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Study of Biogas Composition on Operational and Non-Operational Landfill Sites from Poland

GRZEGORZ PRZYDATEK[1*], NARCIS BARSAN[2*], ARTUR ŚWIGUT[1]
[1]Engineering Institute of State University of Applied Sciences in Nowy Sącz, Zamenhofa 1a, 33-300 Nowy Sacz, Poland
[2] Vasile Alecsandri" University of Bacau, Faculty of Engineering, Department of Environmental Engineering and Mechanical Engineering "157 Calea Marasesti, 600115, Bacau, Romania

Abstract: *An assessment of the variability of biogas components captured in an active and closed municipal waste landfill sites differing of amount deposited waste, activity period with their passive degassing, was presented in the article. The results of research did not show significant differences between components of LFG from studied landfill sites. But was confirmed that the two landfill sites including used landfill site, became at the last phase degradation of waste and advantage the anaerobic processes at the low value below 0.02 of CH_4/O_2 indicator. It was demonstrated by the very low average methane content below 1%, and significant higher of oxygen above 19%. This confirm that only way of biogas utilization is to burn it in flare on the landfill sites*

Keywords: *biogas, waste, methane, composition, landfill sites*

1. Introduction

The increase of municipal waste is due to urbanization and have a negative impact to human health and a quality of life in general [1, 2]. The changes in waste management which took place in the recent years are aimed to reduce the amount of generated municipal waste and waste deposited at landfill sites [3].

Therefore, one of the important elements of waste management remains the storage [4], which consists in placing waste in specially landfills. In Poland, over the past years, a noticeable decrease of active landfill sites number of has amounted to 125 [5]. This favorable trend does not diminish the environmental issues that these facilities can produce during their operation and after their closure in principal because are considered as an active biochemical reactor. The potential problems generated by municipal waste landfills also concerns the people and depends on the age of the landfill site [6].

In the case waste landfills one of major factors that affect the environment is the presence of landfill gas (LFG), which are mixture resulting from the decomposition of organic compounds, mainly consisting of: methane (CH_4 50-60%), carbon dioxide (CO_2 40-50%) and small traces other gases [7]. Some research [8] showed that the content of the gas components depending on its source.

The biochemical reactions from waste landfills include through three phases: an aerobic phase, an acid phase and the methanogenesis. During these processes the main indictor is CH_4 which determines the future management of biogas [9]. This gas may be used for energy production (i.e. by burnt to produce heat), used as fuels for gas turbines to recover electric power or combined heat and power [10].

In order, to reduce the harmful emission of methane to the atmosphere, measures are taken to limit the deposited of organic waste through selective collection before storage [11, 12].

The biodegradable waste contained in municipal solid waste (MSW) has the potential to produce biogas because of anaerobic digestion [13]. On the base of the requirements of the European Commission Directive EC 31/1999 landfill gas must be captured and incinerated, and it is recommended to recover it in the form of energy [14]. According to [15] combustion of a landfill gas in a flare is one of the solutions inflowing the reduction of greenhouse gas emissions.

The aim of the study was to assess the components of LFG captured vertically under the conditions of passive degassing in an operational and non-operational landfill sites from southern Poland, for period 2014-2016, in the context of comparing the parameters variability.

**email: gprzydatek@pwsz-ns.edu.pl, narcis.barsan@ub.ro*

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2. Materials and methods

2.1. Study area

The LFG test was carried out at an active landfill site in S and a closed landfill site in M (Małopolska Voivodship, South Poland) (Figure 1). The monitored parameters were carbon dioxide (CO_2), oxygen (O_2) and methane (CH_4) in an active landfill site for 2014 and 2015, and 2015-2016 for closed landfill site. The LFG composition was determined by using Geotech GA2000 Industry Standard Landfill Gas Monitor. Gas volume emission was not monitored in the research due to the low quantity's detection. The performed analysis included descriptive statistics: arithmetic mean, minimum, maximum and standard deviation (SD) [16]. For the calculation of some statistical parameter values, the measurement result below a given limit of quantification was determined at the level of half the value of this limit, i.e. the output signal or concentration value, above which it can be stated with certain certainty that the sample differs from the so-called limit of quantification blank sample. CH_4/O_2 ratio was also determined, which was also the subject of research conducted by some researchers [17]. The number of LFG composition measurements ranged from 13 to 83.

