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METHODS OF LANDFILL GAS MANAGEMENT. THE CZECH REPUBLIC CASE STUDY

The European legislation sets targets for ending municipal waste to landfill. Despite this Europe-wide trend, almost half of the municipal waste generated in the Czech Republic has been landfilled in recent years. The composition of municipal waste, in particular the high content of biodegradable material, is the reason for landfill gas production. The management of landfill gas is one of the crucial elements of environmental protection in the landfilling process. The article focuses on the comparison of possible ways of landfill gas management at selected landfills in the Czech Republic.

1. INTRODUCTION

Landfills have been a potential source of environmental pollution. The emissions at risk include mainly landfill gas, which has greenhouse gases causing climate change, and landfill leachate, which is a potential threat to groundwater and surface water [1]. Landfilling also results in the loss of land, which cannot be fully used even after the landfill reclamation. Last, but not least, landfilling degrades raw materials that can be used for material or energy recovery [2]. Not only for these reasons, Act No. 541/2020 Coll., on waste, sets out a hierarchy of methods of waste management, where waste disposal, which also includes landfilling, is the least desirable option [3].

The European Union institutions share the same approach to landfilling. However, there have been large differences between the member states of the European Union in terms of the management of municipal waste generated mainly in households, which represents approximately 10% of the total waste generated in Europe. Seven member

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states landfill less than 10% of municipal waste, while eight other member states landfill more than 70% of municipal waste (EU average: 28%). The current Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on landfills introduced a ban on landfilling of separately collected waste and limits the proportion of municipal waste landfilled to 10% by 2030. The Directive is expected to bring economic and environmental benefits such as creating more than 170 000 direct jobs in the EU by 2035; reducing greenhouse gas emissions (more than 600 million tons of CO_2 equivalent between 2015 and 2035); increasing the competitiveness of the EU's waste management, recycling, and manufacturing sectors; minimizing the EU's dependency on import of raw materials and reducing administrative burdens. In addition, the Directive should reduce the environmental and human health impacts described earlier [4].

In 2018, 49% of municipal solid waste was landfilled and only 27% was recycled [5]. In order to adapt to EU regulations, the Czech Republic needs to increase the level of recycling, which is one of the biggest problems and challenges, due to the lack of facilities for material recovery of sorted municipal solid waste components [5].

Although municipal waste landfilling is on the decline (not only due to the above-mentioned legislative steps but also due to the capacity of existing facilities), landfill gas together with landfill leachate emission, which closed landfills produce in smaller quantities, need to be disposed of appropriately.

2. LANDFILL GAS MANAGEMENT IN THE CZECH REPUBLIC

Landfill gas is one of the products of the decomposition processes in landfills. It is mainly caused by the action of microorganisms degrading organic substances present in waste into simpler compounds, with little chemical reactions between the components. Landfill gas is produced by the decomposition of municipal waste, particularly its biodegradable components. The decomposing process has aerobic and anaerobic phases, with landfill gas being generated in the anaerobic phase. The process of landfill gas formation involves four phases, which are hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The production and composition of landfill gas vary depending on many factors such as humidity, pH, type of waste deposited, compaction of waste, and degree of waste decomposition [6]. The main components of landfill gas are methane and carbon dioxide, in varying proportions depending on the stage of the methanogenic process, the age of the landfill, and its depletion. In addition, trace amounts of organic and inorganic compounds such as propionic, acetic, isobutyric, and valeric acids, as well as low molecular weight mercaptans, light aromatic and organosilicic compounds, and traces of sulfate are present in landfill gas [6–9]. The actual composition and quantity of landfill gas can vary significantly in space and time. The main reason why landfill gas is monitored and regulated by legislation and relevant standards is that its main components, methane, and carbon dioxide, are greenhouse gases whose negative effects on the environment are well known; however, methane is much more significant for climate change and therefore its removal from landfill gas is a priority [10, 11].

