INFLUENCE OF AMBIENCE TEMPERATURE AND OPERATIONAL-CONSTRUCTIVE PARAMETERS ON LANDFILL GAS GENERATION – CASE STUDY NOVI SAD

by

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Researches in the area of landfill gas generation and energy utilization are currently underway and widespread in the world for several reasons: reducing effects of greenhouse gases, possibilities for utilizing alternative energy sources, reducing conventional energy resources exploitation, and environmental protection. First part of this research is conducted with an aim to establish the influence of meteorological parameters, primarily ambience temperature, on the methane generation processes at Novi Sad landfill. The second part of the research refers to functional characteristics of landfill such as the waste age, closing practice, and the age of certain parts of landfill body, as well as the waste depth and quantity of generated methane. Based on several years of investigation, it is concluded that methane generation varies in the range of 0-34 vol.% m^3/m^3*, and that seasonal variations have significant influence on methane generation. At low temperatures, during winter, methane generation and migration is stagnant while in summer periods, due to higher temperatures, the process of methane generation is more intensive.*

Key words: *landfill gas generation, landfill, methane*

Introduction

Methane (CH_4) is an important greenhouse gas, with a global warming potential of 21-25 times greater than carbon dioxide [1, 2]. Methane emissions from landfills are estimated to account for 3-19% of anthropogenic CH_4 on a global scale (US EPA 1994). The Kyoto protocol defines the need to reduce disbalance between methane and carbon dioxide emissions, and the White book of the European Union defines the policy for utilizing renewable energy sources. It should be emphasizes significant reduction of fossil fuels reserves which is followed by constant increase of their costs. The policy of increasing proportion of renewable energy

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sources in the overall energy production, as well as great dependence of energy imports in our country, have oriented researches towards possibilities for utilizing landfill gas.

Landfill gas is produced by bacterial decomposition, which occurs when organic waste is decomposed by bacteria naturally present in the waste and in the soil used for landfill cover [3-7]. When deposited in a landfill a proportion of biodegradable waste fraction will begin to degrade through biological and chemical reactions. Waste components that contain significant biodegradable fractions are food, garden waste, textiles, paper, and cardboard products. Bacteria decompose organic waste in four phases, and the composition of the gas changes during each phase [8].

For achieving optimum energy utilization, composition, and constancy of landfill gas the generation level represents the most important factors. However, there are many factors affecting the composition and generation of landfill gas. The most important factors are meteorological parameters (temperature, precipitation, atmospheric pressure, and air humidity), age and type of waste, as well as the site management practice [9, 10]. Meteorological parameters have great influence on the generation, composition, and migration of landfill gas into landfill body. Decreases in atmospheric pressure are associated with increased emissions of landfill gas and hence methane from landfills. Precipitation, snow cover and ice sheets at the landfill surface may substantially influence on emission and composition of landfill gas [11, 12]. However, increased precipitation may result enhanced generation of CH_4. Seasonal changes also affect on landfill gas generation.

Permanency and stability of CH_4 generation on Novi Sad landfill at different seasons was the main goal of this study. The investigation was conducted on representative extraction wells during four test seasons within the period of three year in order to identify seasonal variation of methane generation. Second goal was to determine correlation between methane generation and ambient temperature during summer season. Based on the results obtained, prediction of methane generation stability and concentration was made for the entire landfill surface layer in order to evaluate total landfill gas production and possibilities for energy utilization of methane.

Characteristics of Novi Sad landfill

The existing landfill is located 6 km north of the Novi Sad municipal centre. Distance of south landfill boundary from the highway is 170 m, while distance of west landfill boundary from the regional road is 430 m. The distance from the nearest residential settlements is around 700 m.

Total area of landfill covers 56 ha, with area covered by waste is approximately 22 ha, with fill depth of 2.5-7.5 m. Landfill has been operating almost 30 years and over 1.000.000 m^3 of municipal and building-demolition waste have been deposited until now. Today landfill recevies 360 tons of waste per day, while 3.6 tons of recyclables per day is extracted within the waste separation unit located at the landfill site. Remaining amount of waste is landfilled without any pretreatment. After closure of this site, waste will be deposited at the new landfill site which is located near operating landfill.

