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Research Article

EMISSION ASSESSMENT AT THE ŠTĚPÁNOVICE MUNICIPAL SOLID WASTE LANDFILL FOCUSING ON CH_4 EMISSIONS

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ABSTRACT

The study was conducted to measure the emission from landfill in the years 2005–2011. The results are used to diagnose the emissions of CH_4. The mean value of CH_4 in vol. % in the collection wells ranged from 0 to 2.14 vol. % the mean concentration of CH_4 in mg/m^3 ranged from 0 to 25 251 mg/m^3, the average concentration of CH_4 in mg/Nm^3 at the measuring and control points ranged from 2.2 to 24.1 mg/Nm^3. CH_4 emissions from the landfill do not exceed the reporting thresholds the landfill does not meet conditions for being included in the Integrated Register of Pollutants.

INTRODUCTION

Human activity increases the concentration of greenhouse gases (GHGs) in the atmosphere. This is expected to result in a significant warming of the Earth's surface and other associated changes in climate within the next few decades. The GHGs that are making the largest contribution to global warming are CO_2, CH_4, and N_2O. All three are produced during the management and disposal of wastes [Pikoń and Gaska 2010].

Among the efforts to slow the potential for climate change are measures to reduce emissions of CO_2 from energy use, decrease emissions of CH_4 and other non-CO_2 GHGs, and promote long-term storage of carbon in forests and soil. Management options for municipal solid waste (MSW) provide many opportunities to affect these processes, directly or indirectly. Many attempts were made during recent years to assess the impact on climate change of MSW management systems [Pikoń and Gaska 2010].

Land degradation caused by human activities creates significant adverse effects on the environments and ecosystems worldwide [Thomaz and Luiz 2012, Bai et al. 2013, Li et al. 2013, Chen et al. 2015, Adamcová et al. 2016] and solid waste is an important and emerging environmental problem. It was estimated that 0.5–4.5 kg of solid waste per person per day is produced in different regions of the world [Bakare et al. 2005, Swati et al. 2014, Adamcová et al. 2016]. The most common ways to manage such waste disposal are landfills and incinerators. Actually, up to 95% total municipal solid waste (MSW) collected is disposed of in landfills worldwide [El-Fadel et al. 1997, Swati et al. 2014, Adamcová et al. 2016] and landfilling is the major MSW disposal method used in modern cities [Wong et al. 2015, Adamcová et al., 2016].

MSW landfills have been identified as one of the most important anthropogenic sources of CH_4 emission [Trapania et al. 2013, Ishigaki et al. 2005, Aronica et al. 2009, Lou and Nair 2009]. Indeed, MSWs contain a certain amount of biodegradable organic matter which undergoes anaerobic degradation resulting in the production of the so called landfill gas (LFG), which main component is typically represented by CH_4 [Trapania et al. 2013, Huber-Humer et al. 2009].

Atmospheric CH_4 concentrations have more than doubled during the past 100 years and con-

tinue to rise [El-Fadel et al. 2012, Zhang et al. 2008] with landfills being amongst the largest anthropogenic sources [[El-Fadel et al. 2012, Mackie and Cooper 2009] contributing up to 30% of total CH_4 emissions [Ishigaki et al. 2005, Mackie and Cooper 2009, Borjesson et al. 2000, Spokas et al. 2003, Abichou et al. 2006, Thompson et al. 2009]. With population growth and urbanization, landfills will remain a serious source of atmospheric CH_4, unless recovery control systems are implemented [El-Fadel et al. 2012]. Moreover, CH_4 has been recognized as one of the most significant contributor to global warming [El-Fadel et al. 2012, IPCC 2007], since it more effectively adsorbs infrared radiation than CO_2. In order to minimize its negative effects on the environment as well as to provide an alternative method for energy recovery from wastes compared to others [Messineo and Panno 2008, Messineo et al. 2012], LFG recovery is a suitable tool to effectively control CH_4 emissions from a landfill site to the atmosphere [Lohila et al. 2007]. Bearing in mind this consideration, the measurement of CH_4 emissions may represent a good way to evaluate the effectiveness of LFG recovering systems [Scheutz et al. 2009].

However, up to now few measurements of landfill CH_4 emissions have been reported, due to the heterogeneity of waste composition and temporarily landfill surface covering systems, which give high spatial variability of LFG emissions from the landfill surface as a result [Trapania et al. 2013].