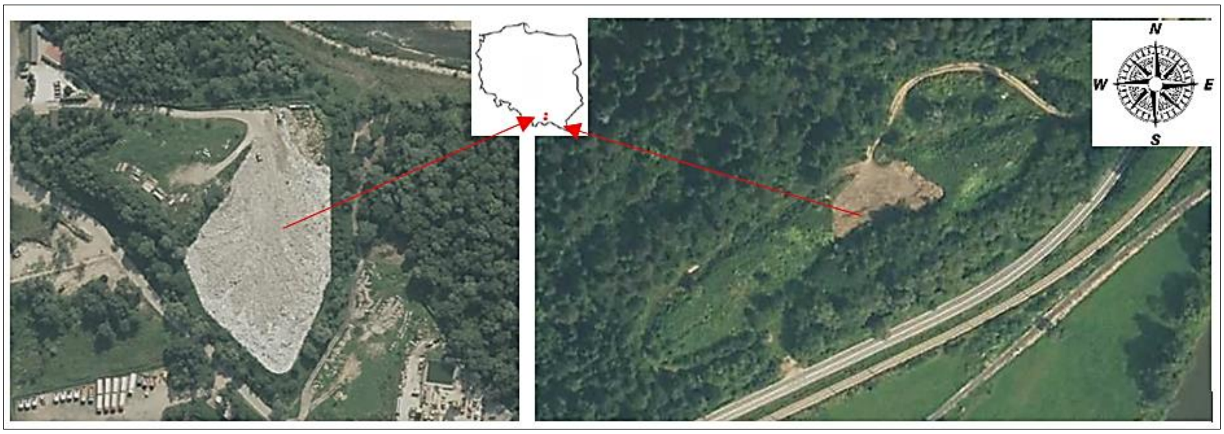

Figure 1. The operational municipal landfill site - S (left), non-operational municipal landfill site M (right) localisation - Malopolska Voivodship (Souther of Poland)

2.1. Non-operational waste landfill sites - M

The analysed closed landfill site is in the south-eastern part of the Nowy Sącz County (N: 49°33'77.54 "E 20°83'92.38) at the border with Slovakia (Figure 1). The total area of landfill site is 0.805 ha. This landfill site is situated on the border of a mountain slope adjacent to the Poprad river valley. There is a slope of the landfill in the south direction. The area of the closed landfill is practically flat, it was shaped during its operation. This object is located between 449.1 - 451 m asl.

The existing mountain climate within two climatic spheres, moderately warm floors up to 700 m asl. with a total rainfall of 700 - 900 mm/year and an average annual temperature of 6 - 8°C, as well as in a moderately cool storey located in the range of 700 - 1100 m asl. with a total precipitation of 1000 - 1100 mm/year and an average annual temperature of 4 - 6°C. Snow cover usually occurs in mid-November to the end of March or the beginning of April. Due to the valley layout, the winds occurring in M are south. Most of the winds are warm winds of the fen type, which occur mainly in winter and spring. It is situated on the geological basis of the Carpathians - Magura Nappe. The mountain peaks are made of thick-bedded, coarse and medium-grained submagurian and magurian sandstones. The sandstone banks are separated by silty and clay shales, also of a small thickness of mudstones. The substrate is mainly made of clays, clays, weathered rock, deluvial and colluvial rubble, as well as in the valleys of streams, rivers, gravel, clays, sands, and clays.

