Environment Protection Engineering

Vol. 41 2015 No. 1

DOI: 10.5277/epe150109

MAGDALENA VAVERKOVÁ[1], DANA ADAMCOVÁ[1]

EMISSION ASSESSMENT AT THE ŠTĚPÁNOVICE MUNICIPAL LANDFILL FOCUSING ON CO_2 EMISSIONS

Emission concentrations from the landfill Štěpánovice have been examined. Measurements were carried out in the years 2004–2011. The results of the study were used to diagnose the emissions of CO_2 as important landfill gas components. They indicate that the concentration of CO_2 emissions and the annual sum of these emissions do not exceed the reporting thresholds and therefore, the landfill does not meet conditions for being included in the integrated register of polluters.

1. INTRODUCTION

In accordance with the Intergovernmental Panel of Climate Change (IPCC), one of the most important threats to wellbeing of human civilization is climate warming due to anthropogenic emission of greenhouse gases [1]. Climate warming is an inevitable and urgent global challenge with long-term implications for the sustainable development of all countries. Warming of climactic system is expected to impact the availability of basic necessities like freshwater, food security, and energy. The Earth's average surface temperature has increased by 0.76 °C since 1850. The IPCC projects that, without further action to reduce greenhouse gas emissions, the global average surface temperature is likely to increase by a further 1.8–4.0 °C this century. Even the lower end of this range would take the temperature increase since pre-industrial times above 2 °C, the threshold beyond which irreversible and possibly catastrophic changes become far more likely [1].

Global climate caused by increasing concentrations of atmospheric carbon dioxide is one of the most significant threats facing the world today [2]. Human activities that contribute to climate change include in particular burning of fossil fuels, agriculture

[1]Department of Applied and Landscape Ecology, Faculty of Agronomy, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic, corresponding author M. Vaverková, e-mail: magda.vaverkova@uake.cz

and land-use changes like deforestation. These cause emissions of greenhouse gases (GHG) remaining in the atmosphere for many decades and trapping heat from the sun in the same way as the glass of a greenhouse. To bring climate change to a halt, global GHG emissions must be reduced significantly. Therefore, there is urgent need to decrease emission of GHG to mitigate climate warming. The most important is reduction of CO_2 emission [1].

The magnitude of the landfill gas contribution to the greenhouse effect have been uncertain, and the subject of some debate. But, as time goes on, the evidence becomes stronger, and the fact of climate change is now accepted by the vast majority of scientists working in this field. Thus, it appears that landfill gases make an important net contribution to the greenhouse phenomenon. Therefore better understanding of formation of landfill gases may help to decrease their emissions from landfill sites [1].

1.1. ENVIRONMENTAL ISSUES OF LANDFILLS

The generation of GHGs is linked with natural processes as well as with human activity. Unfortunately most of society suspects only industrial processes as the source of GHGs. The waste management system is not often suspected to have impact on global warming. In fact, nearly all parts of waste management system plays significant role in GHG emission. The simplest methods (e.g., landfilling) are surprisingly very important sources of GHGs [2].

Landfills cause environmental degradation through leachate generation and GHG emissions [3–5]. Decomposition of organic matter in landfill occurs when water comes in contact with the buried waste, and leachate production and GHG emission are enhanced by an increase in moisture level in landfills. While leachate generation causes vegetation damage, and surface and ground water pollution, GHG emission is implicated in ozone depletion and climate change [6].

After being disposed in landfills, solid waste undergoes complex physicochemical and biological reactions. As a result, organic substances are degraded into leachable liquids or landfill gases. Under anaerobic conditions, the degradation of organic substances generates a large amount of landfill gases comprised of methane and carbon dioxide, along with numerous trace gases such as H_2S, N_2O and CO, CH_4, CO_2 and N_2O are anthropogenic GHG that may significantly contribute to global warming.

As mentioned above, the main components of landfill gases are methane and carbon dioxide. Methane makes up ca. 45–60 vol. %, while carbon dioxide 40–60 vol. %. Landfill gases also contain small amounts of nitrogen, oxygen, ammonia, sulphides, hydrogen, carbon monoxide and less than 1% of non-methane organic components (NMOC), also called non-methane hydrocarbons (NMHCs). Some of them have strong, pungent odour, such as hydrogen sulphide. NMOC such as volatile organic compounds (VOC) and hazardous air pollutants (HAP) may react under the influence of sunlight and form smog. More then 200 NMOC have been identified [1]. Among the landfill gases, carcinogenic substances such as benzene chloride and vinyl chloride may be harmful to the life of the staff and residents of neighbouring areas, while chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs) contribute to depletion of ozone layer and climate change [1].