Generally, two different approaches exist in order to evaluate CH_4 emissions [Sharff and Jacobs 2006]: (1) an indirect calculation based on a straightforward mass balance equation between LFG production, recovery and oxidation in the landfill and (2) a direct approach based on LFG emission measurement from the landfill surface.

It is important to point out that landfill emissions are often based on estimates of CH_4 production applied to the amount of disposed wastes at a given territorial scale [Trapania et al. 2013, Scheutz et al. 2009]. Consequently, emissions are evaluated by means of an indirect calculation based on a straightforward mass balance equation between CH_4 production, recovery and oxidation in the landfill [Sharff and Jacobs 2006]. Contrarily, the approach based on direct measurements of emissions from the landfill surface is often neglected [Capaccioni et al. 2011].

Our research team has been involved in the investigation of environmental problems of pollutants produced and released from landfill facilities. As part of such research efforts, a preliminary study was conducted to measure the emission concentrations from MSW landfill S-OO3 Štěpánovice. Measurements were carried out in the years 2005–2011. In the present study, the central aim was to highlight the importance and the effectiveness of direct measurements in order to evaluate the overall CH_4 emission from a landfill, which can aid to improve landfill operations and management. The individual components of LFG were examined separately due to the scope of available data.

EXPERIMENTAL

The investigated landfill (Štěpánovice, 49°26'15.934"N, 13°16'55.352"E, ca. 405 m) is located in Pilsen Region, western part of the Czech Republic, 1 km north of Štěpánovice commune and 1 km south of Dehtín commune. It started operating during 1996 with an authorized volume of 569 000 m^3 at the moment, it is used to dispose mixed municipal waste. The landfill is formed by three sub-landfills: landfill A (closed in 2003, area 8750 m^2); landfill B (working from 2003, area 26000 m^2); landfill C (that will work after closing part B). The total volume of both (A, B) parts of the landfill is 289000 m^3. Planned service life of the facility is up to year 2018 [Vaverková and Adamcová, 2014a, Vaverková and Adamcová, 2014b, Adamcová et al., 2016].

Every day, up to 37.5 tonnes of waste is authorized for landfilling after careful analysis: the disposed waste includes municipal solid, non hazardous wastes and the material for landfill cover. Wastes may include scraps of paper, plastics and metals, packing, spent tires, textile products, building materials, ashes from municipal solid waste incinerators, polluted terrain from environment reclamation, etc.

The landfill site is located over an impermeable natural clay layer. Bottom and side boundaries may vary according to the period of cultivation, however, they generally include several protective layers, such as a compact clay layer (100 cm), geotextile membranes, gravel (50 cm), geomembranes (2.5 mm) non-woven fabric (1200 g/m^2), pulper products (50 cm) [Vaverková and Adamcová, 2014a, Vaverková and Adamcová, 2014b, Adamcová et al., 2016].

Landfill covers (top and side) are formed by a waste layer (terrain) to stabilize the surface, drainage systems, compact clay (20 cm), soil bentonite and a vegetative soil layer (up to 100 cm). A grassy mantle and/or forestation with local vegetation will complete the recovery of the environment after closing each parcel. Systems for leachate treatment, and gas recovery, collection and treatment are in operation. The landfill is situated in the north part of widely opened valley directed towards W-E. The landfill is surrounded to the N and S by a vegetation belt dominated by *Pinus sylvestris*. The hilly landscape in the western part of the study area is used for agriculture, as well as the eastern lowland. The climate of the area is typically inland, with mean annual rainfall over 582 mm and mean annual temperature of 8.0°C (maximum 32.3°C and minimum -4.5°C during the reporting period) [Vaverková and Adamcová, 2014a, Vaverková and Adamcová, 2014b, Adamcová et al., 2016].

In total 323 913 tonnes of waste were placed into the MSW landfill Štěpánovice between 1996 and 2011, of which 67 141 tonnes amounted to biodegradable waste. The development of the volume of waste to be deposited, with focus on the amount of biodegradable waste, is illustrated in the following figure (Figure 1).