There is GZWP (Main Underground Water Reservoir) No 438 layers, Nowy Sącz Magura in the area of the landfill site. The reservoir is located within the flysch Carpathians, it is separated according to individual criteria, to protect the most efficient rocks, which is a source of drinking water supply.

The landfill site M was established in 1969 and was used until 2010. Previously period this landfill site was modernized, after which it was classified as a non-hazardous landfill. Two quarters were separated in the landfill site, in which 3.043 Mg of waste was deposited.

The landfill site has an embankment built of impermeable soil. The foot of the slope and its interior have been lined with a bentomat (impermeable layer). Behind the shaft, on its inner side, there is a drain made of a Ø 150 mm PVC pipe. The bottom layer of the landfill is made of 65 cm thick bentomats; geotextiles (g = 800 g/m^2); Slabs 15 cm thick; shock absorbent recycled closed cell polyethylene foam material 3.5 cm thick.

Two troughs have sealed slopes and the bottom, which protects against contamination (contamination) of groundwater.

The landfill site drainage system consists of two lower and upper drains. The drains are made of Ø 150 mm PVC pipes and are situated in a gravel and sand bed with a thickness of about 25 cm. The collected leachate is discharge to a sealed tank, and then transported to the sewage treatment plant.

The degassing of the landfill site is provided by a pipeline and two degassing chambers are connected through HDPE pipes Ø 150 mm in a gravel and sand bed [18].

2.2. Operational municipal landfill site - S

The active municipal waste landfill site in S is located in the Nowy Sącz County, more precisely in the south-eastern part of the Małopolskie Voivodship (N: 49°55'31.74 " E: 20°65'68.55) (Figure 1). It is situated in the area of two climatic levels in a warm temperate climate with the sum of annual precipitation in the range of 800 - 1000 mm/year and an average annual temperature in the range of 6 - 8°C, in a cool temperate climate with precipitation 1000 - 1400 mm year - 1 and an average temperature in the range of 4 - 6°C. The days with snow cover range from 113 to 125 days/year.

This landfill site covers area of 1.45 ha is located at an altitude of 307-309 m asl. and within the Western Carpathians, built of flysch sediments. Flysch sediments consist of conglomerates, sandstones, and shales. The Poprad River, which is a tributary of the Dunajec River, flows near the landfill site. In this area, there is the GZWP (Main Underground Water Reservoir) No 437, associated with Quaternary alluvial sediments. This type of reservoirs as a pore center are located in Holocene sand-gravel and sand formations [18].

The landfill site in S was established in 1999 and covers an area of 1.45 ha. The landfill site includes the first sector with an area of 0.57 ha, intended for reclamation, the operating capacity of which is 86.268 m^3, and the second active sector with an area of 0.88 ha and an operating capacity of 134.932 m3. Residual waste delivered to the landfill is subject to compaction. The total amount of waste deposited in the landfill was 5,266.32 Mg.

The landfill site was embanked with waste generated as well as clay-rocky and sand-gravel deposits. The embankment of the landfill rises to a height of 2 to 5 meters asl. The bottom of the first and second plots has been sealed with synthetic insulation. The insulation was made of HDPE geomembrane with a thickness of 2.5 mm as well as geotextile to separate the deposited waste from the ground.

The landfill is drained with Ø 100 mm drains placed on the bottom in the quarters in a gravel and sand bed, thickness of 25 cm. The collected leachate is discharge to a sealed tank.

The degassing of the active landfill site in S consists of 5 wells. These wells were made of HDPE pipes in a gravel and sand bed [19, 20].

3. Results and discussions

The LFG composition from closed landfill sites [21] showed that the average oxygen content 19.47% and was slightly lower by 1.03% compared to the result obtained in an active landfill site (Table 1). Standard deviation of 1.21% occurred in the closed landfill site. In this landfill site, the highest maximum value of 1.80% was also characterized by the determination of CO_2 in the closed landfill site. The average content of this determination in a closed landfill was 0.14% higher in relation to an active landfill site. The standard deviation result in this facility was also higher by over 0.30%.