Landfill exploitation started on Field IIIa (fig.1), and continued on Field I, Field II, and Field IIIb, after closure of Field IIIa. During closure of Field I, Field II, and Field IIIa in 2001, waste was covered with inert material. Also, drainage system and passive gas extraction system were installed and collection tanks for leachate were built. These improvements have contributed to elimination of odours, prevention of watercourses pollution and reduced risk of explosion. During closure, installation of gas wells was also performed in order to enable migration of landfill gas into atmosphere and to prevent accumulation of methane into landfill body.

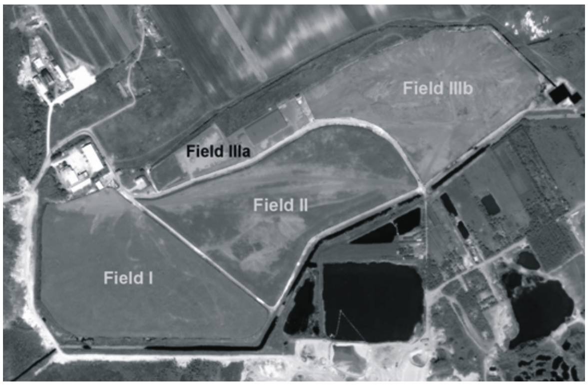

Figure 1. Position and view of the landfill in Novi Sad

The Field I have installed 29 extraction wells, the Field II 33 extraction gas wells while the Field III consists of two subfields IIIa and IIIb, with 43 gas wells. The gas extraction wells are distributed across entire landfill body but most of them were placed near landfill boundaries in order to prevent horizontal migration of landfill gas outside the landfill body.

Installed passive system for landfill gas extraction, passive gas wells, operates based on pressure difference and gas diffusion from landfill body into the atmosphere [13]. Adopted standards for passive systems are ventilation openings "wells" which are made from perforated plastic tubes wrapped with a layer of gravel (fig. 2). Extraction well diameters are 0.5-1.0 m and their depth varies 50-90% of the waste depth.

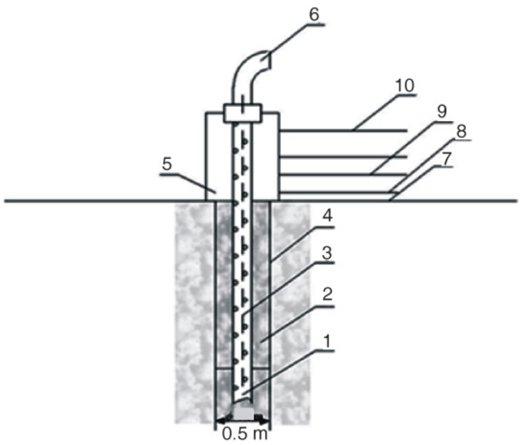

Figure 2. Extraction gas well scheme
(1) – exixting garbage, (2) – gravel with granulation over 32 mm, (3) – plastic perforated tube ϕ160 mm, (4) – protective insulation, (5) – concrete cover ϕ 0.7 m, (6) – exhoust pipe, (7) – final layer of waste, (8) – foil, (9) – inert cover, (10) – humus

Measurement methodology

Measuring of landfill gas was performed with GfG-Polytector II. The Polytector II is used for various principles of detection depending on the monitored gas. The catalytic combustion (CC) and the thermal conductivity (TC) are proven principles for measuring flammable gases in order to prevent explosions. Electrochemical sensors (EC) with various features are used for measuring the large range of toxic gases and oxygen. The infrared sensor (IC) provides extraordinary results in measurement of carbon dioxide (CO_2). The Polytector II is certified and tested for use in different conditions. The certificate is "DMT – Gesellschaft fur Forschung und Prüfung, Fachstelle für Sicherheit elektrischer Betriebsmittel". The ex-certificate is BVS 99.E.2016 and for classification it is Eex ib d IIC T5. Polytector was used in this research for measuring concentrations of LEL MK201-1 0-100% LEL CH_4 methane. Lower explosive limit (LEL) is the minimum gas concentration mixed with air in volumetric percentage at room temperature which induces flame expansion after contact with the ignition source. The mixtures with compositions below LEL concentration are not suitable for burning.