Gas management of the MSW Štěpánovice landfill is performed by vertical and horizontal systems. Vertical system is created by special well at the bottom of the landfill. Along with growing weight of waste the well continuously lengthens thanks to sliding arms with diameter of 600–1000 mm. Through the centre of each well runs a perforated pipe HDPE DN 100–200 covered with aggregate fraction 35/64. Wells that are placed in clips of 40×40 m up to 60×60 m are sealed with cover in order to prevent the flow of landfill gas into the air. The cover prevents the air to enter the landfill site and its mixing with landfill gas (risk of explosive compound). Horizontal gas management is created by perforated pipeline placed in horizontal layers with 5 and 10 meters distance. Pipeline is run parallel in distance of 20–30 cm and with incline of minimum 2% (more optimal incline is considered 5–7%).

MONITORING THE CH_4 CONCENTRATION IN LANDFILL GAS

When biodegradable waste is disposed to a landfill, the quality and quantity of landfill gas within the landfill body is monitored. Since this kind of waste is stored at the MSW Štěpánovice landfill, the obligation to monitor landfill gas applies.

The methods of monitoring LFG provides the Czech National Standard ČSN 83 8034. Typical landfill gas composition as stated in the Czech National Standard ČSN 83 8034 is shown in Table 1. More detailed information regarding the monitoring process of landfills in the Czech Republic is provided in the Czech National Standard ČSN 83 8036.

Parameters monitored in analyzing the landfill gas are CH_4, CO_2, O_2 and atmospheric pressure. This paper focuses only on monitoring the concentration of CH_4 occurring in the landfill gas generated at the MSW landfill in Štěpánovice.

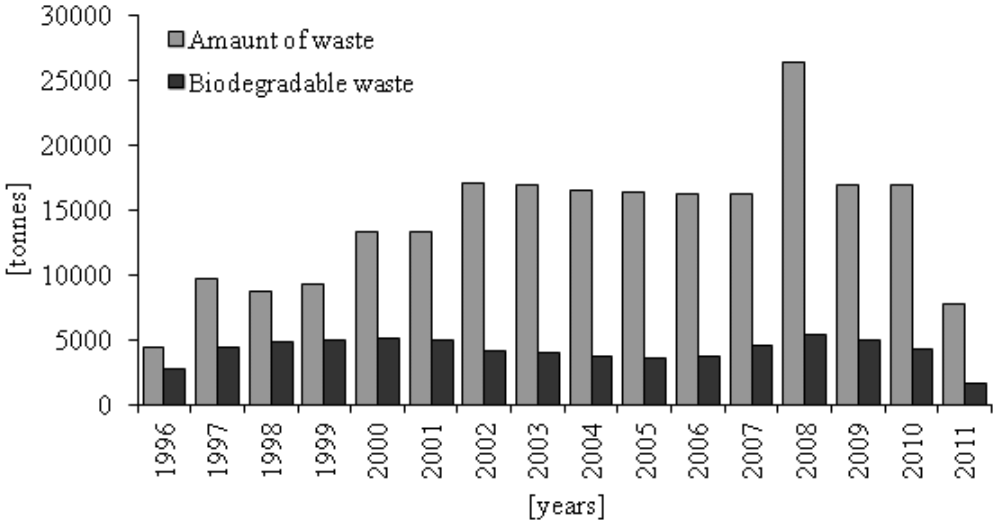


Figure 1. The volume of waste placed into the MSW landfill Štěpánovice between 1996 and 2011

Table 1. Composition of landfill gas (stabilized methanogen phase, anaerobic environment, static state) pursuant to the Czech National Standard ČSN 83 8034 (ČSN 83 8034, p.19)

Components		Typical values	
Name	Code	vol. %	mg/m^3
Methane	CH_4	60 to 64	-
Carbon dioxide	CO_2	30 to 36	-
Oxygen	O_2	0	-
Nitrogen	N_2	0 to 3	-
Hydrogen	H_2	0.0 to 0.05	-
Carbon monoxide	CO	0	-
Hydrogen sulphide	H_2S	-	0.1 to 5.0
Nitric oxide	N_2O	0.0 to 0.2	-
Organically bound halogens	-	-	20 to 60

The research aimed at observation of the development of LFG emissions (CH_4 emissions) at fixed time intervals was carried out in the period from 2005 to 2011. In general, the composition of LFG is determined from samples obtained from facilities of degasification and drainage systems, alternatively from monitoring wells in the landfill body or from surrounding area.

