CONTINUOUS MONITORING OF LANDFILL GAS

Marek Martinec, Jana Chumchalová*, Pavla Renkerová, Martin Kubal

University of Chemistry and Technology Prague, Technická 5, 166 28 Prague 6, Czech Republic
**e-mail:jana.chumchalova@vscht.cz*

The original design of a landfill gas monitoring unit is presented together with the observations and results from the continuous testing operation. The monitoring unit included the gas flow meter, a set of sensors and supporting electrotechnical components in total price of about five hundred EUROS. The monitoring unit showed very good performance characteristics and durability in current operational conditions of a municipal waste landfill. The results collected within the six days continuous testing run clearly proved the advantages of this long-termed approach over simple individual measurements according to current Czech technical standards. The landfill gas extraction well selected for the testing run showed relatively poor performance as far as gas production and methane concentration were concerned. It was evidenced that the waste deposited around the extraction well was in the final stage of its stabilization.

Keywords: landfill gas, monitoring, municipal waste

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1. Introduction

Landfill gas is one of the products of the decomposition processes running in landfills. It is mainly generated by the action of microorganisms which degrade the organic substances present in waste into more simple compounds, with minor participation of chemical reactions between waste components. For typical recent composition of municipal waste the landfill gas usually contains about 40 to 50 % of methane, approximately the same part of carbon dioxide and trace amounts of volatile organic compounds and sulfane [1]. The main environmental impact of landfill gas follows from the fact that both methane and carbon dioxide are greenhouse gases. The actual composition (as well as production) of landfill gas may significantly vary both spatially and over the time. It is thus very important to monitor the landfill gas parameters for the whole life cycle of a landfill. Municipal waste deposited to a landfill typically undergo through the five steps degradation process (one aerobic and four anaerobic) before it is stabilized to such a degree that landfill gas production became negligible [2]. Even after that - in the period of postclosure care - the landfill body monitoring system should be kept in operation. The EU legislation generally require to restrict the environmental impact of the landfill over a period of at least 30 years after terminating the landfill operation (in the Czech Republic Act no. 383/2008 Coll.).

There were 178 landfills (of all categories) whose operation was reported for the territory of the Czech Republic for the year 2014 [3]. The general conditions of depositing waste to landfills are defined in the Decree of 11 July 2005 No. 294/2005 Coll., while the technical details on landfill gas monitoring are specified in directly connected Czech technical standard ČSN 83 8036 (Waste landfilling - Monitoring of landfills). Here it is required to monitor quality and quantity of gas developed in the landfill body if the waste deposited contains biodegradable components. The minimum monitoring frequency is stated for once per year if the annual amount of deposited waste is less than 30 000 tons and twice per year if this annual amount is higher. The landfill gas monitoring should be running through the whole waste biodegradation period, till the mean concentration of combustible components is less than 1% vol. Further technical details on landfill gas monitoring are defined in the Czech technical standard ČSN 83 8034 (Waste Landfilling – Degasification of Landfills). It is important to the scope of this paper that the standards require discontinuous sampling of landfill gas.

There exist several techniques for the monitoring of landfill gas [4]. The most important one is based on the collection system monitoring, where the gas is sampled directly in the extraction system. Monitoring may be done either at the individual wells or at the input to the combustion unit. The concentrations of methane, carbon dioxide and oxygen are typically analysed together with the gas temperature, pressure and flow rate. Another landfill gas monitoring technique includes the surface monitoring approach, which is used to control the integrity of landfill body caps. The other monitoring strategy is based on ambient air sampling which is applied to monitor the landfill area for excess of methane and other gases.

According to its quality and quantity - the both are changing in time - the landfill gas may basically be processed in three different ways [5]. Landfill operators should primarily recover the maximum available amount of energy from the landfill gas. So when its production and methane contents are high enough it is preferred to drive it to combined heat and power utilisation. As the landfill gas generation rate declines over the time and methane content becomes lower the energy recovery systems are replaced by burning in flares. At even lower production and methane concentration, when a flare cannot be sustained, the controlled chemical or biological methane oxidation systems are considered to be the best available techniques.