1.2. ANAEROBIC BIODEGRADATION OF MUNICIPAL SOLID WASTE IN LANDFILLS

The essential reaction in a landfill is anaerobic biodegradation of the organic component of municipal solid waste (MSW). The reaction is in four stages (Fig. 1). Firstly, the complex molecules are hydrolyzed by bacteria into soluble products (like glucose). Secondly, these soluble products are converted by acid forming bacteria to simple organic acids, carbon dioxide and hydrogen; the principal acids produced are acetic acid (ethanoic acid), propanoic acid, butanoic acid and ethanol. And finally, methane is formed by bacteria either by breaking down the acids or by reducing CO_2 with H_2 [7].

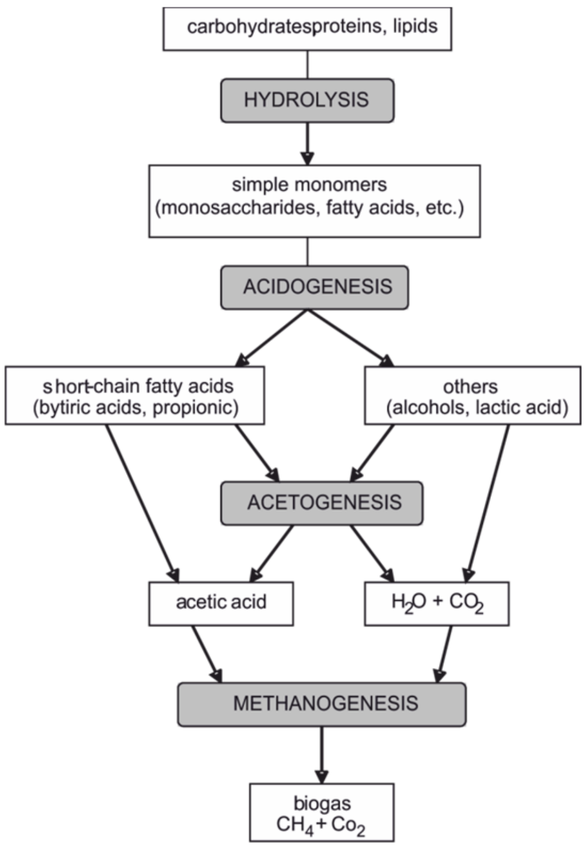

Fig. 1. Scheme of the process of biogas formation (after [1])

As part of the investigation of environmental problems of pollutants produced and released from landfill facilities, a preliminary study was conducted to measure the emission concentrations from MSW landfill S-OO3 Štěpánovice. Measurements were carried out in the years 2004–2011. The results of this field measurement study are used to diagnose the emissions of CO_2 as important landfill gas (LFG) components. The individual components of LFG were examined separately due to the scope of available data.

2. EXPERIMENTAL

2.1. FIELD INVESTIGATION. SITE DESCRIPTION

The landfill under investigation is located 1 km north of Štěpánovice commune and 1 km south of Dehtín commune. GPS coordinates of the test point – 49°26′15.934″N, 13°16′55.352″E. In this area, the mean annual precipitation is 582 mm and the mean annual temperature is 8.0 °C.

Fig. 2. General site location [8]

The landfill has been operating since summer 1996. It is situated in the north part of widely opened valley directed towards W-E. The bottom part of this area is restricted with a nameless stream being the right tributary of the Úhlava River. The upper part of the area is covered with woodland vegetation predominated by *Pinus sylvestris*. The south slope is used for agriculture. The landfill is located at the north slope from the valley axis. In the past, the landfill area was used as meadow [9, 10]. In terms of maintenance, the landfill is classified in the S-category – other waste, sub-category S-OO3. The landfill has a total authorized volume of about 569 000 m^3; at the moment, it is being used to dispose mixed municipal waste. The landfill (Fig. 2) is formed by three sub-landfills: landfill A (closed in 2003, area 8750 m^2); landfill B (working from 2003, area 26 000 m^2); landfill C (that will work after closing part B) (Fig. 3).

