INSTABILITY IN PRODUCTION OF LANDFILL GAS DURING LANDFILL BUILDING

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Abstract: *The separation and combustion of methane, which is the main component of landfill gas, represents significant contribution to the reduction of gas emission with greenhouse effect. By building sanitary landfill "Livade" in Podgorica, the conditions were made for building system for landfill gas capturing, which is the first phase in control of emission from landfill and its efficient usage. The problems of building and exploitation of the landfill gas capturing system, which is based on network of vertical wells, that are during the filling of landfill, made by principle of elevation, are presented in the paper.*
***KEYWORDS**: LANDFILL GAS, MUNICIPALE SOLID WASTE, CAPTURING SYSTEM*

1. Introduction

Landfill of municipal solid waste is located south-east from Podgorica, 5 km from city centre, on the location "Livade", just next to local road Podgorica – Dinosa, near the Cijevna river, which flows to the south. The landfill area, until now, has been the place for unselective and uncontrolled waste dump for more than 50 years, on classical way and without appropriate measures in human environment protection. On the landfill primarily is dumped waste from communities Podgorica and Danilovgrad, and since the beginning of 2008. waste from some seashore communities.
With main project of rehabilitation and organization of city landfill, it is expected that the waste be dumped in organized and arranged way, according to the regulations that apply in countries of European Union, where priority is given to human environment protection.
Because of that, as a part of solution to the waste disposal and storage problem, considering that release of landfill gas represents physical (explosion), chemical (harmful substance in surrounding air) and physiological (odour) risk for people who work and live in the vicinity of landfill, system for landfill gas capturing is predicted, its transport in controlled way and in the first phase its combustion (treatment) [1,2].

2. The dynamics of landfill filling

The sanitary landfill (in its final form) should consist of six cells dimensions 100 × 200 m, which are located in the central part of complex. Every cell has implemented system for collecting and dispositioning leachate waters, system for capturing and dispositioning of biogas, and system for collecting and dispositioning of pure atmosphere water. In first period construction of 1.500.000 m^3 of landfill is predicted, with three cells of 500.000 m3 each and it is planned that construction of every cell should be completed in year that preceded its usage.
Waste layers are stamped down with 6-7 crossings by 29 t compactor. In that way we reach the density of 750-850 kg/m^3. For calculation the average density of 800 kg/m^3 is used, which means that total mass of waste of one cell is 400.000 t. Three cells will be built during start year, 4th year and 12th year; that is, filling of second cell begins in 2009, and of third in 2017.
Fourth cell should be opened around year 2030. Such time inconsistency is conditioned by the fact that filling of the first cell is accelerated by income of waste from old landfill rehabilitation, and temporary waste income from seashore community. During first ten months of 2005. approximately 305.000 m^3 of old waste was placed in the first cell as a result of old landfill rehabilitation, with assumed 50% of organic matters, which has already started with decomposition. The mass of old waste is estimated based on transported waste per 160.000 t. The dynamics of first cell filling is established by measuring disposed waste of 50.000 t annually until 2008. Usual daily quantity of waste which arrives to landfill is 150 m3, and with the waste coming from the seashore it is 250 m^3. For the summer season it is predicted quantity of 300 m^3 of loose waste. The two years contract for waste disposal from the seashore communities is signed. In that way waste quantity during 2009. is increased up to 70.000 t.
From 2009. introduction of waste selection programme should start, which results in decrease in disposed waste quantity, increase in organic matter percentage in disposed waste, which leads to increase in landfill gas production. It is assumed that public education and waste selection should also compensate increase of population in municipality of Podgorica, so that disposed waste quantity should decrease to 35.000 t annually starting from 2014. That waste quantity is retained until the end of calculations.

3. Landfill gas capturing wells

The biogas capturing system predicted by the project is based primarily on network made of vertical extraction wells, which are during the filling of landfill made by principle of elevation (fig.1).