Besides landfill gas quantitative and qualitative variations caused by waste heterogeneity there is another important aspect which should be taken into account within any monitoring strategy applied to a landfill body - the natural airflow in unsaturated subsurface zone [6]. Airflow in the subsurface porous medium can be induced by various natural forces, such as atmospheric pressure fluctuations, topographic effect, water table fluctuations, and infiltration. Atmospheric pressure fluctuations are of main importance for landfill gas monitoring.

The fluctuations of surface atmospheric pressure induce the fluctuations of air pressure in the subsurface, whose time delay and amplitude attenuation depend on the unsaturated zone structure and air permeability. Gas movement in the unsaturated zone induced by these natural fluctuations is referred to as barometric pumping or atmospheric pumping [7, 8]. When the atmospheric pressure falls, gases are drawn upward out of the subsurface into the atmosphere. Conversely, when the atmospheric pressure increases, fresh air is pushed downward into the subsurface. Generally, the fluctuations of atmospheric pressure increase soil-atmosphere gas exchange. [9]. In a homogeneous porous medium, the depth of the propagation of air pressure into the subsurface can be from several meters to over 10 m. In a heterogeneous system, with low permeable layers at the surface the propagation of gas pressure into the subsurface may be much greater [10, 11]. Within a landfill body, the atmospheric pressure fluctuations may significantly influence both waste degradation processes and landfill gas characteristics. Surprisingly extensive and rapid changes in landfill gas flux and composition were repeatedly observed during a drop or rise in atmospheric pressure [12, 13, 14].

It follows from the introduction that landfill gas monitoring system must typically respond to significant time and spatial variations in gas parameters. To provide really valuable information on landfill body behaviour the monitoring system should be able to continuously monitor particular landfill sections, if not individual extraction wells. This would be extremely expensive today using currently available technical tools. Thus the goal of this work is to design and construct a simple and inexpensive monitoring unit with capacity to continuously detect and record landfill gas parameters at a single extraction well.

2. Experimental

2.1. Construction of landfill gas monitoring unit

Basic concept of the landfill gas monitoring unit constructed to the purpose of this paper is shown in Figure 1. The unit was connected to the pipeline of a selected gas extraction well (with closed valve) through the two sampling ports and a flexible hose bypass.

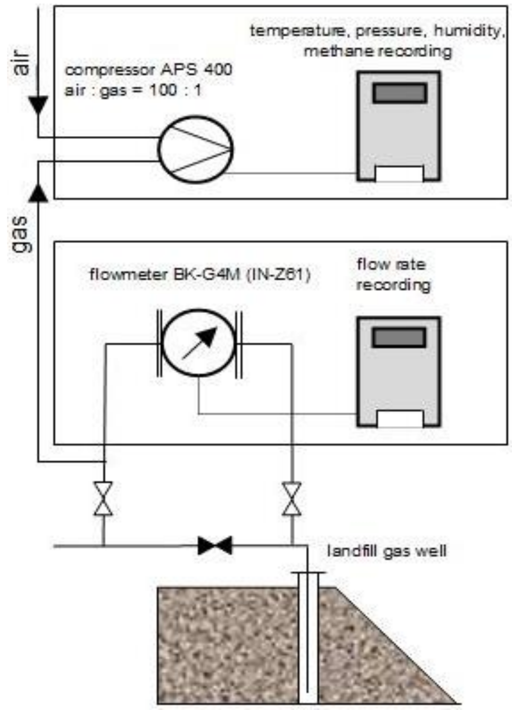

Figure 1: Construction scheme of landfill gas continuous monitoring system

The selected vertical extraction well was anchored to the bottom sealing layer of the landfill body and penetrated (with perforation) through its whole height which was about 40 m. All the landfill gas extracted from a given well was passed through a monitoring unit and its flow rate recorded once per 30 seconds (diaphragm gas meter BK-G4M equipped with low frequency pulse transmitter IN-Z61). A small part of the landfill gas was divided at the output from the flow meter, mixed with air in 1:100 ratio (to meet the range of methane detection) and driven to the methane concentration, temperature, pressure and humidity sensors. Methane concentration was measured by means of a semiconductor MQ-4 gas sensor working in the 100 - 10000 ppm range. The three other parameters were measured by combined digital BME280 sensor. The both recording units, together with the relevant sensors and electronic elements were situated into special watertight protective casings which were special designed and produced by 3-D printing (see Figure 2).