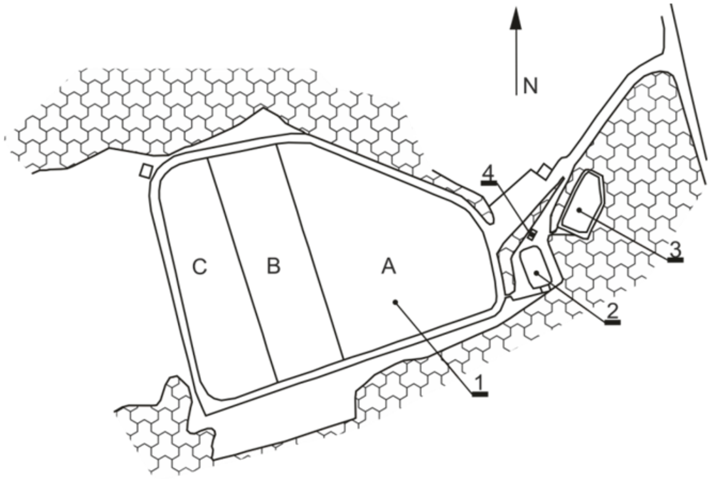

Fig. 3. Map of three sub-landfills: 1 – landfill, 2 – drained water tank, 3 – rainwater reservoir, 4 – entrance gate

The total volume of both (A, B) parts of the landfill is 289 000 m^3. Planned service life of the facility is up to year 2018. The waste generation and composition in 2004 –2011 is presented in Table 1 and Table 2.

Table 1

Waste generation in 2004–2011 [Mg]

Year	Waste	Biodegradable waste	Total	Year	Waste	Biodegradable waste	Total
2004	16 463	3 686	20 149	2008	26 433	5 391	31 824
2005	16 320	3 647	19 967	2009	16 980	4 971	21 951
2006	16 189	3 729	19 918	2010	16 891	4 320	21 211
2007	16 180	4 484	20 664	2011	7 798	1 663	9 461

Table 2

Waste composition in 2004–2011 [Mg]

Waste type	2004	2005	2006	2007	2008	2009	2010	2011
Waste tanned leather	6.34	4.65	4.34	2.18	2.26	1.45	1.87	1.23
Wastes from processed textile fibres	104.49	63.14	140.02	26.88	22.89	39.52	25.36	22.19
Coal fly ash			2.21		13.27		64.94	71.69
Plastic packaging	62.83	69.94	79.07	67.88	72.46	72.38	80.24	40.82
Mixed packaging	30.39			43.84	53.39	56.3	224.35	169.04
Concrete	189.05	280.07	250.96	328.83	234.61	256.01	246.99	347.78
Bricks	3329.97	3867.8	4004.69	3841.42	4763.29	3685.69	4651.02	1870.39
Tiles and ceramics	26.63	137.96	36.38	127.07	41.14	63.68	31.36	17.8
Soil, stones and dredging spoil							1562.96	1162.98
Insulation materials	18.4	2.99	3.86	69.84	19.74			
Gypsum	15.72	3.55	22.54	1255.44	6935.3	990.68	1185.74	614.53
Mixed construction wastes	779.36	985.04	1577.7			39.59	41.39	20.79
Screenings		4.94	5.31	10.78	2.36	125.77	113.77	34.31
Waste from desanding	143.72	117.94	95.42	101.6	113.98			
Biodegradable waste			0.73	1	5.81	7.94	1.31	
Soil and stones	2278.05	2216.57	2648.82	2138.18	6163.59	3692.65	561.94	
Mixed municipal waste	7308.01	7360.08	7435.23	7789.54	7518.88	7593.9	7623.3	3150.79
Waste from markets	193.78	168.09	153.75	120.7	151.64	165.28	136.17	49.36
Street-cleaning residues	400.5	317.8	183.71	353.02	461.46	332.85	430.4	268.58
Bulky waste	5107.87	4285.12	3250.43	4357.47	5234.53	4797.84	4183.22	1614.3
Total	19995.11	19885.68	19895.17	20635.67	31810.60	21921.53	21166.33	9456.58

The total amount of each type of waste placed in the landfill MSW Štěpánovice in 2004–2011 is shown in Fig. 4. The greatest amount of waste placed in the landfill in the reported period represents the mixed municipal waste (55 780 Mg), followed by bulky waste (32 831 Mg) and bricks (30 014 Mg).

