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THE PROCESS OF CREATION AND ANALYSIS OF THE LANDFILL GAS FROM THE LANDFILL IN THE REGION OF PCHINJA

PROCES STVARANJA I ANALIZA DEPONIJSKOG GASA SA DEPONIJA U PČINJSKOM REGIONU

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ABSTRACT

In this paper the processes that take place in the dumps and methods of formation of the landfill gas were first theoretically analysed, and then on the specific cases. The proper management of the landfill gas is examined. The potential treatment of the landfill gas is shown through the scheme, and it provides an overview of how the landfill gas can be used for combined heat and power generation. The results of measurements of the concentration and composition of the landfill gas in the Pchinja region are presented, as well as on the landfills in Vranje, Bujanovac, Trgovishte, Bosilegrad and Vladicin Han. The systematic monitoring pointed to an inadequate placement and the insufficient number of biothorns. The conclusion is that the minimal measures of protection from an explosion and fire are not done correctly. Further researches should be directed toward preventing the release of hazardous gases from the landfill body into the atmosphere. It is necessary to find positive solutions for the re-use of the landfill gas as a renewable energy source.The aim is to move from passive to active extraction systems.

***Key words:** landfill, waste, landfill gas, methane, renewable energy sources.*

REZIME

U ovom radu su najpre teorijski, a zatim i na konkretnom primeru analizirani procesi koji se odvijaju u deponijama i način formiranja deponijskog gasa. Istražene su mogućnosti pravilnog upravljanja deponijskim gasom. Kroz šemu potencijalnog tretmana deponijskog gasa, dat je prikaz kako se deponijski gas može koristiti za kombinovanu proizvodnju toplotne i električne energije. Prikazani su rezultati merenja koncentracije i sastava deponijskog gasa u Pčinjskom regionu, na deponijama u Vranju, Bujanovcu, Trgovištu, Bosilegradu i Vladičinom Hanu. Sistematski monitoring je ukazao na neadekvatno postavljanje i nedovoljan broj biotrnova. Zaključak je da nisu ispoštovane minimalne mere zašite od eksplozije i požara. Dalja istraživanja treba usmeriti ka sprečavanju oslobađanja opasnih gasova iz tela deponije u atmosferu. Neophodno je pronaći rešenja za pozitivnu ponovnu upotrebu deponijskog gasa, kao obnovljivog izvora energije. Cilj je da se pređe sa pasivnih, na aktivne sisteme ekstrakcije.

***Ključne reči:** deponija, komunalni otpad, deponijski gas, metan, obnovljivi izvori energije.*

INTRODUCTION

The landfill gas is a very dangerous gas, and if you do not take care of, it can significantly damage the environment and the atmosphere, because its largest component is methane *(Klusman, and Dick, 2000)*. The transpiration of landfill gas is prevented by setting up the large perforated pipes in the landfill, that is to say, in the landfill body, and horizontal connection of them. Through a compressive installation the landfill gas is sucked, compressed, dried and directed to the gas engine, or methane is used as a fuel in nearby industries.

MATERIAL AND METHOD

The landfill gas is formed in the dump body during the time, where the amount of gas depends on the composition of waste and its age. The creation of the landfill gas is an inevitable consequence of disposal and decomposition of waste materials containing organic matters. Since the landfills also produce a large number of bacteria, they decompose large amounts of waste under anaerobic conditions, and thus the landfill gas - methane occurs as the by-product of such decomposition.

The before mentioned landfill gas is produced by decomposition of organic substances under the influence of microorganisms in anaerobic conditions. The overpressure appears in the center of the landfill, and the landfill gas goes into the environment.

The composition of landfill gases depends on the structure of waste materials and mainly consists of methane, carbon monoxide, carbon dioxide and hydrogen. The average composition of the landfill gas is 35-60 % methane, 37-50 % carbon dioxide, and smaller amounts of carbon monoxide, nitrogen, hydrogen sulfide, fluorine, chlorine, aromatic hydrocarbons and other trace gases can be found.

RESULTS AND DISCUSSION

The Process Of Forming The Landfill Gas

The process of formation of the landfill gas is influenced by numerous factors: the characteristics of the waste material, oxygen in the landfill, the content of moisture, the temperature and time when the waste is discarded.

Character waste

The landfill gas is generated by bacterial activities. The growth in the amount of a generated gas is connected with the amount of the organic waste in the landfill. Increasing the amount of the organic waste also increases the amount of a generated gas. Certain types of organic waste contain large amounts of nutritive ingredients for bacteria - sodium, potassium, calcium and magnesium, which causes greater activity of bacteria and thus a larger amount of a generated gas. Certain types of waste contain compounds that negatively affect the activity of bacteria, causing a reduction in the generation of a gas. In the case of bacteria that produce methane the adverse effect is the presence of salts in high concentrations.

Oxygen in the landfill

The production of methane begins when all the oxygen is consumed. With more oxygen in the landfill, the aerobic bacteria decompose waste in a longer period of time. If the waste is only partially covered with a layer of soil, or if it is frequently stirred, there will be more oxygen, and the aerobic bacteria will live longer, and in a longer period of time will produce carbon dioxide and water. If the waste is compact, the methane production will start earlier, as soon as anaerobic bacteria replace aerobic bacteria. Anaerobic bacteria begin production only when aerobic bacteria consume all the oxygen, so that any presence of oxygen in the landfill will led to a slower process of methane production. Changes in atmospheric pressure may also affect the appearance of oxygen from the environment in the landfill, and this possibility exists in layers on lower depths, where there is a phase of aerobic decomposition of waste.