2.2. Installation of monitoring unit at the landfill

The monitoring system was installed at the municipal waste landfill Ekologie s.r.o. (Lány, Middle Bohemia). Testing extraction well was situated in a recultivated section (capped with low permeable barrier and vegetative layer) where solid waste loading was performed between 2009 - 2011. All the components of the monitoring system were placed in two watertight plastic boxes (electrical enclosure Thalassa NSYPLM43G). Each one was fixed to an adjustable holder to 1.5 meter height (see Figure 3).

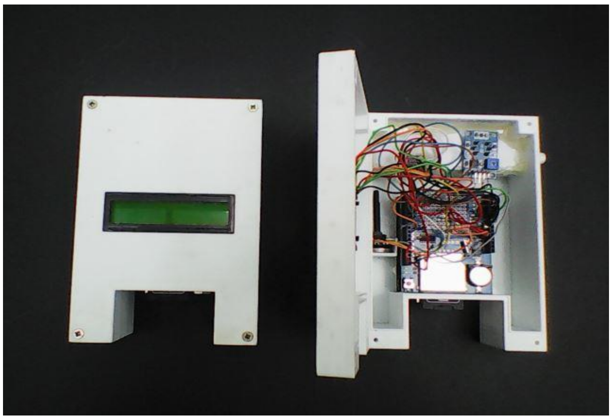

Figure 2: Recording unit for temperature, atmospheric pressure, air humidity, methane concentration (right open), and landfill gas flow rate (left closed)

Figure 3: Continuous monitoring unit installed at landfill gas extraction well

3. Results and discussion

The landfill gas monitoring unit designed to satisfy the demands for continuous detection of gas parameters as well as the requirement for cheap and simple construction arrangement has been shown in Figures 1 - 3. It should be noted here again that landfill gas monitoring is typically discontinuous process carried out (according to the Czech technical standards ČSN 83 8036, ČSN 83 8034) once or twice per year, based on annual waste loading capacity. The only continuous instrumentation for measurement of landfill gas characteristics is usually installed at the input to combustion system.

The first set of tests carried out at with the monitoring unit installed at the individual gas extraction well (Figure 3) was directed to the operational safety and reliability of unit components. In particular, the unit was required:

- to detect all the parameters measured without failures within broad outdoor temperature and humidity range;
- to keep stable calibrations as well as mixing ratio landfill gas : air in APS 400 compressor;
- to survive attacks of animals;
- to start automatically and continue in recording after electricity blackout.

The monitoring unit was installed first at the landfill in August 2016 and it was in testing operation till November 2017. The testing was interrupted several times to carry out minor correction and revisions and to check out the calibrations. Through this time period the unit was exposed to a wide temperature range (~ 60ºC inside the plastic box in a sunny summer day) and many weather extremes. Within the long-termed testing operation all the adjusted calibrations showed very good stability with practically insignificant deviations. Here it should be underlined that the monitoring unit (as a cheap but continuous system) was mainly expected to provide information on trends related to landfill gas characteristic in one partial section of a landfill. It was the primary and original profit expected. The absolute values of the parameters recorded were of secondary importance here.

There were only a few minor mechanical damages at the outer parts of the unit mainly caused by wind, but all of them easy to repair. The main complication identified during the long-termed testing consisted in high interest of insects and birds for the plastic boxes. Occasional openings were satisfactory here for different kinds of insect to occupy the internal space of the boxes. The birds tended to penetrate the boxes and flexible hoses.