The LFG was sampled on specified measuring sites and control points. Their location and number were defined by laboratory accredited for measuring emissions. The allocation of measuring and control points for CH_4 emissions at the MSW Štěpánovice landfill is illustrated in Figure 2.

In total there are 29 measuring points in the area of the MSW landfill in Štěpánovice that served for measuring LFG concentrations. The measuring points were established within a rectangular network of 25 × 30 m, altogether 25 measuring points. The other four measuring points (collection wells) were located around the accumulation sump (measuring points 1 and 3 are located 20 m from the sump centre, measuring points 2 and 4 were located 12 m from the sump centre).

The LFG samples are collected in the period of most favorable conditions for microorganisms to produce the landfill gas. The condition is that outdoor temperatures must not fall below 5°C. The samples were taken twice a year. Measuring the concentrations of CH_4 on the surface of the landfill in the reported period (2005-2011) was carried out by company SANTEO Ltd., which is authorized for measuring emissions.

RESULTS AND DISSCUSION

Measured concentrations of CH_4

LFG is a gas that is produced from waste deposited in a landfill by biodegradation processes, as well as gas arising biotically in landfills. The composition and measuring amount of emerging gas depends on the composition of waste, the age of waste, waste moisture and the changes thereof, the degree of compaction of waste, the pH of water environments at landfill, the achievable degree of anaerobization, the presence of inhibitors or substances toxic to microorganisms, on the technology of waste disposal, the method and rate of waste transport, etc. The measured concentrations of CH_4 in vol. % in the collection wells (collection

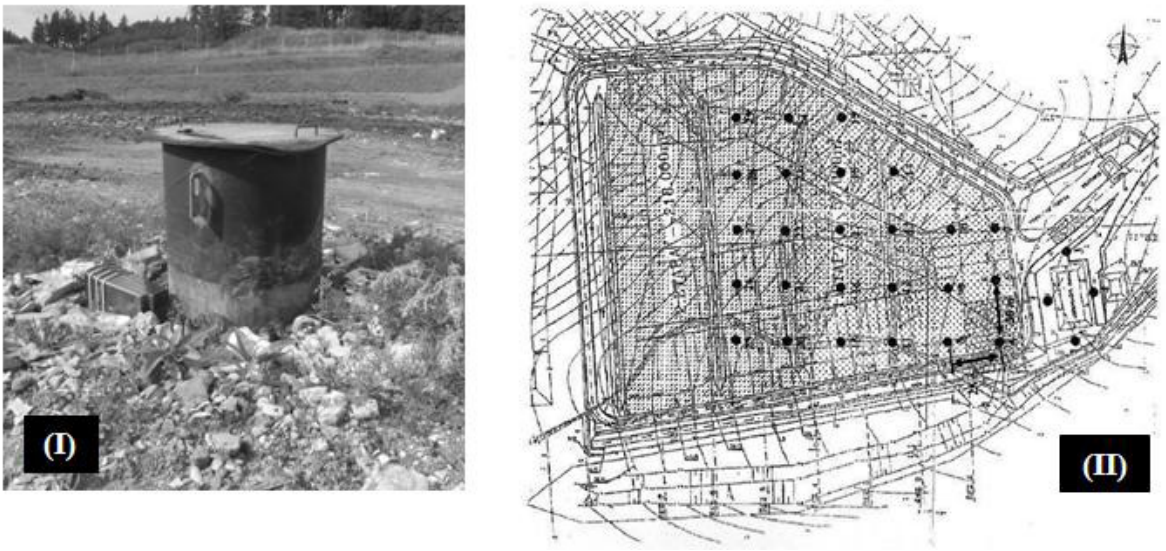


Figure 2. Collection wells (I), scheme of sites measuring CH_4 at MSW Štěpánovice landfill (II)

wells 1,2,3 and 4) and the mean values of CH_4 in vol. % at the measuring points in the period 2005-2011 are shown in Figure 3.

In the years 2005–2011 the mean value of emissions of CH_4 in vol. % in the collection wells (1,2,3 and 4) ranged from 0 to 2.14 vol. %. The production of CH_4 emissions in these measuring points was low. The highest average figure of CH_4 emission was measured on 6 October 2008 and amounted to 2.14 vol. %. The lowest mean values (0 vol. %) were observed in the period from 25 October 2005 to 8 June 2006. The highest emissions of CH_4 in vol. % was showed by collection well no. 3. It can be stated that the highest emission rates of CH_4 in vol. % from all four collection wells were monitored in the period from 27 May 2008 to 6 October 2008.