To reduce the climate change impacts of landfill gas, it must be treated and disposed of. According to Directive 31/1999/EC, landfill gas must be collected from all landfills collecting biodegradable waste and the landfill gas must be treated and recovered. If the collected gas cannot be used for energy production, it must be incinerated. In the Czech Republic, the technical requirements for landfills and conditions for their operation are set out in Decree No. 273/2021 Coll. on Details of Waste Management, [12]. In relation to landfill gas management, this Decree lists several relevant Czech technical standards, the most important of which is the Czech technical standard ČSN 83 8034 (Landfilling of waste – Landfill degasification). This standard specifies the basic categorization of landfills according to the development of landfill gas. Landfills where waste without a biodegradable component is disposed of, are referred to in the standard as gas-free landfills and therefore do not require a degasification system. Landfills with gas production are divided into three classes according to the average volume fraction of methane at a depth of 0.4 m [13].

- Class I includes landfills with an average CH_4 volume fraction at a depth of 0.4 m of lower than 0.074. Class I landfills do not need to operate a degassing system.
- Class II refers to landfills with an average CH_4 volume fraction at a depth of 0.4 m of 0.074–0.35. For landfills in this category, a degassing system is mandatory, but a passive degasification system is recommended. It is not necessary to extract and dispose of landfill gas during active landfilling, provided that the landfill body is kept gas-tight during landfilling by covering it with technical material, and at the same time a gas-tight degasification system is continuously constructed.
- Class III refers to landfills with a high mean volume fraction of CH_4 at a depth of 0.4 m, namely higher than 0.35. Degasification of these landfills is necessary and may be passive or active with conditional use of the gas for energy production.

Passive landfill degasification of the landfill occurs by the landfill gas overpressuring itself. A passive degasification system consists of vertical or horizontal degasification drains (also called wells). These drains carry the landfill gas to a disposal facility, which in the case of passive degasification is an open bed biofilter (also referred to as a compost filter or bio-oxidation filter). Biofilters are an economically acceptable option for landfill gas disposal in the case of active landfills (classes I and II) and in the case of aftercare of a closed landfill [6]. The content of biofilters varies according to the needs of each landfill. Typically, it is a filling of compost and wood chips or mulch bark in varying proportions [6, 14, 15]. If the compost-only filling is used, it is then advised to add an inactive component, such as fine-grained gravel to improve the gas flow in the filling [14]. The disposal of landfill gas in biofiltration units is carried out with the help of microorganisms t naturally present in the filling. The presence of methanotrophic bacteria, which oxidize methane to carbon dioxide and thus reduce the environmental impact of landfill gas is essential. Adequate humidity is important for the proper functioning of the system. Excessive moisture reduces the efficiency of the system. Another factor affecting the efficiency of the biofilter is its temperature, which is not adjusted under normal operating conditions.

Active landfill degasification is defined by the standard as degasification under pressure. The pressure is developed in an external device such as a pumping station, which is connected to the degasification system. The active degasification system is usually terminated by a waste gas disposal facility in the form of flaring or a cogeneration unit that allows the gas to be used for energy recovery in the production of heat and power [17]. If the landfill gas is used for energy recovery, it may be treated due to its content of undesirable impurities. This mainly involves the removal of moisture, H_2S, siloxanes, and other minor components to prevent corrosion and mechanical damage to the cogeneration unit and associated equipment during the long-term combustion of landfill gas [8]. Landfill gas treatment plants are used when the quality of the gas does not meet the requirements set by the manufacturer of the installed cogeneration unit. Most often, landfill gas treatment plants consist of a condensing part to remove moisture and an activated carbon charge to remove other components [18, 19].

Fig. 1. Cogeneration unit

According to earlier research, landfill gas treatment in the Czech Republic is divided into three options [20]. The most common method of landfill gas management is using cogeneration units, i.e., the combustion of landfill gas with energy recovery, which is the most advantageous method of landfill gas management, despite the limitations of landfilling and not establishing new landfills (Fig. 1). This is followed by the use of a biofilter/biooxidation filter (Fig. 2), which is mainly applied in landfills with a small projected capacity, and the least used is the flaring of landfill gas (Fig. 3). In the case of landfill gas recovery using a cogeneration unit, these units are usually operated by an entity other than the landfill operator [20].