2.2. LANDFILL GAS MANAGEMENT

Landfill gas management is usually referred to the biogas generated in landfills as landfill gas (LFG) since it defines the origin of the biogas. The anaerobic process begins after the waste has been in the landfill for 10–50 days. Although the majority of

CH_4 and CO_2 are generated within 20 years of landfill completion, emissions can continue for 50 years or more [11]. It takes almost 30–50 years for a landfill to stabilize in producing landfill gas continuously. One kilogram of waste generates around 0.18 m^3 of carbon dioxide and 0.25 m^3 of methane over several years of decomposition [12].

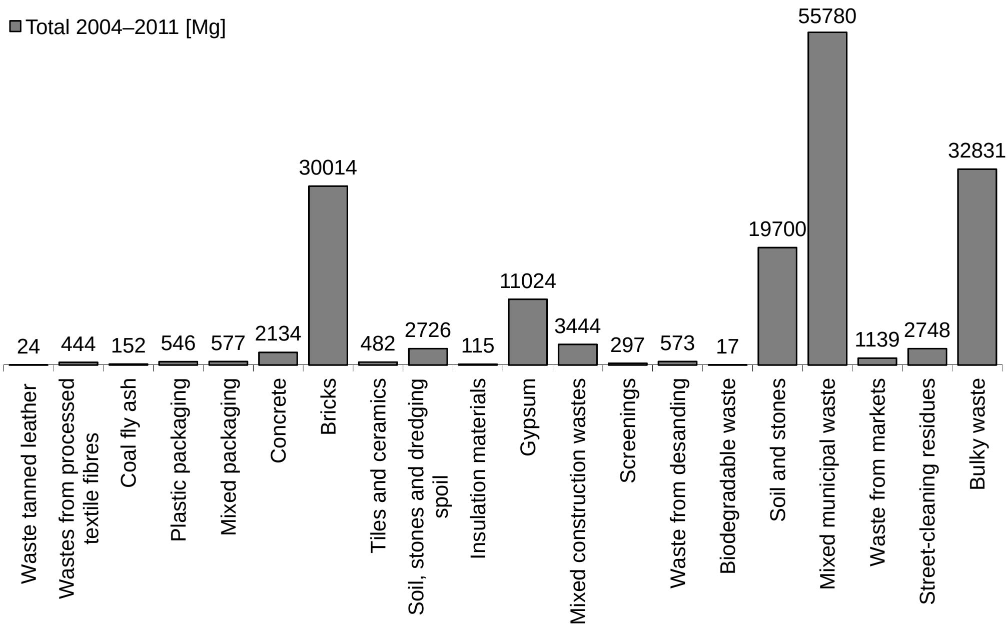

Fig. 4. Total quantity of individual waste in 2004–2011

According to Directive 31/1999/CE *LFG shall be collected from all landfills receiving biodegradable waste and the LFG must be treated and used. If the gas collected cannot be used to produce energy, it must be flared*. With respect to the uncontrolled emission of LFG to atmosphere, collection and flaring already provide with a strong reduction of greenhouse effect (GHE) because of the global warming potential (GWP) of methane (GWP L′ 21) reduction to the GWP of carbon dioxide (GWP L′ 1). Further, LFG can be collected and fed to energy conversion systems to produce electric/thermal energy, according to Directive 31/1999/CE. Energy recovery can contribute to reduce GHE, because of the indirect effect of avoided CO_2 emissions from avoided conventional energy production [13].

During the phase of operation or after-treatment, the landfill operator is obliged to exercise the control of landfill inputs, control of landfill outputs, and to check the landfill technical facilities. The landfill has a monitoring system being primarily used to monitor groundwater quality and landfill gas composition.

Monitoring of the landfill body serves to secure nearby surroundings against possible adverse effects of the landfill. The monitoring has to meet requirement stipulated in the decision on integrated permission (IPPC) for the landfill operator, issued by a competent authority (Regional authority or Ministry of the Environment). The main target of integrated prevention (IPPC) is to protect environment as a whole from industrial and agricultural pollution by regulating installations [14].

Gas management of the landfill TKO Štěpánovice is performed by vertical and horizontal systems. Vertical system is created by a 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. A perforated pipe HDPE DN 100-200 covered with aggregate fraction 35/64 runs through the centre of each well. 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 m distance. Pipeline is run parallel in distance of 20–30 cm and with the incline of minimum 2% (more optimal incline is considered 5–7%).