A significantly low average methane content of 0.09% was found in the tested gas in the closed landfill site, with a higher average content (0.32%) of this component in the operational landfill site. The value of the standard deviation of methane on this object was also higher by 0.48% then in the compared one.

During the first two years, the average O_2 content increased by 0.34% in the non-operational landfill site. For the other indicators were recorded a decrease respectively 0.08% for CH_4 and 0.16% CO_2 (Table 1).

In the case of operational landfill site during, the average O_2 content dropped by 0.08%. On the contrary, the content of CH_4 and CO_2 showed an increase of 0.14 and 0.12% (Table 2).

The CH_4/O_2 ratio in the closed landfill site was at average 0.005 and significantly differed from that obtained in an active landfill site, which was 0.016 and significantly differed from 1.

In 2015, for the case of active landfill site were recorded a higher average of O_2 content 20.46%, in comparison with the closed landfill were O_2 content was 19.30%. These results can be compared with the high content of oxygen in biogas showed by [22]. Similarly, the average CH_4 content in the active landfill site was at highest value of 0.34% compared to 0.09% in the closed landfill site. On the other hand, the average CO_2 content in closed landfill site was one of the highest values in the entire research period and amounted to 0.58%, and in an active landfill site it was only 0.16%.

Table 1. Composition of biogas from non -operation landfill site

Period	Average value [%]			
	O_2	CO_2	CH_4	CH_4/O_2
2015	**19.30**	**0.58**	**0.13**	0.007
2016	19.64	0.42	0.05	0.003
Average	19.47	0.50	0.09	0.005
	Value [%]			
Min.	18.60	0.20	0.05	-
Max.	21.50	1.80	0.30	-
SD	1.21	0.60	0.11	-

Table 2. Composition of biogas from operational landfill site

Period	Average value [%]			
	O_2	CO_2	CH_4	CH_4/O_2
2014	20.54	0.30	0.30	0.015
2015	**20.46**	**0.42**	**0.34**	0.017
Average	20.50	0.36	0.32	0.016
	Value [%]			
Min.	12.90	0.30	0.30	-
Max.	21	0.30	0.30	-
SD	0.95	0.29	0.59	-

Analysis of the results study of LFG composition captured in two municipal waste landfill sites at different amounts of deposited waste, showed a very high average oxygen content, within 20%, both in the active landfill site and the closed one. There was a noticeable decrease in this ratio in the used landfill site, as opposed to the closed one. According to [23], the advantage of aerobic processes over anaerobic ones could be caused by the easy access of oxygen to the deposited waste (Figure 2).

Rodin et al. [24] showed another component of biogas - carbon dioxide, as a global threat due to its classification as greenhouse gases. The average content of this indicator in a closed landfill was 0.14% higher than that shown in an active landfill with a downward trend. Higher CO_2 content in studies at the landfill site was shown by Yang [17]. Kumar et al. [25] noted that a decrease in CO_2 content is possible up to 25 years after the methanogenesis phase.

Another LFG component - methane is also considered as indictor significantly affects the greenhouse effect [26]. Usually, its contents depend on the biodegradable part of municipal solid wastes and also on design of landfill sites [27]. The average methane content of 0.34% was the highest in the active landfill.

The closed landfill site showed a decrease in methane content, as well as its lowest share of 0.09%. Ciuła et al. [28] also showed the lowest content of CH_4.