Fig. 2. Biofilter

Fig. 3. Landfill gas pumping station and flare

3. CASE STUDY. LANDFILLS IN THE CZECH REPUBLIC

According to earlier research [20], certain landfills were selected as representatives of individual landfill gas management options applied in the Czech Republic. The case study also includes recent changes in landfill gas management. The selected landfills have a medium capacity, i.e., 400 000–1 000 000 m^3, which corresponds to a normal compaction coefficient of 1.35 t/m^3 and a capacity of 540 000–1 350 000 t. The case study uses information publicly available in the IPPC information system and information provided by landfill operators. The final choice of landfills depended on the possibility of obtaining specific information on landfill gas management and, in particular, on the willingness of the operators to cooperate. The geographical location of the landfills is shown in Fig. 4.

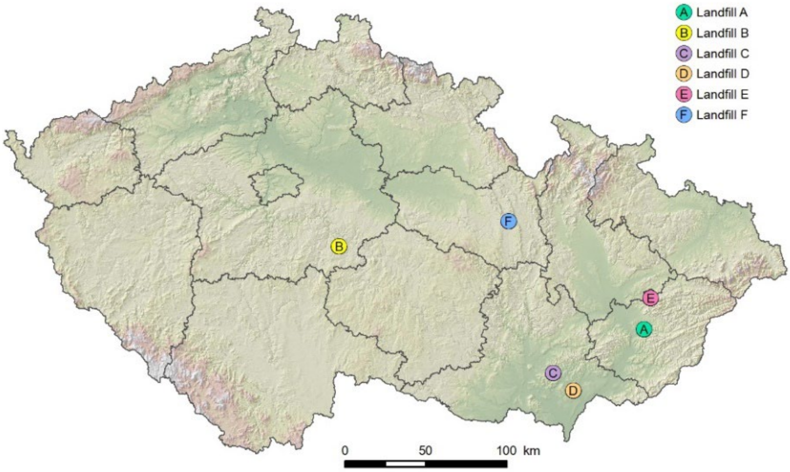

Fig. 4. Geographical location of the selected landfills

3.1. LANDFILL A

Landfill A with a current capacity of 987 827 m^3 is located near the city of Zlín in south-eastern Moravia. There are three different cells of the landfill (Cell I, II, and III). The year of construction and closure of the first cell of the landfill is unknown, the second cell was built in 1997 and closed in 1999. The current third cell was built in 2002 and is still in operation. Cell III consists of eight sections with different capacities (total of 987 827 m^3). Cell III is expected to be closed in 2050.

The management of landfill gas from landfill A is unique since treated landfill gas has been used in the municipal heating plant since 2000. The landfill gas is collected in wells and pumped into pipelines. When the pipeline or the heating plant is out of service, the gas is flared. The landfill gas is treated (dried) and piped through a medium-pressure pipeline to the fluidized bed boiler in the heating plant. The heating plant is operated by an entity other than the landfill operator. The quality of the landfill gas in the wells is monitored twice a year. Averages of landfill gas composition measurements in the degassing wells from 2017 to 2020 are shown in Table 1. The gas composition is also monitored in the landfill body at depth of 0.6 m and 0.4 m below the surface (Table 2). The amount of landfill gas varies. In 2017, 142 358 m^3, in 2018,194 852 m^3, in 2019, 507 123 m^3, in 2020, 582 600 m^3 of gas was extracted.