2.3. MONITORING THE CO_2 CONCENTRATION IN LANDFILL GAS AT THE ŠTĚPÁNOVICE LANDFILL OF MUNICIPAL SOLID WASTE (MSW)

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

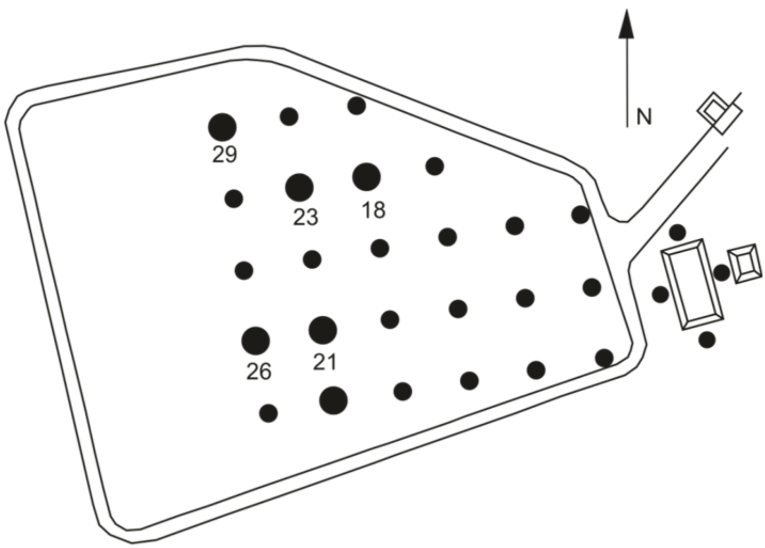

Fig. 5. Layout of sampling points [15]

The landfill gas was sampled on specified measuring sites and control points. Their distribution and number were determined by the laboratory accredited for measuring emissions. The layout of measuring and control points is illustrated in Fig. 5. On the site of the MSW landfill in Štěpánovice, 29 measuring points have been located that served for measuring the concentrations of the LFG. The measuring points were established within a rectangular grid 25×30 – altogether 25 measuring points. The other four ones were located around the accumulation sump (measuring points 1 and 3 at the distance of 20 m from the sump centre and measuring points 2 and 4 at the distance of 12 m from the sump centre).) Sampling sites in Fig. 5 to measure CO_2 concentrations were the points No. 18, 20, 21, 23, 26 and 29.

Table 3

Sum of carbon dioxide emissions from the collection wells

Year	Mass flow [kg/h]	Number of hours	Total annual amount [kg]
2009	4.745	8760	41 566
2010	4.895	8760	42 880
2011	4.996	8760	43 765

The monitoring was conducted by the accredited laboratory which was taking the samples in the period of most favourable conditions for microorganisms to produce the LFG. The condition is that outdoor temperatures must not fall below 5 °C. The frequency of measuring the CO_2 concentration in the air mass was twice a year and the monitoring covered the period from 2004–2011. CO_2 concentrations for individual years in the studied period are presented in Table 3.

The air mass concentration of CO_2 was measured by CO_2 detection tubes. The manufacturer of these tubes is the Kavalier glass works. Detection of carbon dioxide by the tube is based on the reaction of carbon dioxide with hydrazine hydrate mediated by redox indicator. The reaction is c carbon dioxide and is not disturbed by the attendance of other gases.

3. RESULTS

3.1. MEASURED CONCENTRATIONS OF CARBON DIOXIDE

LFG is a gaseous product generated spontaneously from landfill bodies through the process of anaerobic decomposition of biodegradable wastes. Methods to establish the production of LFG are very complicated and the acquisition of sufficiently accurate input data is difficult. The measured average values of the concentrations of carbon dioxide emissions in the studied years are presented in Fig. 6. As shown in the figure 6, the concentration of CO_2 in 2004 varies considerably from those in other years. This difference does not result from the waste composition (Table 2, Fig.4) landfilled during that year. Since no data from previous years are available, the cause of such significant difference cannot be reliably deducted.