During trial measurements of methane concentrations in landfill gas, it was noticed that at various measurement depths different concentrations of methane can be detected. Measurements were carried out at various basic meteorological elements several times during the day, and at different quantities of moisture in the soil (wastes).

It is noticed that methane concentration in gas wells vary depending on the depth. Between 0.5-1 m depth, lower concentrations of methane and relatively high concentrations of oxygen O_2 are identified. Between 1-2 m depth, the methane concentration increased while the oxygen concentration decreased gradually.

Several repeated measurements on the gas wells at the various weather conditions and at the different depth of extraction wells determined that highest stability of methane concentrations were at 2 m depth, at all measuring points. It is important to mention that depth of 2 m was measured from the lower edge of the exhaust pipe of the gas well. Due to mentioned facts and in accordance with the established objective of this research, further measurements were conducted at 2 m depth specifically. Measuring cycles in 2 years period were planned in order to determine influence of seasonal variations regards to ambiance temperature, on landfill gas generation. Also during 12 days period frequency measurements were carried out with an aim to define direct influence of temperature on concentration and generation of methane. These measurements are performed at Field IIIa, because this field represented the oldest and the part of landfill with thinnest layer of disposed waste. It was assumed that influence of temperature to reaction response will be the most intensive on Field IIIa due to small waste depth [14]. Also it was assumed that methane production at the oldest landfill part will be more stable than production on other parts of landfill [8].

In order to perform comprehensive monitoring, concentrations of CO_2, O_2, H_2S, *etc*., in landfill gas were also concerned. Measurements were carried out at representative measuring points (gas extraction wells). Choice of gas wells was performed in order to include landfill parts which mutually differ considerably. These differences relate to age and depth of disposed waste at a relevant location, waste composition and landfill cover. These characteristics may

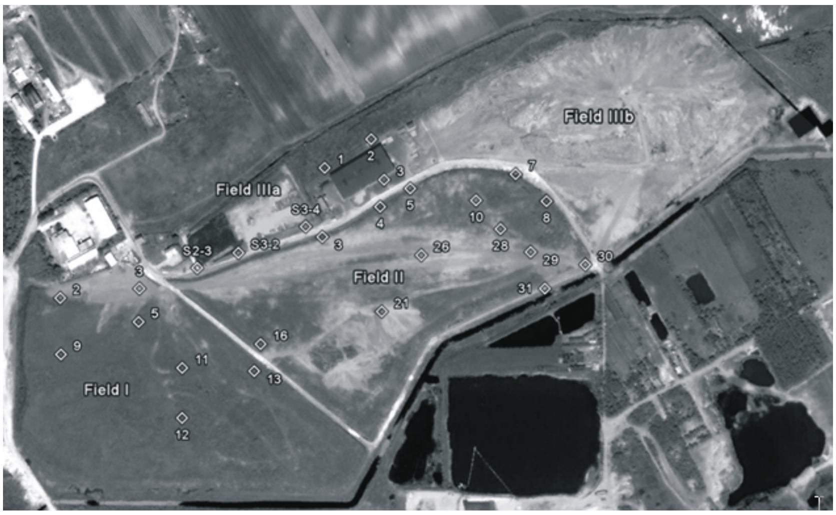

Figure 3. Locations of representative gas wells on landfill in Novi Sad

have important influence on concentration and generation of methane and other compounds of landfill gas. Also, it was necessary to include a certain number of representative wells near landfill boundaries, due to higher level migration of landfill gas in landfill body and atmosphere.

Waste depth on Field I and Field II are approximately 4 and 7 meters, while on Field IIIa, as the oldest part of landfill waste, depth is 3 m. Locations of the representative gas wells are shown on fig. 3.

