment of Waste Properties (Waste Catalogue)):

- 20 02 03 – other non-biodegradable waste,
- 20 02 01 – biodegradable waste.

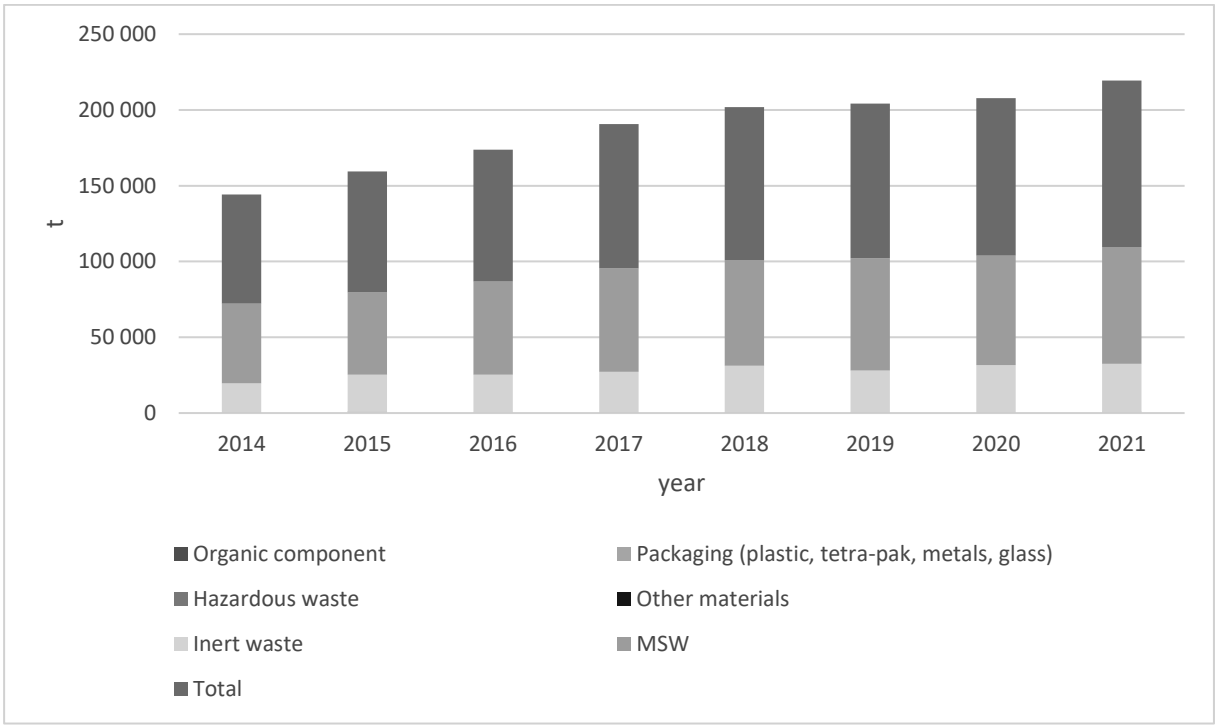

Fig. 1 Quantity and composition of landfilled municipal waste between 2014 and 2021