The Czech National Standard ČSN 83 8034 divides landfills with proven generation of landfill gas into three classes, based on the intensity of its production, namely according to the measured values (in vol. %) of CH_4 concentration at a depth of 0.6 m. The parameters in line with the Standard are listed in Table 2.

Based on the results of CH_4 emissions measurement the MSW Štěpánovice landfill is categorized into Class I, whereby neither degasification/degasification system nor energetic use of gas is necessary.

If subsequent research of the development of LFG at the landfill body confirmed generation of CH_4 emissions, the mean concentrations of which exceeded the threshold for Class I, the LFG would require utilization or disposal by passive degasification system. In case of crossing the boundary values of Class II, the LFG would require utilization or disposal by passive or active degasification system.

The measurement of CH_4 emissions in mg/m^3 was realized in the same time period as the measurement of CH_4 in vol. %. The measurement was carried out twice a year, by means of identical company that carried out the measurement of CH_4 in % vol. The obtained results are demonstrated in the following figure (Figure 4).

In the years 2005–2011 the mean concentration of CH_4 emissions in mg/m^3 in the collection wells (1,2,3 and 4) ranged from 0 to 25 251 mg/m^3. The production of CH_4 emissions at these measuring points was low. The highest average CH_4 emission figure was measured on 27 September 2007 and amounted to 25 251 mg/m^3. The lowest mean values (0 mg/m^3) were recorded in the period from 25 October 2005 to 8 June 2006. The highest CH_4 emissions in mg/m^3 was showed by collection well no. 3. It can be stated that the highest CH_4 emissions in mg/m^3 from all four collection wells were observed in the period from 27 September 2007 to 6 October 2008.

Samples from the remaining 25 measuring points were taken at the same time intervals as CH_4 emissions measurements took place in the collection wells. These measuring points are located at regular distances within the landfill

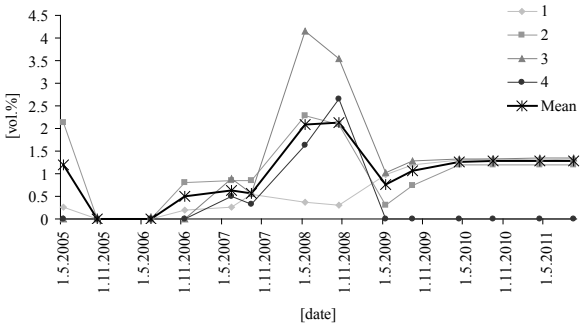


Figure 3. Concentration of CH_4 in volume percentage – the collection wells in 2005–2011

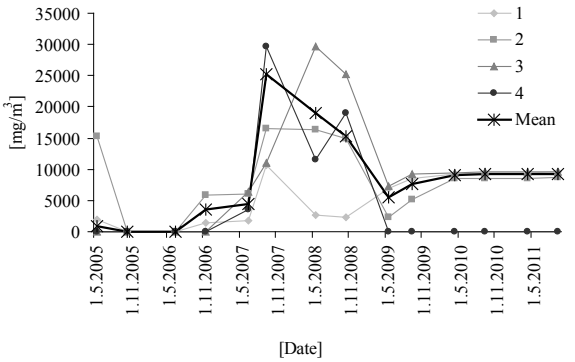


Figure 4. Figures of CH_4 in mg/m^3 – collection wells in 2005–2011

Table 2. Classification of landfills according to the ČSN 83 8034

Class	Degasification	Medium concentration at depth of 0,6 m	Degasification system	Energetic use of gas
I.	Not necessary	< 7.4 vol. %	None	None
II.	Necessary	7.4-35 vol.%	Passive	None
III.	Necessary	> 35 vol.%	Passive or active	Conditionally possible

body (Figure 2). The following statistical values were calculated on the basis of the obtained values of CH_4 emissions: the mean CH_4 concentration [mg/Nm^3], median [mg/m^3], the minimum value [mg/m^3] and the maximum value [mg/m^3]. For better clarity these data were recorded in graph (Figure 5).