Results

Measurement of landfill gas composition shows that concentration of methane reach 34% m^3/m^3, however most results vary between 5-20% of methane vol. m^3/m^3 (tab. 1). Obtained results show absence of methane during winter, at temperature below 0 °C (at landfill parts with lower depth), while during rest of the year season concentration of methane show certain dependence of ambient temperature (fig. 4).

Table 1. Results of seasonal measurement of methane concentration on Field IIIa

Extraction well	Autumn I	Winter I	Spring I	Summer I	Autumn II	Winter II	Spring II	Summer II
Temp. [°C]	15	–5	16	26	5	–3	20	7
S2-4	2.5	0	4.5	5	2.5	0	1.5	6
S3-2	12	0	15.5	1	1	0	4	8
S3-4	0	0	12	22.5	6	0	19.5	12
DIII-1	4.8	0	6	10.5	6	0	4.5	8
DIII-2	5.1	0	7	5.5	10	0	3	4
DIII-3	4.5	0	26	15	3.5	0	6	1.5
DIII-4	9	0	26	34.5	32	0	22	20

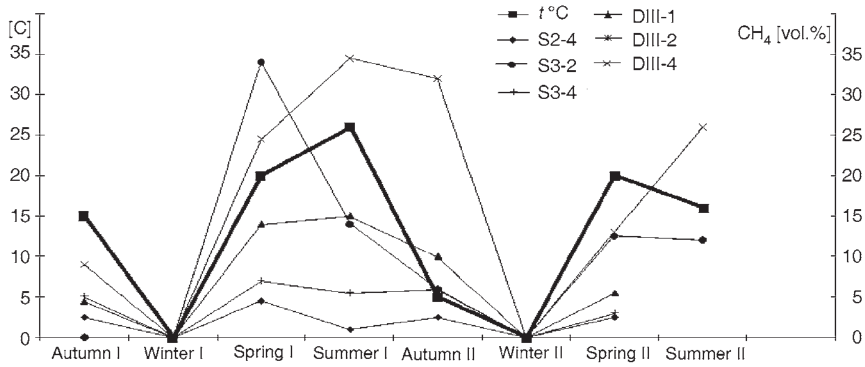

Figure 4. Relations between ambiance temperature and methane concentration during two years of measurement

Simultaneously with established measurements cycles on the seasonal level, one measurement cycle during 12 days was performed with an aim to define short term influence of temperature on concentration and generation of methane.

Data analysis show that for gas extraction wells set "S" (S2-4, S3-2, S3-4) correlation is $R^2 = 0.52$ with statistical significance $P = 0.03$, while for "D" set of gas wells (DIII-1, DIII-2, DIII-4) $R^2 = 0.37$ and $P = 0.08$. This indicates that direct correlation of temperature on methane concentration can not be determined due to presence of other factors that influence methane generation (fig. 5).

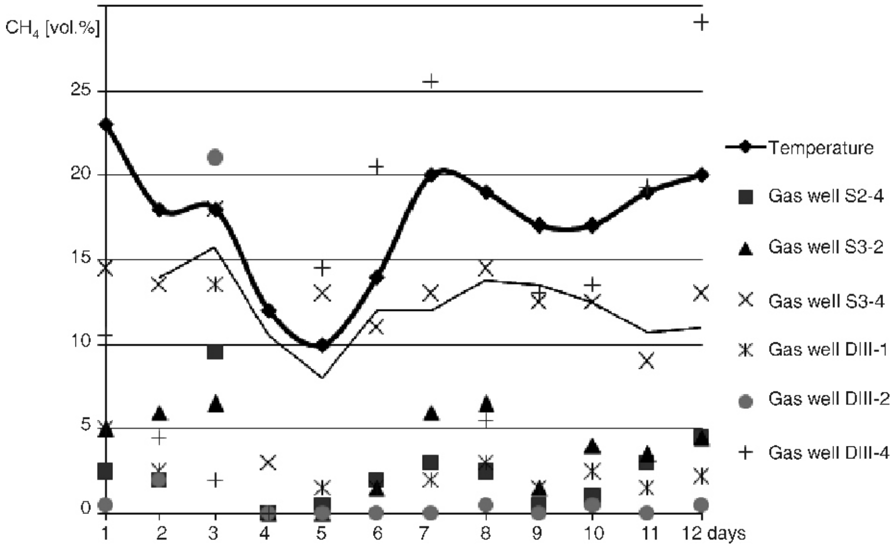

Figure 5. Correlation of methane concentration and ambiance temperature during 12 days continuous measurements period