Table 1

Composition of landfill gas in degasification wells (Landfill A)

Component	Year			
	2017	2018	2019	2020
CH_4, vol. %	32.4	32.7	33.7	33.9
CO_2, vol. %	28.2	28.7	23.5	22.6
N_2, vol. %	31.6	30.9	35.8	36.4
O_2, vol. %	7.9	7.8	7.1	7.1
H_2S, ppm	45.9	15.6	0.0	0.0

Table 2

Composition of landfill gas in a landfill body (Landfill A)

Component	Year			
	2017	2018	2019	2020
CH_4, vol. %	19.9	21.8	14.7	16.6
CO_2, vol. %	17.1	20.3	19.4	19.1
N_2, vol. %	54.3	45.3	51.7	50.5
O_2, vol. %	8.8	12.4	14.3	13.9
H_2S, ppm	4.0	0.0	0.0	0.0

3.2. LANDFILL B

Landfill B with a current capacity of 854 200 m^3 is located in the Central Bohemian Region. The Cell III of Landfill B, currently in operation, is built on the earlier Cell I (built in 1996 and closed in 2010) and Cell II (built in 2003 and closed in 2020). The degassing vertical wells are routed above the surface of the landfill reclamation layers to the top surface of the modified landfill body. The wells are capped at the ends and equipped with a valve for the sampling of landfill gas.

The landfill gas management of landfill B uses landfill gas from all three cells in the cogeneration unit (TEDOM CENTO 160 SP BIO, output 172 kW). The cogeneration unit is run by the landfill operator. The generated electricity is used in the landfill operational facilities and surplus electricity is fed into the grid. The heat produced is not used and is discharged through the cooling system to the cooling collector located on the roof of the cogeneration unit. The gas composition is annually monitored in the landfill body at depth of 0.6 m and 0.4 m below the surface (Table 3). The amount of landfill gas varies. In 2017, 402 100 m^3, in 2018, 444 264 m^3, in 2019, 416 492 m^3, in

2020, 433 361 m^3 of gas was extracted. Electricity production was relatively stable between 2017 and 2020, with an average of approximately 540 000 kWh.

Table 3

Composition of landfill gas in landfill body (Landfill B)

Component	Year			
	2017	2018	2019	2020
CH_4, vol. %	31.4	39.4	29.4	22.6
CO_2, vol. %	38.4	26.2	28.2	19.4
N_2, vol. %	31.1	30.0	39.1	50.6
O_2, vol. %	1.1	4.4	3.3	7.4
H_2S, ppm	428.4	7.0	47.5	107.0

3.3. LANDFILL C

Landfill C with a current capacity of 802 866 m^3 is located in the South Moravian Region. The currently operated Cell II of the landfill is a continuation of the earlier Cell I (built in 1994 and closed in 2011) and was built in 2008, with an expected lifetime until 2033. Between 2017 and 2020, only weak methane leaks with an average of 0.6 $dm^3/(m^2 \cdot h)$ were monitored on the surface of the second stage of the landfill.

The landfill gas management of Landfill C consists of a bio-oxidation filter. The landfill gas moves with the pressure drop towards the exit point (filter), where the gas is dispersed by its own overpressure through the bio-oxidation filter. The filter material consists of a mixture of compost and coke. The gas composition is annually monitored in the landfill body at a depth of 0.6 m and 0.4 m below the surface (Table 4). The amount of landfill gas is not monitored as it is not pumped through the measuring equipment.

Table 4

Composition of landfill gas in landfill body (Landfill C)

Component	Year			
	2017	2018	2019	2020
CH_4, vol. %	31.3	27.9	24.1	20.9
CO_2, vol. %	34.5	35.1	26.8	23.3
N_2, vol. %	32.2	33.0	38.4	47.5
O_2, vol. %	2.1	1.6	5.8	5.9
H_2S, ppm	100.7	253.0	126.0	31.8

3.4. LANDFILL D

Landfill D with a current capacity of 801 736 m^3 is located in the South Moravian Region. The currently operated Cell II of the landfill is a continuation of the earlier Cell I (built in 1994 and closed in 2008), and was built in 2007. In 2022, the operator of the landfill applied for a capacity extension and permission to construct Cell III with a capacity of 138 162 m^3. The whole landfill will increase by one hectare but will remain within the already fenced landfill cell.

The gas wells of Cells I and II are connected to the cogeneration unit (TEDOM CENTO T160 SP BIO NOC CS, output 150 kW) via a drop pipe. The electricity produced is fed to the grid and the heat created is not used and is discharged through the cooling system to the cooling collector.