In the years 2005–2011, the average concentration of CH_4 emissions in mg/Nm^3 at measuring and control points (25 control points) ranged from 2.2 to 24.1 mg/Nm^3. The production of CH_4 emissions at the measuring and control points was low. The highest average CH_4 emission figure at the measuring and control points was recorded on 25 May 2009 and amounted to 24.2 mg/Nm^3. The lowest average values (2.2 mg/Nm^3) were recorded in the period between 4 May 2005 and 25 October 2005. The highest generation of CH_4 emissions in mg/Nm^3 from all collection and measuring points was observed in the period from 23 September 2010 to 22 September 2011.

For the purpose of reporting threshold and in accordance with the conditions for entering the Integrated Register of Pollutants, measurements were taken of CH_4 hourly mass flow in kg in the years 2005-2011. The measurements were taken from the collection wells (1,2,3 a 4). Based on the measured values annual mass flow in kg was determined. The data obtained from the collection wells are shown in Table 3.

Reporting thresholds for CH_4 emissions following out from Annex no. 1 to the Government Regulation no. 368 of 1 October 2003 on the Integrated Register of Pollutants as amended, are presented in Table 4.

The annual amounts of CH_4 emissions released into air from the Štěpánovice MSW landfill in 2005 (52 411.08 kg), 2006 (17 283.48 kg), 2007 (22 898.64 kg), 2008 (68 292.97 kg), 2009 (23 748.36 kg), 2010 (42 880.20 kg) and 2011 (32 324.40 kg) did not exceed the limit stipulated by valid legislation (annual emission into air of 100 000 kg CH_4 emissions). The measured data indicate that the Štěpánovice MSW landfill does not exceed the reporting threshold limit and does not meet the conditions for being registered in the Integrated Register of Pollutants.

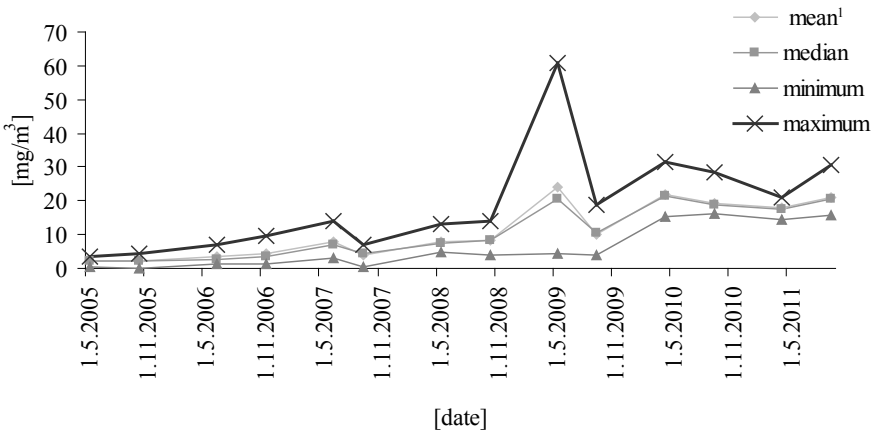
Table 3. Sum of CH_4 emissions from the collection wells

Year	Mass flow per hour [kg]	Number of hours[1]	Total annual amount [kg]
2005	5.983	8760	52 411.08
2006	1.973	8760	17 283.48
2007	2.614	8760	22 898.64
2008	7.796	8760	68 292.97
2009	2.711	8760	23 748.36
2010	4.895	8760	42 880.20
2011	3.69	8760	32 324.40

[1] The number 8 760 is used by accredited laboratory also in case of non-leap year

The same situation was observed in case of CO_2 emissions. The Štěpánovice MSW landfill in the monitored years 2005–2011 did not exceed the reporting threshold limit, thus it did not meet the conditions for being registered in the Integrated Register of Pollutants.

It is difficult to determine the composition (concentration) of LFG based on the composition of the input waste, especially because specific conditions occur and there are interactions of the landfilled waste during the process of decomposition, the influence of which on the emerging LFG is still unclear.



[1] Measurement value under normal conditions at 0 °C, sometimes this physical condition is referred to as mg/Nm^3.