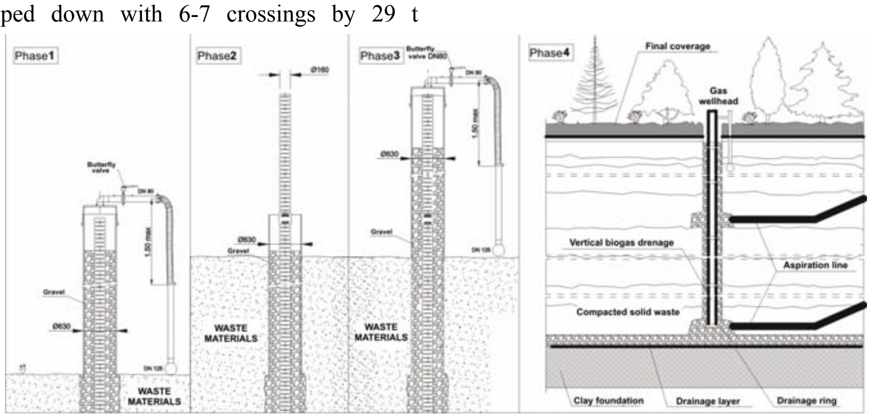

Figure 1. *Phase of extraction wells elevation*

Determine factor while calculating capturing network, which is organised on vertical elements, is called „ radius of influence“. Radius of influence is distance in which well, with applied sub pressure, preserves capability to develop its own action efficiently. The project of capturing network predicts complete coverage of landfill area with wells with radius of influence of approximately 25 metres.

For each parcel is predicted 21 extraction wells divided into three routes (fig. 2). In addition, in order to include complete landfill, after the parcel merging, along the route that separates the parcels 1 and 2, and parcels 2 and 3, another line of extraction wells will most likely be added.

Figure 2. *Landfill „Livade“ – parcels 1 and 2*

4. Analysis of landfill waste

The structure of municipal solid waste, which is disposed in loosely state in the existing landfill, is organic and inorganic origin, and the annual amount is about 50000 t. According to tested samples of municipal solid waste that is disposed, structure is given in tab. 1. Row „the rest“ in morphological analysis is related to batteries, transformers, hospital waste and similar material.

Table 1. Analysis of waste samples from the landfill [1]

Morphological analysis		Organic fractions	
Paper	17%	Humidity at 10 °C	54,0%
Plastics	9%	Volatile matter 600 °C	83,0%
Textiles	5%	Ashes at 600 °C	36.9%
Glass	5%	Carbon (C)	17.1%
Metal	4%	Nitrogen (N)	0,54%
Organic	50%	Total phosphorus (P)	624 mg/kg
Rest	10%	Organic carbon subject to decay	37,0%
Sum	100%		

5. Calculation of landfill gas production

When waste quantity that is taken to the landfill annually is determined, and when the generation of landfill gas per tone of waste, based on composition, is estimated, it is possible to determine total amount of landfill gas that will be generated on whole landfill, including overlapping effects.

For calculation of total amount of landfill gas, US EPA programme Landfill Gas Emissions model (LandGEM) Version 3.02 [19] is used, which is based on empiric First-Order Decomposition Rate Equation

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_o \left[\frac{M_i}{10} \right] e^{-k\tau_{ij}}$$

where:

Q_{CH4} [m^3/year] - annual methane generation in the year of the calculation,
n - year of the calculation, initial year of waste acceptance,
j = 0.1 - year time increment,
k [year^{-1}] - methane generation rate,
Lo [m^3/t] - potential methane generation capacity,
Mi [t] - mass of waste accepted in the i-th year,
t_{ij} - age of the j-th section of waste mass Mi accepted in the i-th year (decimal years)

Calculations are done separately for each cell. It should be noted that the calculation for the first bath is divided, as much of the other characteristics of waste to create landfill gas, in two parts: the old waste and recently received waste. Extract from the calculation, with the accent on the initial year, is given in tab. 2.

Table 2. Estimated quantity of landfill gas

Year	Landfill gas production [m^3/h]					
	Cell 1 – old waste	Cell 1 – new waste	Cell 2	Cell 3	Landfill total	
					Produced	Captured
2008	69.6	129.3	-	-	198.9	99.5
2009	68.2	182.6	-	-	250.8	125.4
2010	66.8	197.8	52.5	-	317.1	158.6
2015	60.5	162.0	283.4	-	505.9	252.9
2019	55.8	138.0	383.7	19.0	596.5	298.3
2025	49.5	108.6	301.9	367.0	827.0	413.5
2030	44.8	88.9	247.1	587.1	976.9	488.5

6. *Factors that affect landfill gas production*

Decomposing of solid waste in controlled landfill often takes various and complex aspects. It is primarily about the physical, chemical and biological processes that occur at the same time all the time while the waste is not decomposed.