The illustrative set of data measured and recorded by the unit is presented in complex form in Figure 4 for six days period. This time period was selected as a suitable to show both short-termed and long-termed landfill gas variations. For longer periods the data are too compressed when transferred to graphs. The data are presented here as recorded without any processing. The most important part of the data is related to the landfill gas flow and methane concentration. The flow rate line (even if shivering extensively) indicates two different types of behaviour - the first one with zero gas production and the second one with mean flow rate of about 0.5 $m^3.h^{-1}$. There were obviously two different degradation and degasification regimes at the given well and in waste deposited around. The indicated flow rate value of 0.5 $m^3.h^{-1}$ would have been probably much higher without installing the monitoring unit, where the gas had to pass through 5/4 inch flexible hose and 1 inch sampling ports instead of standard 100 mm pipeline. Similarly to the flow rate dependance it is possible to observe two levels of methane concentrations in Figure 4. The first one is numerically situated around the value of 100 ppm, which is (according to the laboratory calibration) equal to zero methane content. The methane detector used is not fully selective to methane. The second concentration level is only slightly higher and corresponds numerically to about 150 ppm, which after correction to zero level and to dilution ratio 1:100 corresponds to methane content in landfill gas about 0.5%.

The data presented in Figure 4 were collected from early version of the landfill gas monitoring unit, which will further be improved. Irrespective of this technical drawback these long-termed continuous data bring significant progress compared to single measurement only, which in fact may be situated to any part of the lines showed in Figure 4. Besides good operational reliability the unit may further be characterized by a inexpensive price. The components necessary to complete the unit were available at the market in the total price of about five hundred EUROS. Approximately 60% of this sum was related to gas flow rate section. Future improvement of the unit will be directed to installation of carbon dioxide sensor so that both anaerobic and aerobic degradation products will be monitored together in the landfill gas.