Figure 5. Figures of CH_4 emission concentrations in mg/m^3 at measuring points in the landfill body in 2005–2011

Table 4. Reporting thresholds for CH_4 emissions according to Integrated Pollution Prevention and Control (IPPC)

CAS no.*	Reported substance	Annual emissions into atmosphere [kg]	Annual emissions into water [kg]	Annual emissions into soil [kg]	Reporting threshold outside the operation [kg.year^{-1}]
74-82-8	Methane (CH_4)	100 000	-	-	-

* CAS no. – Chemical Abstract Service Registry Number

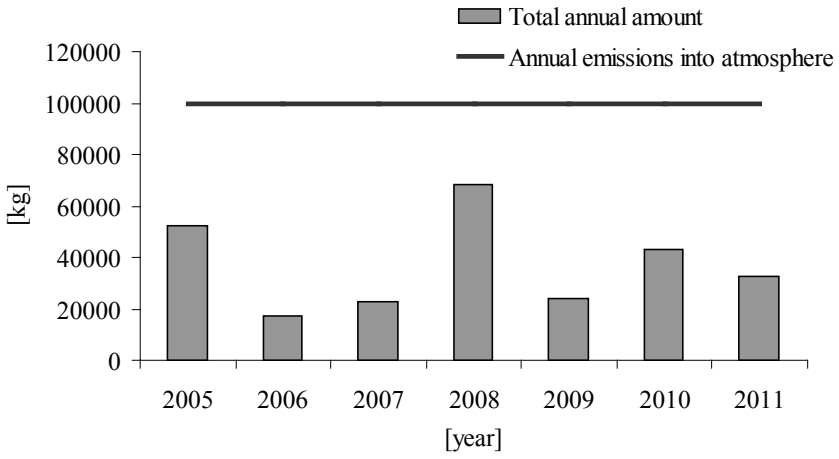


Figure 6. Annual mass flow in kg – collection wells in 2005–2011

SUMMARY

Landfills are an important element of waste management, both today and in the future. The complexity of landfills is increasing and there are many aspects which may affect emissions to air, which are poorly documented today. There is a need to develop better practices with regard to operation and emission control, in particular to better adapt the techniques to different waste materials [Fischer et al. 1999].

As mentioned in literature [Pikoń and Gaska 2010, Trapania et al. 2013, Ishigaki et al. 2005, Aronica et al. 2009, Messineo and Panno 2008, Lohila et al. 2007], the landfill may be a potential source of air pollution, specifically of CO_2, CH_4 and similar emissions, which are the most frequent subject of research. The quantity of landfill gases depends on the properties of waste (composition and age) and multiple environmental factors (oxygen content, humidity, temperature).

The main aim of this study was to evaluate CH_4 emissions based on direct measurements. Direct measurement method was found to be reliable and easy to use. The subject of the research was realized between 2005 and 2011. The annual sum of CH_4 emissions was measured in the period 2005–2011. In the years 2005–2011 the mean value of emissions of CH_4 in vol. % in the collection wells (1,2,3 and 4) ranged from 0 to 2.14 vol. %. In the years 2005–2011 the mean concentration of CH_4 emissions in mg/m^3 in the collection wells (1,2,3 and 4) ranged from 0 to 25 251 mg/m^3. In the years 2005–2011 the average concentration of CH_4 emissions in mg/Nm^3 at the measuring and control points (25 control points) ranged from 2.2 to 24.1 mg/Nm^3. The production of CH_4 emissions in the collection wells and at the measuring and control points alike was low. The annual amounts of CH_4 emissions released into air from the MSW Štěpánovice landfill in 2005 (52 411.08 kg), 2006 (17 283.48 kg), 2007 (22 898.64 kg), 2008 (68 292.97 kg), 2009 (23 748.36 kg), 2010 (42 880.20 kg) and 2011 (32 324.40 kg) did not exceed the limit stipulated by valid legislation (annual emission into air of 100 000 kg CH_4 emissions).

The measurement results indicate that the concentration of CH_4 emissions and the annual sum of these emissions emanated from the MSW Štěpánovice landfill do not exceed the reporting thresholds and therefore, the landfill does not meet conditions for being included in the Integrated Register of Pollutants. Thus, in line with the legislation, the landfill operation is not considered as a source of CH_4 GHGs. However abstracting from the legal requirements, the landfill can be considered a possible source of CH_4 emissions.

A development of this study will regard more intensive survey all year round, in order to evaluate seasonal variations of CH_4 emissions and to validate the results obtained in the present study.

Based on the monitoring outcomes as well as biomonitoring of the MSW Štěpánovice landfill it can be stated that the production of LFG is not a significant factor influencing the nearest surroundings of the landfill.

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