The cogeneration unit is operated under contract by an entity other than the landfill operator. Based on this contract, the operator of the cogeneration unit pays the landfill operator a proportional share of the earnings from the electricity sold. In the case of Landfill D, there are assumptions about this contractual relationship that the contract is unilaterally beneficial only for the operator of the cogeneration unit and the situation is being addressed by the local authorities.

Table 5

Composition of landfill gas in landfill body (Landfill D)

Component	Year			
	2017	2018	2019	2020
CH_4, vol. %	15.7	16.1	21.5	21.2
CO_2, vol. %	19.4	15.9	13.3	15.1
N_2, vol. %	61.8	62.7	57.4	57.0
O_2, vol. %	3.3	5.4	8.0	6.8
H_2S, ppm	186.2	65.4	63.7	19.1

The gas composition is monitored annually in the landfill body at depth of 0.6 m to 0.8 m below the surface (Table 5). The amount of landfill gas varies. In 2017, 457 151 m^3 of gas was extracted, in 2018, 503 470 m^3, in 2019, 423 489 m^3, in 2020, 391 471 m^3. Electricity production was relatively stable between 2017 and 2020, averaging at about 909 000 kWh.

3.5. LANDFILL E

Landfill E with a current capacity of 720 000 m^3 is located in the Zlín Region. The currently operated Cell III of the landfill continues the earlier Cell I (built in 1996) and Cell II (built in 1998). The projected capacity includes the planned stages, but even so, the lifetime of the landfill is assumed to the year 2025. No landfill gas management is applied at this time. According to the technical report of the landfill biogas investigation, the average CH_4 volume fraction at a depth of 0.4 m was 0.060 in 2019, 0.215 in 2020, and 0.305 in 2021. These measurements correspond to category I landfill in 2019, and category II in 2020 and 2021, but according to the possibility of not using any landfill gas management system during active landfilling (category II landfill), the absence of a passive degasification system is also available. The gas composition is monitored in the landfill body at depth of 0.6 m to 0.8 m and 0.4 m below the surface (Table 6).

Table 6

Composition of landfill gas in a landfill body (Landfill E)

Component	Year			
	2017	2018	2019	2020
CH_4, vol. %	22.3	14.5	18.2	23.4
CO_2, vol. %	23.8	20.3	25.3	30.0
N_2, vol. %	46.5	58.8	50.0	45.2
O_2, vol. %	7.5	6.4	6.5	1.4
H_2S, ppm	50.6	136.3	36.6	36.9

3.6. LANDFILL F

Landfill F with a current capacity of 442 798 m^3 is located in the Pardubice Region. Landfill F includes 11 cells, the first one was already built in 1992, seven cells are closed, two are currently operated and the last two cells are planned. Although this landfill differs from earlier examples in having a lower capacity, it is the largest landfill to use simple combustion of landfill gas with a flare. The installed system consists of a pumping station and a VTP 600/50 flare, which is 5.5 m high. The flare is a self-supporting, the vertical combustion chamber of steel construction, hot-dip galvanized. It is a steel casing with ceramic fiber insulation up to a temperature of 1250 °C. The assembly of the torch and the ignition burner is controlled and secured automatically by a UV probe and electromagnetic valves. The flame ignition of the control burner is controlled automatically. The combustion of biogas occurs only in the combustion chamber, therefore the flame itself is practically invisible. Due to the residence time of the flue gas in the combustion chamber at a temperature of 1200 °C, its composition complies with the requirements of the regulations and standards of the Ministry of the Environment of the Czech Republic.

Table 7

Composition of landfill gas in a pumping station (Landfill F)

Component	Year			
	2017	2018	2019	2020
CH_4, vol. %	38.5	48.0	56.6	49.8
CO_2, vol. %	30.2	29.0	37.5	37.5
N_2, vol. %	0.0	1.9	0.6	0.4

The monitoring of the gas composition in the pumping station in 2017–2020 is presented in Table 7. The gas composition is also monitored in the landfill body at a depth of 0.6–0.8 m below the surface (Table 8). The amount of extracted landfill gas varies.