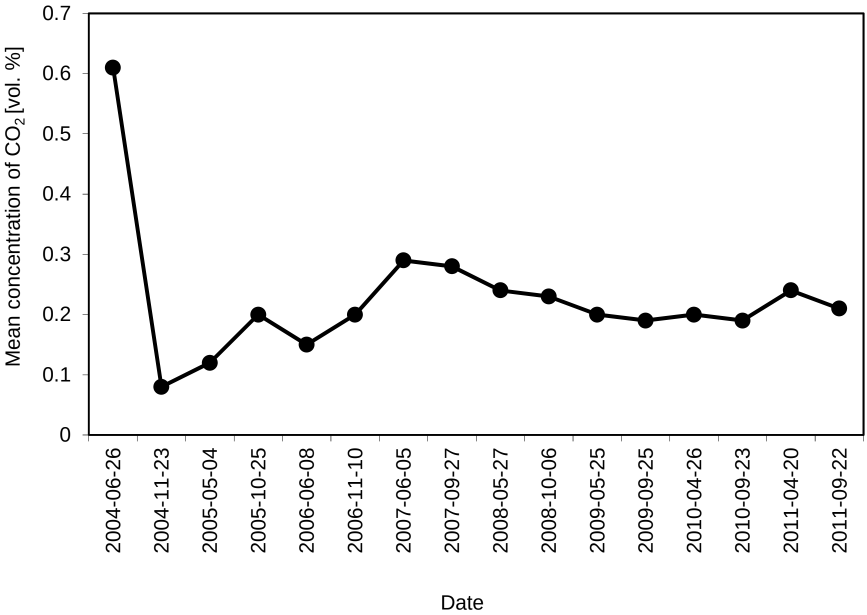

Fig. 6. Mean CO_2 concentrations in 2004–2011

For the purpose of reporting threshold and in line with the conditions for entering the integrated register of pollutants, measurements were taken of CO_2 hourly mass flow in kg in the years 2009–2010. The measurements were taken in gas wells. The results are presented in Table 3. The reporting thresholds for CO_2 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 [14] are presented in Table 4.

Table 4

Reporting thresholds for CO_2 emissions according to IPPC [kg]

CAS No.[a]	Reported substance	Annual emissions into atmosphere [kg]	Annual emissions into water [kg]	Annual emissions into soil [kg]	Reporting threshold outside the operation [kg/year]
124-38-9	CO_2	100 million	–	–	–

[a]CAS No. – Chemical Abstract service registry number.

The annual amounts of CO_2 emissions released into air from the Štěpánovice MSW landfill in 2009 (41 566 kg), 2010 (42 880 kg) and 2011 (43 765 kg) did not exceed the limit stipulated by valid legislation (annual emission into air of 100 milion kg CO_2 emissions). The measured data indicate that the concerned source of pollution – Štěpánovice MSW landfill does not exceed the reporting threshold limit and does not meet 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.

4. SUMMARY

Though carbon dioxide is present in landfill gas in concentrations analogous to methane, and ultimately a large fraction of the methane generated is actually converted to CO_2 before it reaches the atmosphere, either biologically in the cover soil or by combustion, the emissions of CO_2 from landfills are generally not considered. They are not relevant in the global CO_2 budgets when compared to the emissions originating from the combustion of fossil fuels [16]. However a better knowledge of processes governing CO_2 emissions and their more precise quantification could be useful on a world-wide scale, in the frame of a global assessment of the role of landfills as carbon sinks [16]. In view of the probable shift towards proportionally higher CO_2 emissions from landfills, CO_2 emissions should also be considered as to their impacts on a more local level on the landfill cover soil and vegetation, as well as the possible interactions of CO_2 in the mitigation processes of other gaseous compounds [16].

Different waste treatment options for municipal solid waste should be studied in a system analysis, for instance different combination of recycling (cardboard, plastics, glass, metals), biological treatment (composting) and incineration as well as landfilling. According to Pikoń, index of environmental burden in global warming impact category should be calculated [17].

The Štěpánovice landfill of MSW is situated in the Czech Republic, Pilsner Region. The landfill was put into operation in 1996 and is meant for the deposition of SOO3 class MSW. As mentioned in literature [1–4, 16, 17], 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 subject of research was monitoring of the concentration of CO_2 emissions from Štěpánovice landfill, which was realized from 2004 to 2011. The annual sum of CO_2 emissions was measured in the period 2009–2011. The results of measurements indicate that the concentration of CO_2 emissions and the annual sum of these emissions emanated from the MSW landfill in Štěpánovice do not exceed the reporting thresholds and therefore, the landfill does not meet conditions for being included in the integrated register of polluters. Thus, in line with the legislation, the landfill operation is not considered as a source of CO_2 greenhouse gas (GHG). However abstracting from the legal requirements, the landfill can be considered a possible source of CO_2 emissions.