Landfill gas is composed as a mixture of hundreds of different gases. By volume, we can say that it is primarily composed of two gases: 40-60% of methane (CH4) and 40-60% of carbon dioxide (CO2). In combination with these gases, oxygen (O2) and nitrogen (N2) are also present, because they are present in the form of air in free spaces in the waste, at the time of disposal, or they are attracted from the atmosphere by dynamic action of aspiration. In lower quantities, there are ammonia, sulphide, hydrogen, carbon monoxide and non-methane organic compounds (NMOCs).

Estimates related to the generation of landfill gas on one controlled landfill, require knowledge of numerous parameters that are related to the dynamics of landfill filling, chemical and physical characteristics of waste, way of disposing and covering waste, and to the local climatic and hydro geological conditions [3,4,7].

Table 3. Factors that influence the generation of landfill gas

Characteristics of the environment	Characteristics of waste	Ways of management
Precipitation	Composition and moisture content	Depth control landfills
Air temperature	Granulation during disposing	The method of waste disposing
Sunlit	Density	Materials for temporarily overlap
Windiness	Pre-treatment	

Waste composition.The more organic waste present in a landfill, the more landfill gas is produced by a bacterial decomposition. Some types of organic waste contain nutrients, such as sodium, potassium, calcium and magnesium that help bacteria thrive. When content of this nutrients increases, landfill gas production also increases. Alternatively, some wastes, especially industrial, contain dissoluble salts of copper, zinc and nickel that are harmful for development of methanogenic bacteria.

Oxygen in the landfill. Only when oxygen is used up methane generation occurs. Oxygen in any amount destroys the activity of methanogenic bacteria, however, they form spores, and when anaerobic conditions are restored, their activity continues. The more oxygen present in a landfill, the longer will activity of aerobic bacteria last. If waste is poorly compressed during the disposal, more oxygen is available and vice versa, good composting and compressing speeds up the beginning of activity of methanogenic bacteria. Barometric pressure and wind also have impact on its presence. At the higher wind and barometric pressure, atmospheric air is repressed through the surface layers deeper in the landfill, which causes termination of activities methanogenic bacteria and termination of anaerobic phase, and start of the aerobic phase.

Moisture content. The presence of a certain amount of water in a landfill increases gas production because moisture encourages bacteria growth and enables transport of nutrients and bacteria's along whole landfill cell. Weight content of moisture higher than 40% speeds up the production, where the maximum speed is achieved in the mass content of 60-80%. Compacting waste in this way slows down the speed of water penetration through the landfill. The occurrences of heavy rainfalls are suitable for the creation of landfill gas. Moisture content of the landfill can also be increased by bringing additional water or by recirculation of leachate water through the landfill.

Temperature. Temperature is important for the process of decomposition because it is directly connected with the speed of biological activity in landfill. Warmer temperatures, the optimal 25 to 45 °C, enhance the production of gas. Colder temperatures inhibit bacterial activity. Below 10 °C, bacterial activity drops off dramatically. Weather changes have a great importance on the production of gas in shallow landfills. Capped, deep landfills usually maintain stable temperature. Temperature of a landfill increases as a result of aerobic activity of bacteria and as a result of chemical reactions during the decomposition of waste. As a general rule, emission of NMOCs doubles with every 8 °C increase in temperature.

Age of waste. Freshly laid waste produces more gas. Landfills produce noticeable amounts of gas within 1 to 3 years. Highest production of gas usually occurs 5 to 7 years after waste is dumped. Almost all gas is produced within 20 years after waste is dumped, however, small amounts of gas may continue to be emitted from a landfill for up to 50 years. A low-methane content scenario, assumes that slowly decomposing waste starts with the production of methane after 5 years and continues for next 40 years. Different parts of a landfill may be in the different phases of decomposition process at the same time, depending on the time of disposal and the composition of waste in each section.

7. *Productivity analysis of sanitary cell 1*

Exploitation of landfill gas started in february 2008. In the first phase is predicted that landfill gas is sent from extraction station to high temperature flare where it combusts. Landfill gas combustion with an average of 50% methane even without its economic valorization has a significant ecological contribution related to reduction of methane emissions in the atmosphere and thus to reduction of greenhouse effect. It also reduces the possible health risk by destructing most non-methane organic components and harmful air pollutants that contribute to smog appearance in the local area, it improves ecological conditions on the landfill (with limitation of landfill odour), and reduces the risk of explosion caused by landfill gas accumulation.