In 2017, 78 762 m^3 was extracted, in 2018, 109 041 m^3, in 2019, 204 191 m^3, in 2020, 334 974 m^3.

Table 8

Composition of landfill gas in landfill body (Landfill F)

Component	Year			
	2017	2018	2019	2020
CH_4, vol. %	37.1	43.6	42.0	42.0
CO_2, vol. %	26.4	28.1	26.3	29.6
N_2, vol. %	34.4	23.6	26.4	25.1
O_2, vol. %	2.1	2.6	5.4	2.9

The landfill gas monitoring in the body of all landfills was conducted using bar punch probes. For landfills B, C, D, and E, monitoring was carried out by the same company using a BIOGAS5000 portable gas monitor. Landfills A and F were monitored by different companies, but in both cases, the same GA5000 portable gas monitor was used for the analyses. In the period 2017–2020, landfill gas monitoring at each landfill was carried out by the same companies. The monitoring of biogas quality and quantity at the filling stations, if performed, is done by online analyzers that are part of the filling stations.

4. CONCLUSION

In the Czech Republic, landfilling is a commonly used technique for municipal waste disposal. The legislation of the Czech Republic obliges landfill operators to manage landfill gas, which is one of the emissions generated by landfilling. Landfills in the Czech Republic are divided into three categories according to the amount of methane detected at a depth of 0.4 m, two of which require passive or active landfill degasification.

The selected medium-capacity landfills were evaluated in terms of landfill gas management and composition. All the landfills surveyed were constructed in the last 25 years, and the cells where waste is currently disposed of are less than 20 years old, therefore a gradual decrease in gas production can be expected due to the age of the landfills. The composition of the landfilled waste also plays a large role in the quantity and quality of landfill gas.

Overall, the composition of landfill gas in terms of methane content does not differ much in all monitored landfill, though landfill operators have been using different types of landfill gas management. The economic feasibility together with an assessment of the amount of landfill gas produced/removed is crucial for the choice of landfill gas management technology.

The amount of landfill gas is monitored only in the case of the installation of a pumping station (landfills A, B, D, F). The available information shows that the composition of the landfill gas at landfill F, which currently incinerates gas without recovery, in terms of quality and quantity, allows combustion for electricity generation, but only in the last two years. It cannot be assumed, however, that the installation of a cogeneration unit would be worthwhile given the overall minimum capacity of the entire landfill and therefore its lifespan. The operation of a cogeneration unit requires the training of personnel and usually an external specialist in case of equipment failure. This can be an unnecessary burden for some landfill operators because the cogeneration unit is often operated by an external company under contract. In the case of Landfill D, where the cogeneration unit is operated as described, the contractual relationship is currently being reassessed due to a possible disadvantage for the landfill operator, as a producer of fuel for the cogeneration unit.

Landfill C produces gas with a sufficient amount of methane for theoretical use, but due to the absence of information on the amount of gas, it cannot be determined whether its use in a cogeneration unit would be economically beneficial.

Landfill E has not yet installed any landfill gas management systems, although a sufficient mean volume fraction of CH_4 at 0.4 m depth has been confirmed in the last two years to place the landfill in Category II with an obligation to use a degasification system. This landfill, however, benefits from the exception specified in the Standard not to extract and dispose of landfill gas during active landfilling, provided that the landfill body is kept gas-tight during landfilling by covering it with technical material and at the same time a gas-tight degasification system is continuously constructed.

In landfill A, the landfill gas is used for energy recovery in the heating plant. Considering the CH_4 content, which is consistently around 33%, incineration in the boiler of the heating plant seems to be the ideal technological solution for landfill gas management in the current energy crisis. However, it is more likely, that based on the toughening legislation regarding the management of biodegradable waste and composition of waste disposed of in landfills, the landfills will fall into categories I or II according to the Czech Technical Standards ČSN 83 8034.

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