It can be observed that concentration of methane follows the temperature curve but with a delay. The temperature is decreasing from 1st to 3rd day, while the quantity of detected methane is increasing. From 7th to 9th day, the temperature is also decreasing while quantity of detected methane is increasing. Finally from 10th to 12th day, methane generation is decreasing although the temperature is increasing. Czepiel *et al*. [15] found a significant inverse correlation between CH_4 emissions and barometric pressure consistent with the results of Young [16]. During short term measurements the atmospheric pressure was relatively constant, 1006-1008 mbar, thus the pressure did not have variable influence on methane generation and migration from the landfill body. It can be noticed that correlation between measured methane concentrations and temperature is possible to be determined since the curve representing mean values of measurements has similar shape with the curve of ambience temperature. The observed differences concerning direct correlation between methane generation and ambient air temperature are comparatively smaller regard to temperature dependence during seasonal variations. During these periods, dependence is almost regular and implies the growth of methane generation with increased ambience air temperature. In short measurement period dependence is disturbed due to inertness of complex biodegradation processes which react with delays to temperature changes in small range.

Table 2. Measured concentration of methane at representative gas wells

Field	Extraction wel	CH_4 [%vol.]
		Spring
Field 1	DI-2	5
Field 1	DI-3	2
Field 1	DI-5	8
Field 1	DI-9	3
Field 1	DI-11	3
Field 1	DI-12	2
Field 1	DI-13	0
Field 2	DII-3	14
Field 2	DII-4	24
Field 2	DII-5	1
Field 2	DII-7	5
Field 2	DII-8	16
Field 2	DII-10	6
Field 2	DII-16	1
Field 2	DII-21	28
Field 2	DII-26	34
Field 2	DII-28	18
Field 2	DII-29	12
Field 2	DII-30	11
Field 2	DII-31	12
Field 3a	S2-4	1.5
Field 3a	S3-2	2
Field 3a	S3-4	2.5
Field 3a	DIII-1	2.5
Field 3a	DIII-2	0
Field 3a	DIII-4	4

In order to establish the influence of other parameters affecting methane generation like waste disposal practice and age of disposed waste, research were made at 26 representative gas wells at the Novi Sad landfill.

Experimental results shown in tab. 2, and kriging 3-D analysis of measured data, provided results which indicate intensive concentration of methane at landfill parts where the waste was disposed in the last three or four years and much lower concentration on landfills parts where the waste was disposed few decades ago.

Several models related to generation and migration of landfill gas has been developed according to literature. One of the most often used models is differential 1-D model for adequate, dispersive and reactive transport of gas through porous medium. 1-D model can be combined with the 2-D kriging geo-statistical model in order to developed pseudo 3-D model. The accuracy of kriging assessment depends on the quality of obtained semi--variogram fitting. In the ArcInfo GIS software, the best fitting, compatibility with actual semi-variance points is obtained by applying non-linear approximation of the smallest square. Previous application of kriging in the case of the landfill provided different results. Czepiel [15] used kriging for establishing total flux from the landfill surface and found that autocorrelation of data obtained from points was at mutual spaces between points for sampling which were at the distance of 0.6-7 m. The fluxes were determined by applying corresponding variogram with combined exponent (the Gauss' model). Börjesson [17] used three different approaches for determining overall methane emissions from the landfill surface: kriging with logarithm transformed data, kriging with discarded extremes, and linear interpolation of measured results. Data indicates that measurement of flux is in correlation within the range of 70 m. However, Klusman *et* *al*. [18] did not manage to find correlation between data of adjacent points for flux within the range of 30 m.