Table 4. Overview of realized landfill gas production in 2008

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Average daily [m^3/h]		42.4	62.7	56.9	71.9	18.9			54.4	48.3	72.7	69.3
Av. daily min [m^3/h]		39.2	38.4	39	52				44.5	45.3	48.6	41.7
Av. daily max [m^3/h]		49.8	100.3	90	97				97.4	98.2	98.1	102.2
Flare temp.min [^oC]		826	853	836	842				825	743	814	805
Flare temp.max [^oC]		897	928	920	898				905	849	928	938

Given consideration to predicted way of gas capturing and during the raise of sanitary cell, problems related to organization of delivery and waste compression occurred, because transport paths around extraction wells are now intersected with transportation pipelines (fig. 2). In the phase of raising the landfill, transportation pipelines are set visibly with temporary fixation with appropriate pins with the holders. In order to allow waste transportation and disposal, some wells are temporary sealed and unhooked from transport line, and pipeline is relocated to facilitate the work of heavy machinery. Extraction from all wells at the same time is almost never performed at this stage. This causes considerable fluctuations in the production of landfill gas, which can be seen in tab. 4, where the amount of daily production in some months varies more than two times. This often relocation of pipelines is suitable for emptying of pipelines from the resulting condensate.

From the standpoint of meteorological conditions, given the frequent exclusion of certain wells and lines, direct link in the phase of raising the landfill cannot be determined. Although preliminary climate analysis (tab. 5) of air temperatures and amount of rainfalls indicate that year 2008 in the majority of Montenegro was one of the warmer since instrumental measuring are used, while the annual sum of rainfalls was generally in the range of normal values [20].

Table 5. Overview of hidrometeorologic data for the city of Podgorica [20]

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Temperature MYA	5.4	7.3	10.4	14.1	24.2	25.6	26.2	26.9	21.8	16.6	11.1	7.0
Temperature 2008	6.8	8.2	11.2	15.2	26.5	26.8	27.1	28.5	21.9	17.7	12.7	8.3
Rainfall MYA	191.6	166.5	159.0	145.2	63.1	52.8	38.5	26.5	119.6	164.2	188.5	220.5
Rainfall 2008	209.1	63.1	317	71.0	40.4	125.7	28.2	17.2	76.1	149.8	208.4	347.5

However, by comparing the cumulative amount of rainfalls and the annual surplus/deficit for 2008. year to cumulative production for 2008. year, it shows that the curves have the same character, and that the reduced amount of rainfalls is followed by decreased production (figure 3 and 4).

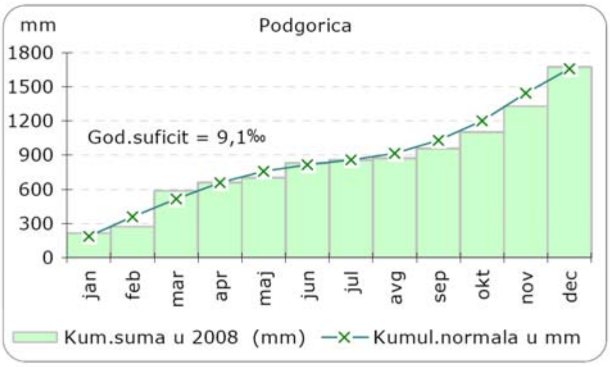

Figure 3. Cumulative rainfalls for the city of Podgorica in 2008. [20]

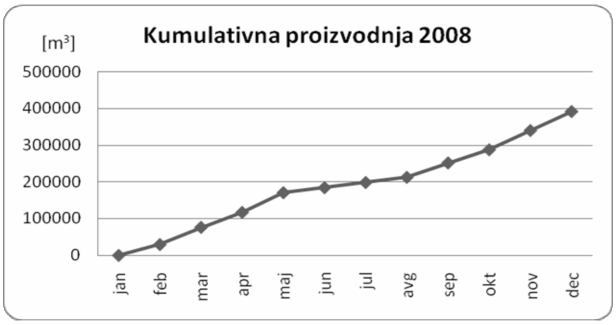

Figure 4. Cumulative production of landfill gas from sanitary cell 1 in 2008.