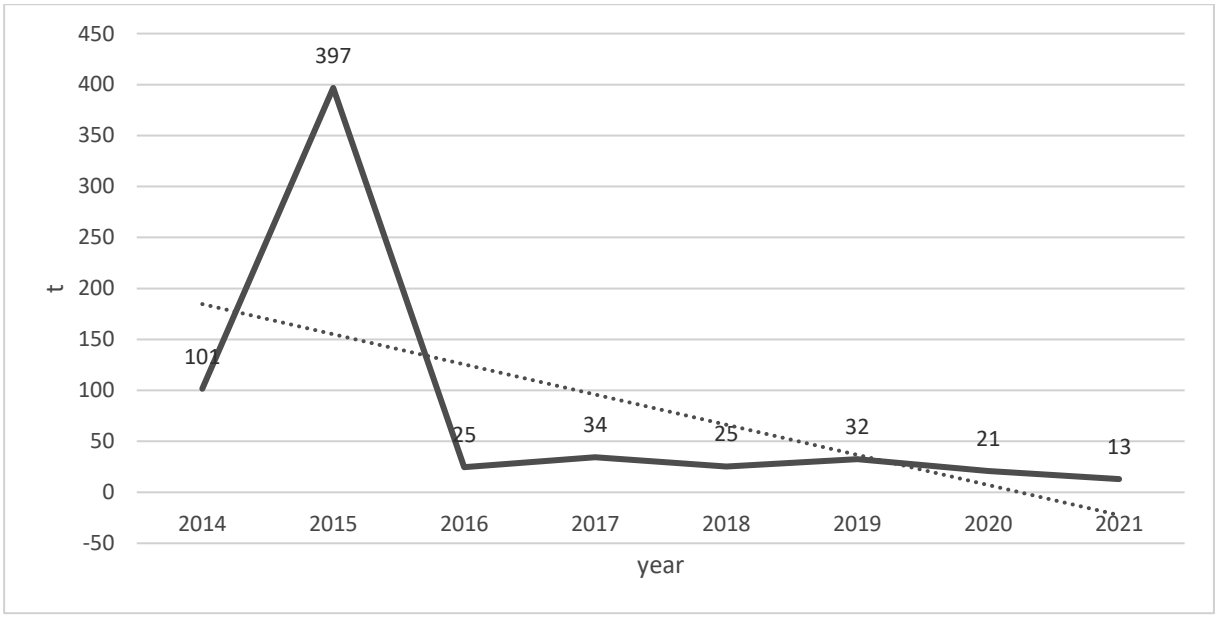

Fig. 2 Amount of directly landfilled organic waste, cat. no. 20 02 03 and 20 02 01

The organic component of mixed municipal waste also contributes to a large extent to the development of landfill gas. The amount of landfilled MSW increased by 46.62% between 2014 and 2021 from 52 640 tons to 77 182 tons per year. The analyses of MSW show that the share of the organic component is between 17 and 26% (*Najfus, 2021*). Considering the composition of MSW, it can be concluded that MSW contributes largely to the generation of landfill gas.

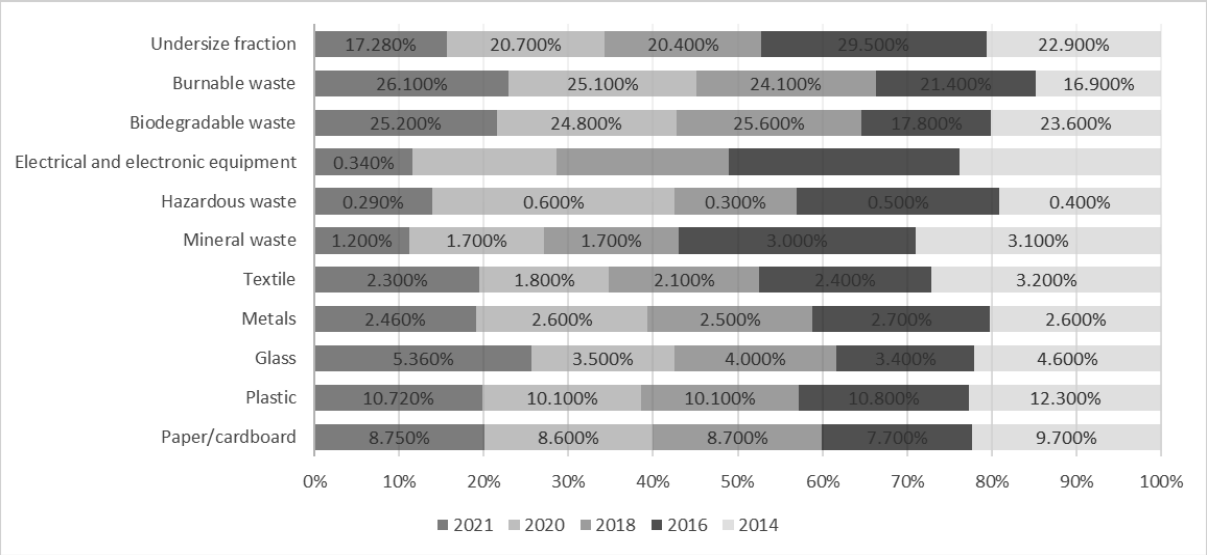

Fig. 3 Average composition of MSW

Fig. 3 shows that the amount of the organic component in the MSW varies between 17 and 26 %. For the years not shown, the composition of the MSW is not provided and the same composition as in the previous year is considered. Table 2 shows the recalculation of the organic component in the MSW.