Since measurements at available gas wells at the landfill in Novi Sad are within the range of 50 m, and based on previous research, the 3-D visual analysis of results by kriging method is considered to be appropriate. After kriging analysis (fig. 6) it can be noticed that there is a shift of landfill gas concentration front towards the part of the landfill where waste is currently being disposed.

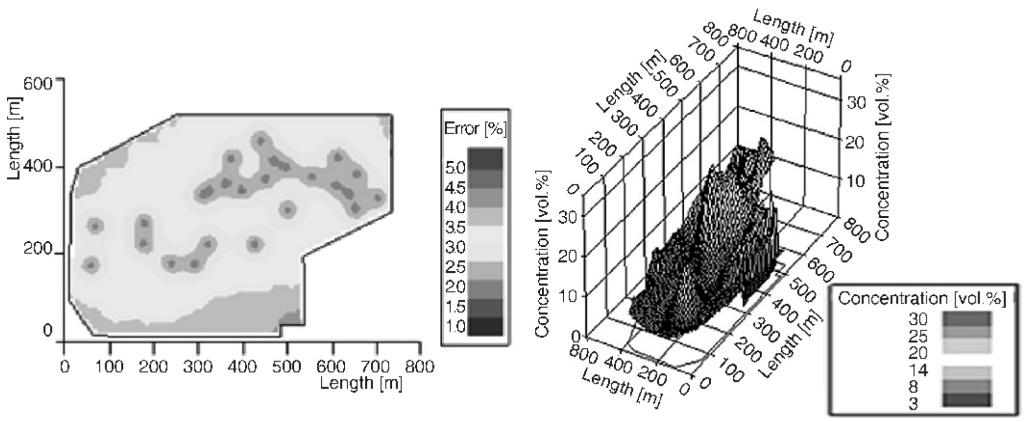

Figure 6. Kriging analysis – Visual presentation of measurement data for determination of influence of waste age to methane production on Novi Sad landfill

In old parts of the landfill, lower concentrations of methane are measured because the process of degradation and methane generation is slower and less intensive than process at places where disposed waste is 1 to 5 years old. Analysis of results by means of the kriging method represents an analysis of results measured in the *in vivo* experiment.

Conclusions

Experimental researches have been devised and designed in order to analyze the influence of seasonal variations of ambiance temperature on the stability and quantity of generated landfill gas, with special emphasises on methane.

Deviations of strict dependence of methane generation and temperature, as well as "delays", that is, inertia occurring relevant to those two parameters can be explained by insufficient depth of the landfill's body, with influence of other significant factors on methane generation. The influence of temperature on biochemical processes intensity reduction is indicated by decreased methane detected in gas wells with decreasing ambient temperature. For example on gas well S3-4 during the summer and autumn concentration of methane in landfill gas was about 6% by volume, during the spring less than 3%, and in winter season methane concentration was not detected. The inertia in this phenomenon is explained by the absence of insulation regards to small depth of disposed waste. With increasing depth of landfill waste, the ambiance temperature has less influence on landfill gas generation stability at Novi Sad landfill. Measurements on gas well DII-4, which is located on Filed II with waste depth of about 7 m, show methane content of 27% and 31% by volume in summer and autumn and 20% and 24% by volume during winter and spring.

By sphere interpolation and visualisation of functional dependence of methane concentration and outside temperature with spatial co-ordinates of the source, spatial 3-D models have been obtained which have defined and confirmed the assumptions. The area at the Field I and at the Field IIIa represents the oldest parts at which biochemical processes are in final phase with low level of methane generation. On Field II and partially on the Filed IIIb, where waste is still disposing, the generation of landfill gas and methane is more intensive. Taking into account comparative data analysis based on the literature, theoretical considerations, modelled results, and original experiments, it can be concluded that depth of landfill body in Novi Sad is not sufficient for continuous – stable generation of landfill gas, particularly methane, during the entire year regard to influence of ambiance temperature. Although landfill gas potentials are obvious, the use of methane for energy utilization at the Novi Sad landfill is not efficient under the present conditions.

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