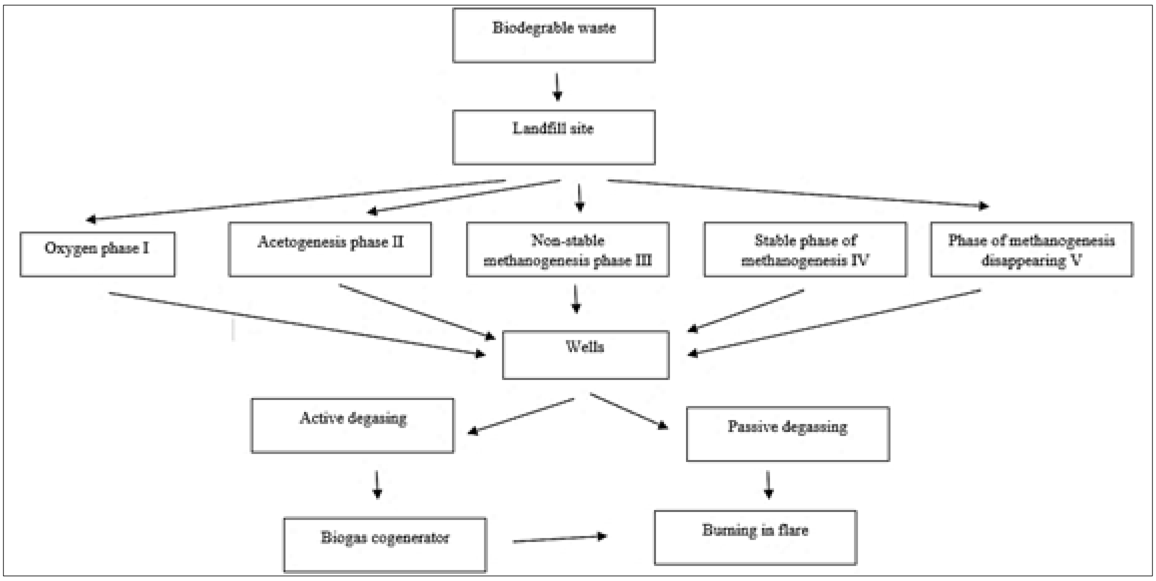

Figure 2. Capture and utilization of LFG in landfill sites during active and passive their degassing conditions

The decrease of CH_4 content in the field of the studied landfill site should be considered positive in the context of minimizing negative impact on the environment. It must be noted that higher organic waste content usually has an impact on the high methane content. Another factor, which can impact on the generation of methane in a landfill site, is the moisture content on the level 40-70% [29-31].

The composition of gas in the analysed landfill sites basically did not show any significant differentiation of its components at the high average share of O_2 over 19% and a low share of CO_2 not exceeding 0.60%. According to Porowska [6] oxygen is a component of the landfill gas in the final stage of the facility operation. On the other hand, the average CH_4 content remains very low, below 1%, with a CH_4/CO_2 ratio below 0.02, which indicates that the last phase of waste degradation has occurred [32], despite the using of one of the landfill sites. This generally did not demonstrate the economic exploitation of LFG. Spokas et al. [33] and Christophersen et al. [34] showed a high proportion of CH_4 at its content of more than 50%, enabling energy recovery in combined form. Other researchers [35, 36] have shown that organised landfill gas intake reduces greenhouse gas emissions to the atmosphere. Due to the low CH_4 content, the indicated method of biogas utilization in the analysed landfill sites may be combustion in a flare (Figure 2).

4. Conclusions

Analysis of the composition of LFG captured in two municipal landfill sites at the different amounts of deposited waste, remaining in two different phases with passive degassing showed:

• high average oxygen content at the level of approx. 20%, which occurred both in the active and non-operational landfill sites with a noticeable decrease in the used landfill site, confirms the advantage of aerobic processes over anaerobic ones,

• CO_2 content in a closed landfill site, which was higher by 0.14% than that indicated in an active landfill site, with a noticeable decrease,

• a very low average of CH_4 content of less than 1% in an active landfill and 0.10% in a closed landfill site at the CH_4/CO_2 ratio below 0.02, confirms the last phase of waste degradation,

• the direction of biogas utilization is indicated by possibility of its flaring due to the low share of greenhouse gases.

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