At the end of October in 2008. it started with the filling of sanitary cell 2, and stopped with waste disposal to sanitary cell 1.This quickly filling up of cell 1 is conditioned by the problems with the disposal of waste in some coastal municipalities except those with which the contract was signed, which disposed their waste during 2008. on the landfill “Livade”. Sanitary cell 1 is not fully completed, because it is awaited for the natural subsidence of waste. After that the filling in of cell with fresh waste will be done, along with final planning and cell covering. Therefore, it is interesting to consider the production in sanitary cell 1 during the month of January 2009 and compare to existing meteorological data [21].

Climate of January: in the majority of Montenegro was hot, somewhere extremelly hot; positive deviations of all parameters of air temperature, except the absolute maximum; large positive deviation of minimum temperature, up to +15 °C; monthly sum of rainfalls generally above climatic normal; extreme cyclonic activity in the period 19-25 January and abundant rainfalls.

Even now, all capturing wells are still not operational. Their disconnection is a consequence of allowing access to the landfill for levelling the ground, and emptying condensate from transportation pipelines because at this phase due to ground subsidence curves on pipelines occur, which prevent drainage of condensates by the principle of natural fall. In the final configuration (after the subsidence of waste) transportation pipelines will be buried at a depth greater than 60 cm in trench covered with fine material which is not drainage one, followed by carrying out adequate natural fall, which should allow free drainage of condensates to separation wells.

It can be seen (figure 5) that the production of mid-January was stabilised at about 100 m^3/h, and that the combustion of landfill gas at the flare was continuous. Stability of production is accompanied by the beginning of abundant rainfalls at the area of Podgorica (figure 6).

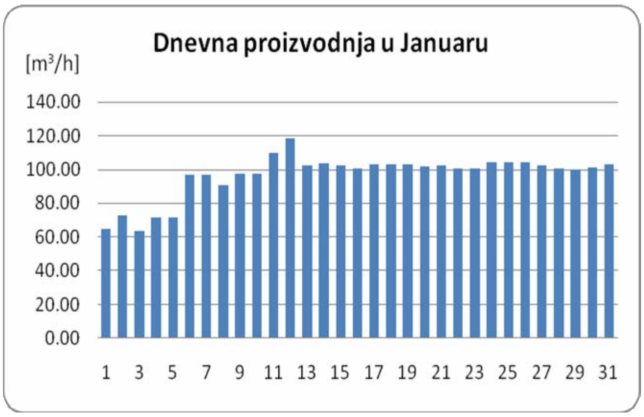

Figure 5. Overview of the daily production of landfill gas from sanitary cell 1 during January 2009.

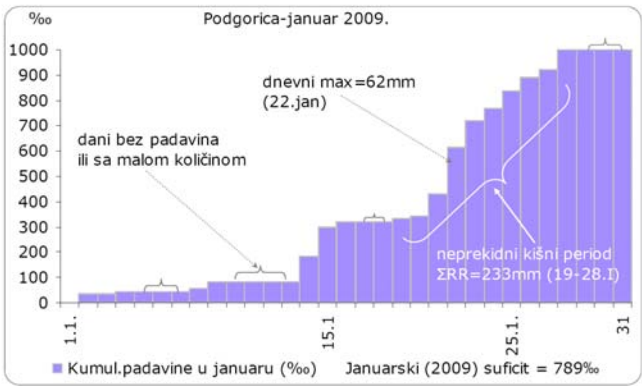

Figure 6. Cumulative rainfalls for city of Podgorica during January 2009. [21]

8. Conclusion

Landfill "Livade" in Podgorica is the only operational sanitary landfill in Montenegro. The construction of the landfill started in 2006 by digging the first parcel. System for landfill gas capture is predicted at the landfill. The main component of landfill gas is methane (40-60%), which by the IPPC Directive, is considered as polluter that contributes to global warming 21 times more than carbon dioxide. Therefore, it is important to reduce the emission of methane from municipal solid waste landfill. This can be done either by direct burning at the flare, as it is the case here, or landfill gas can be used as fuel gas for gas internal combustion engines, or at boilers for production of electric and/or heat energy. One of the ways of its economic valorization is the addition of gas in the gas line system when it exists. Landfill gas exploitation in the first year showed large fluctuations in the amount of captured gas, that are primarily caused by difficult conditions of the network maintenance, in the phase of raising the landfill. Considering that the sanitary cell 1, which was the object of discussion, is not finished, the direct influence of weather conditions on the amount of captured gas is noticed.

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