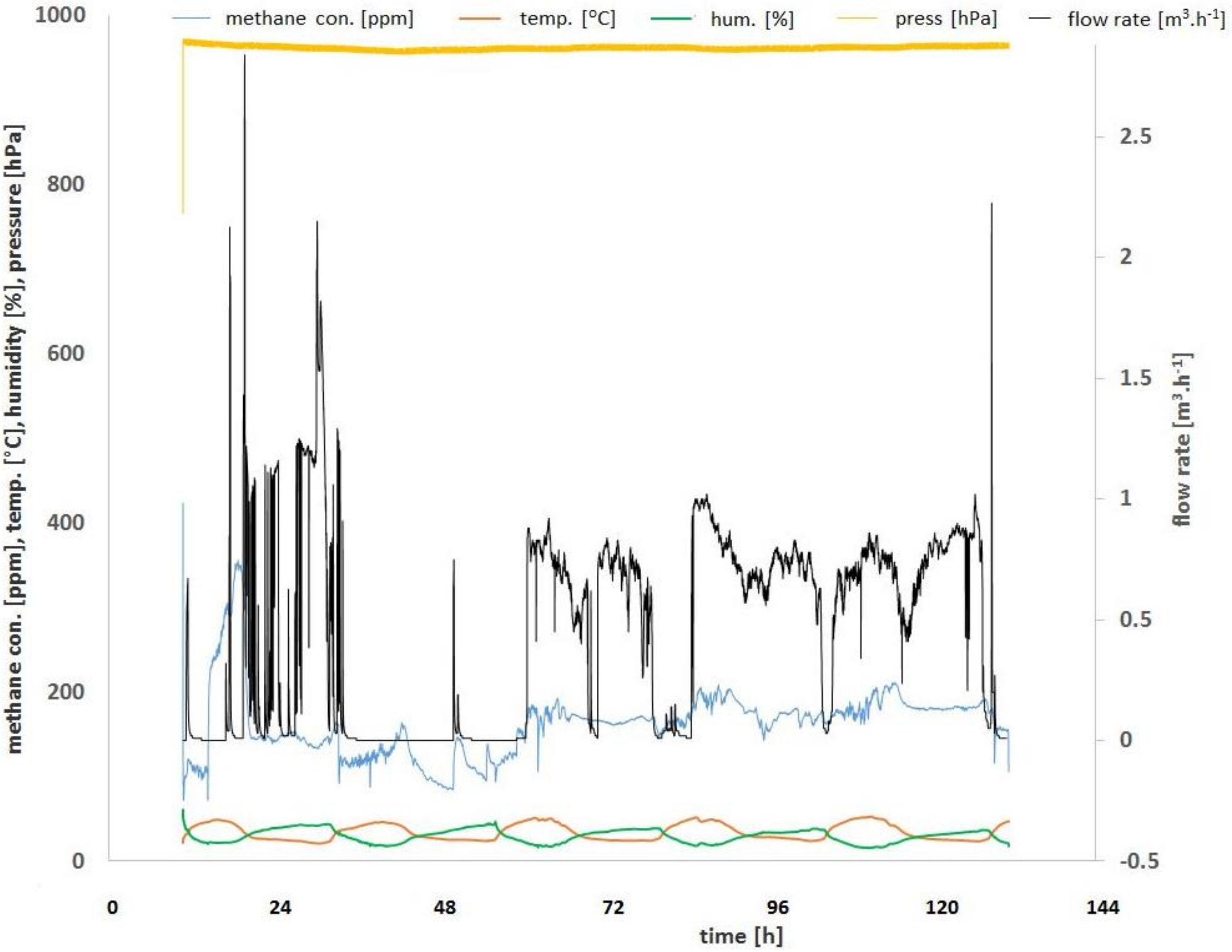

Figure 4: Complex data recorded within six days testing operation of the continuous monitoring unit at an individual landfill gas extraction well

4. Conclusions

Simple and inexpensive continuous monitoring unit was constructed to examine the long-termed behaviour of landfill gas. The unit was completed from the components in total price of about five hundred EUROS and can simultaneously measure and record five parameters of landfill gas - flow rate of gas, methane concentration, temperature, humidity and atmospheric pressure.

The monitoring unit was installed at the individual gas extraction well and tested through a six days run. Low concentration of methane in the gas together with relatively small gas production indicated that the waste deposited at a given section of the landfill has already been stabilised to very high degree. The continuous approach to the landfill gas monitoring proved to be much more profitable over the single sampling strategies required by current Czech technical standards.

5. References

1. Straka F. et al.: Bioplyn, GAS s.r.o., Praha 2006.
2. Bove R., Lunghi P.: Electric power generation from landfill gas using traditional and innovative technolo-gies, Energy Conversion and Management, 47 (11–12), 2006, 1391-1401.
3. MŽP ČR: Plán odpadového hospodářství České republiky pro období 2015 – 2024, https://www.mzp.cz/cz/poh_cr_prislusne_dokumenty, downloaded February 20, 2019.
4. EPA VICTORIA: Landfill gas fugitive emissions monitoring guideline, February 2018, https://www.epa.vic.gov.au/~/media/Publications/1684.pdf, downloaded February 20, 2019.
5. Kuraš M.: Odpady a jejich zpracování, Vodní zdroje Ekomonitor, spol. s.r.o., 2014.
6. Xingxing Kuang et al.: Review on airflow in unsatura-ted zones induced by natural forcings, Water Resour. Res., 49, 2013, 6137–6165.
7. Nilson R. H. et al.: Atmospheric pumping: A mecha-nism causing vertical transport of contaminated gases through fractured permeable media, J. Geophys. Res., 96(B13), 21, 1991, 21 933–21 948.
8. Auer L. H. et al.: The effects of barometric pumping on contaminant transport, J. Contam. Hydrol., 24(2), 1996, 145–166.
9. Nilson R. H., Lie K. H.: Double-porosity modelling of oscillatory gas motion and contaminant transport in a fractured porous medium, Int. J. Numer. Anal. Meteorol., 14(8), 1990, 565–585.
10. Massmann J., Farrier D. F.: Effects of atmospheric pressures on gas transport in the vadose zone, Water Resour. Res., 28(3), 1992, 777–791.
11. Elberling B. et al.: Gas transport in a confined unsatura-ted zone during atmospheric pressure cycles, Water Resour. Res., 34(11), 1998, 2855–2862.
12. Christophersen M. et al.: Lateral gas transport in soil adjacent to an old landfill: Factors governing emissions and methane oxidation, Waste Manage. Res., 19(6), 2001, 595–612.
13. Young, A.: The effects of fluctuations in atmospheric pressure on landfill gas migration and composition, Water Air Soil Pollut., 64(3–4), 1992, 601–616.14.
14. Nastev M. et al.: Gas production and migration in landfills and geological materials, J. Contam. Hydrol., 52(1–4), 2001, 187–211.