Tab. 2 Conversion of the organic component in MSW

Compo-nent Year / Amount	2014	2015	2016	2017	2018	2019	2020	2021
					t			
Organic compo-nent in MSW	12 424	12852	10 956	12 132	17 823	18 936	17 911	19 450
Organic compo-nent directly land-filled	101	396	23	34	25	31	21	13
Total organic com-ponent	12 524	13 248	10 980	12 167	17 849	18 967	17 932	19 463

From Table 2 is notable, when the organic component in the MSW is included, the amount of organic material in the landfill is increasing, both as a unit and as a percentage of the total amount. Paper and cardboard have not been included in the organic component due to its unclear chemical composition. Despite the overall increase in the amount of organic material in the landfill, Fig. 4 shows that the amount of landfill gas that is used in the cogeneration unit is decreasing despite the larger amount of organic material. *Sauve and van Acker (2020)* also conclude that the amount of landfill gas decreases with time.

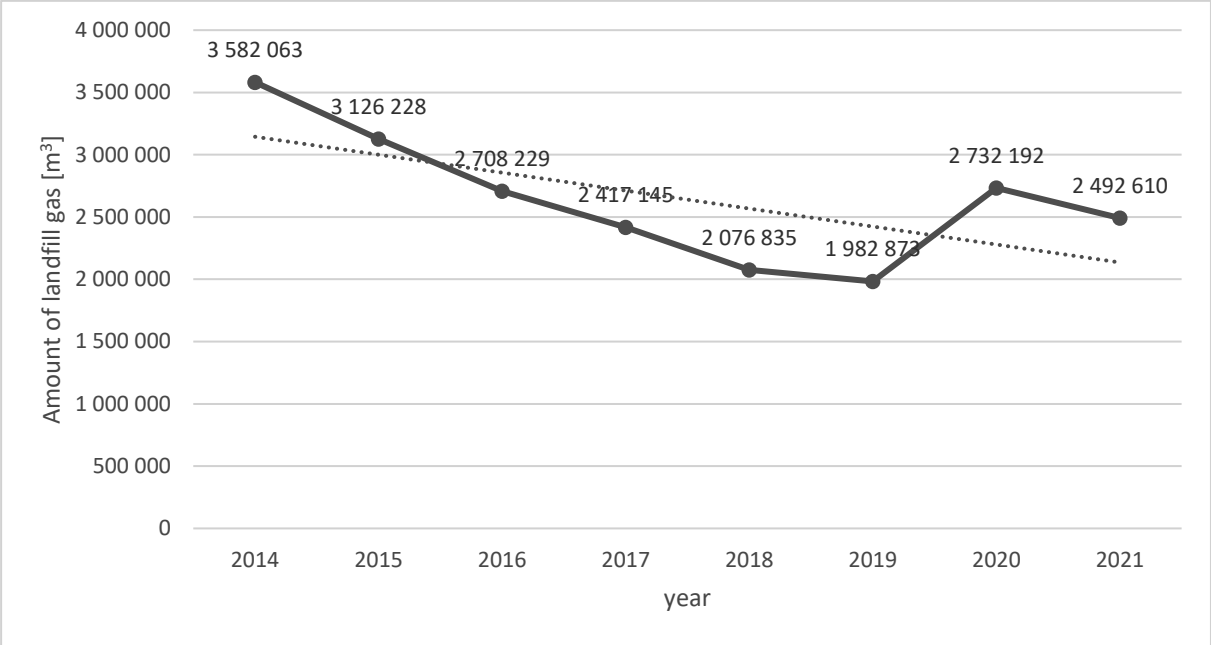

Fig. 4 Gas consumption in the cogeneration unit

CONCLUSIONS

Legislative restrictions on landfilling of organic material, excluding the organic component in MSW, can be seen in Fig. 2. The restriction is mainly due to the development of the collection network for organic waste and the diversion of previously landfilled waste to composting plants. Despite this legislative pressure, the amount of organic material in landfill is increasing, mainly due to increased landfilling of MSW. At the same time, the amount of gas consumption in the cogeneration unit has been decreasing gradually since 2014. The decreasing trend in gas consumption is probably due to the quality of the landfilled organic component. Directly landfilled municipal waste, i.e. waste catalogue numbers 20 02 03 and 20 02 01, consists primarily of an organic component derived from plant production, i.e. grass, leaves, fruit and vegetables. Diversion of these materials from landfill may affect the amount of landfill gas. The organic component contained in the MSW is mainly made up of the living animal component, e.g., food residues, meat, etc. Considering the potential energy and environmental benefits, the use of organic waste in a biogas plant is better than landfilling (*Mavridis & Voudrias, 2021*).
Furthermore, it can be concluded from the results that the amount of landfill gas depends not only on the amount of organic material but also on other parameters such as waste moisture, waste composition, waste age, quality of collection network and compliance with the landfilling procedure (*Duan et al., 2022*). The results show that there is still a large amount of organic component in MSW. Therefore, in the future, it is necessary to develop a collection network for collecting organic waste, food residues such as meat, to reduce the amount of organic waste in MSW.