Biological monitoring with the use of biondicators has been taking place in the surroundings of TKO Štěpánovice landfill since 2007. Within the monitoring, protected species have been found and identified, such as, e.g. *Polygala chamaebuxus* and *Juniperus communis*, *Epipactis helleborine*, *Cladonia arbuscula*, *Juniperus communis*, *Epipactis helleborine*, *Populus tremula*, *Polygala chamaebuxu and Triturus vulgaris.* Also lichens, e.g. *Cladonia arbuscula*, *Xanthoria parietina* and *Hypogymnia physodes* have been recorded.

Based on the monitoring outcomes as well as biomonitoring, it can be stated that the production of LGH (its composition CO_2) is not a significant factor influencing the nearest surroundings of the landfill.

ACKNOWLEDGMENT

This study was supported by the Research Plan No. MSM6215648905 *Biological and technological aspects of sustainability of controlled ecosystems and their adaptability to climate change* financed by the Ministry of Education, Youth and Sports of the Czech Republic.

REFERENCES

[1] STASZEWSKA E., PAWŁOWSKA M., *Characteristics of emissions from municipal waste landfills*, Environ. Prot. Eng., 2011, 37 (4), 119.

[2] PIKOŃ K., GASKA K., *Greenhouse gases emission mitigation relevant to changes in MSW management system*, J. Air Waste Manage. Associat., 2010, 60 (7), 782.

[3] BOLAN N.S., THANGARAJAN R., SESHADRI B., JENA U., DAS K.C., WANG H., NAIDU R., *Landfills as a biorefinery to produce biomass and capture biogas*, Bioresour. Technol., 2013, 135, 578.

[4] LOU X., NAIR J., *The impact of landfilling and composting on greenhouse gas emissions. A review*, Bioresour. Technol., 2009, 100 (16), 3792.

[5] SCOTT J., BEYDOUN D., AMAL R., GARY L., CATTLE J., *Landfill management, leachate generation, and leach testing of solid wastes in Australia and overseas*, Environ. Sci. Technol., 2005, 35 (3), 239.

[6] VENKATRAMAN K., ASHWATH N., *Phytocapping. Importance of tree selection and soil thickness*, Water Air Soil Pollut., 2009, 9 (5–6), 421.

[7] THEMELIS N.J., ULLOA P.A., *Methane generation in landfills*, Renew. Energ., 2007, 32 (7), 1243.

[8] Google, 2013, available from: <www.maps.google. com>, modified by M. Vaverková, D. Adamcová.

[9] VAVERKOVÁ M. D., ADAMCOVÁ D., *Can vegetation indicate municipal solid waste landfill impact on the environment*?, Pol. J. Environ. Stud., 2014, 23 (2), 501–509.

[10] ADAMCOVÁ D., VAVERKOVÁ M.D., *Degradation of biodegradable/degradable plastics in municipal solid waste landfill*, Pol. J. Environ. Stud., 2014, 23 (4), 1071–1078.

[11] POPOV V., *A new landfill system for cheaper landfill gas purification*, Renew. Energ., 2005, 30 (7), 1021.

[12] BADE SHRESTHA S.O., NARAYANAN G., *Landfill gas with hydrogen addition. A fuel for SI engines*, Fuel, 2008, 87 (17–18), 3616.
[13] LOMBARDI L., CARNEVALE E., CORTI A., *Greenhouse effect reduction and energy recovery from waste landfill*, Energy, 2006, 31 (15), 3208.
[14] RUSKO M., TUREKOVÁ I., OČENÁŠOVÁ D., *Integrated prevention and pollution control as an important tool of environmental policy in Slovak Republic*, Research Papers, 2010, 18 (28), 141.
[15] VAVERKOVÁ M., *Research of phytoindicators in the nearest surrounding of the Štěpánovice landfill*, Dissertation Thesis, Department of Applied and Landscape Ecology, University in Brno, Brno 2010.
[16] FISCHER C., *Gas emission from landfills*. *An overview of issues and research needs*, Swedish Environmental Protection Agency, Stockholm, Sweden, October 1999.
[17] PIKOŃ K., *Environmental impact of waste management system. System location issues*, World Environmental and Water Resources Congress, EWRI 2011, Palm Springs, California, USA, 22–26 May 2011.