REFERENCES

1. Cáb, I. S., & ŠEděnková, I. M. (2019, September 3). Rizika vzniku a kumulace hořlavých plynů při skládkovaní odpadů. TZB-info. https://www.tzb-info.cz/pozarni-bezpecnost-staveb/18395-rizika-vzniku-a-kumulace-horlavych-plynu-pri-skladkovani-odpadu
2. Duan, Z., Kjeldsen, P., & Scheutz, C. (2022). Efficiency of gas collection systems at Danish landfills and implications for regulations. Waste Management, 139, 269–278. https://doi.org/10.1016/j.wasman.2021.12.023
3. Friesenhan, C., Agirre, I., Eltrop, L., & Arias, P. L. (2017). Streamlined life cycle analysis for assessing energy and exergy performance as well as impact on the climate for landfill gas utilization technologies. Applied Energy, 185, 805–813. https://doi.org/10.1016/j.apenergy.2016.10.097

4. Jiří Najfus, EKO-KOM a.s. (2021). Rozbory skladby směsného komunálního odpadu z obcí v roce 2020 – EKO-KOM. EKO-KOM a.s. https://www.ekokom.cz/rozbory-skladby-smesneho-komunalniho-odpadu-z-obci-v-roce-2020/
5. Kumar, A., & Sharma, M. (2014). Estimation of GHG emission and energy recovery potential from MSW landfill sites. Sustainable Energy Technologies and Assessments, 5, 50–61. https://doi.org/10.1016/j.seta.2013.11.004
6. Mavridis, S., & Voudrias, E. A. (2021). Using biogas from municipal solid waste for energy production: Comparison between anaerobic digestion and sanitary landfilling. Energy Conversion and Management, 247, 114613. https://doi.org/10.1016/j.enconman.2021.114613
7. Obersky, L., Rafiee, R., Cabral, A. R., Golding, S. D., & Clarke, W. P. (2018). Methodology to determine the extent of anaerobic digestion, composting and CH4 oxidation in a landfill environment. Waste Management, 76, 364–373. https://doi.org/10.1016/j.wasman.2018.02.029
8. Ríos, A. M., & Picazo-Tadeo, A. J. (2021). Measuring environmental performance in the treatment of municipal solid waste: The case of the European Union-28. Ecological Indicators, 123, 107328. https://doi.org/10.1016/j.ecolind.2020.107328
9. Sanjuan-Delmás, D., Taelman, S. E., Arlati, A., Obersteg, A., Vér, C., Óvári, G., Tonini, D., & Dewulf, J. (2021). Sustainability assessment of organic waste management in three EU Cities: Analysing stakeholder-based solutions. Waste Management, 132, 44–55. https://doi.org/10.1016/j.wasman.2021.07.013
10. Sauve, G., & van Acker, K. (2020). The environmental impacts of municipal solid waste landfills in Europe: A life cycle assessment of proper reference cases to support decision making. Journal of Environmental Management, 261, 110216. https://doi.org/10.1016/j.jenvman.2020.110216
11. Sel, L., Çakmakcı, M., Özkaya, B., & Suphi Altan, H. (2016). Case study on prediction of remaining methane potential of landfilled municipal solid waste by statistical analysis of waste composition data. Waste Management, 56, 310–317. https://doi.org/10.1016/j.wasman.2016.07.023
12. Wang, Y. N., Xu, R., Wang, H., Shi, H., Kai, Y., Sun, Y., Li, W., Bian, R., & Zhan, M. (2021). Insights into the stabilization of landfill by assessing the diversity and dynamic succession of bacterial community and its associated bio-metabolic process. Science of The Total Environment, 768, 145466. https://doi.org/10.1016/j.scitotenv.2021.145466
13. Williams, P. T. (2005). Waste Treatment and Disposal. Wiley.
14. Zheng, Q. T., Rowe, R. K., & Feng, S. J. (2018). Design of vertical landfill gas collection wells considering non-homogeneity with depth. Waste Management, 82, 26–36. https://doi.org/10.1016/j.wasman.2018.10.012

Corresponding author:
Ing. Jan Sonsky, Department of Technological Equipment of Buildings, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6, Prague, 16521, Czech Republic, e-mail: sonskyj@tf.czu.cz