Humidity

The presence of a certain amount of water in the landfill increases the gas production, because moisture encourages the growth of bacteria and the transport of nutrients to all parts of the landfill. A moisture content of 40 % or more leads to a maximal gas production. The compactness of waste affects the reduction of a gas production, because the density of the landfill is increased, and the infiltration of water in all the layers of the waste is reduced. Gas production is higher in a case of heavy rainfall and – or permeable covering layers are present that allow the supply of additional quantities of water in the landfill.

Temperature

Temperature increases bacterial activity, which directly results in the increase of production of gas. On the other hand, low temperatures inhibit bacterial activity, so that the bacterial activity drops significantly below 10 ºC. Weather changes have a significant impact on the shallow landfills. This is due to the fact that bacteria are not isolated comparing to temperature changes on deep landfills where "thick" layers of soil cover the waste. In a covered landfill the stable temperature is held, which leads to an increase in the gas production. Bacterial activity releases the heat, thus stabilizing the temperature of the landfill between 25 º and 45 ºC, and the phenomenon of temperature up to 70 °C was registered in some landfills. Higher temperatures create favorable conditions for volatilization and chemical reactions. As a general rule it can be taken that NMOC emissions (hydrocarbon of nonmethane type) are doubled for every 18 °C.

Age waste

Waste that was later deposited will generate more gas than those placed in a landfill for a longer period of time. Landfills typically generate significant quantities of gas between one and three years. The maxima of generating gas are in the period from five to seven years after the waste is disposed of in a landfill. 20 years after the deposit, the generating of landfill gas is minimal and just in traces, while smaller amounts of gas can be generated even after fifty years *(Ubavin, 2008)*. Different parts of a landfill may be at different stages of decomposition of waste, depending on the age of the waste.

Processes that take place in the landfill

Processes that contribute to the formation of landfill gas are bacterial decomposition, volatilization and chemical reactions. The major part of landfill gas is formed by bacterial decomposition, by bacteria that are naturally present in the waste, as well as by bacteria present in soil used for covering the landfill. Considering that municipal waste is mainly organic origin, which includes food, garden waste, waste from the streets, textiles and wood and paper products, bacteria present in the landfill decompose this waste through four stages, and the composition of a gas changes during each of the stages. The landfill gas can be also produced when certain types of waste, or compounds formed as products of the decomposition of waste, especially organic compounds, changes its state from liquid or solid into a gas. This process is known as the volatilization. Non-methane organic compounds in the landfill gas can be the results of volatilization of specific compounds present in the landfill. The landfill gas, including non-methane organic compounds, can be produced by the reaction of certain compounds present in the waste. For example, if chlorine bleach and ammonia come into contact with each other in a landfill they produce ammonium chloride (NH_4 Cl) - the gas that adversely affects the processes in a landfill. Bacteria decompose the waste into four phases. The composition of the produced gas is changed during each of the four stages of decomposition. Since landfills usually accept waste within a period of 20 to 30 years, the waste in the landfill at the same time can be found in several phases of decomposition. Older waste in one part of the landfill may be in a different phase than those in the other part which is later deposited.

Phase I - aerobic phase

During the first phase of decomposition, aerobic bacteria use oxygen during nutrition, thus breaking long chains of complex molecular compounds that make up the organic waste: carbohydrates, proteins and fats.By-product of this process is carbon dioxide. At the beginning of this phase nitrogen concentration is high (about 20 % oxygen and 80 % nitrogen), but this concentration decreases as the “landfill moves” trough the stages of decomposition of waste. Stage I takes place while the available oxygen is completely used. The first phase can last for days or months, depending on how much oxygen is present in the moment when the waste is disposed of in a landfill, and oxygen levels will vary depending on how compact the landfill is.

$$C_6H_{12}O_6+6O_2 6CO_2+6H_2O \quad (1)$$

Phase II - anaerobic phase, non-methane

This phase of the decomposition begins when all the oxygen is used. With anaerobic processes, bacteria convert compounds formed in the processes of aerobic bacteria in acetic, lactic, formic and other acids and alcohols such as methanol and ethanol. Because of these processes, pH environment of the landfill becomes acidic. As the acids mix with the moisture present in the landfill, it comes to the dissolution of nutrients for the bacteria, so that nitrogen and phosphorus become available to different types of bacteria. The gas by-products of these processes are carbon dioxide and hydrogen. However, if oxygen gets into landfill, microbial processes will be back in the first phase, the phase of aerobic decomposition. At this stage, as a process, first, the hydrolysis occurs (extracellular, enzyme-process) wherein the organic substances are transformed into components that are soluble in water. This process requires a significant presence of moisture and physical contact between the microorganisms and waste. Organic waste is decomposed by the enzyme-catalyzed reactions on the main components:

cellulose → glucose → protein → amino acid → starch → glucose → fat → fatty acid

Gas components are not generated during the phase of hydrolysis *(Ubavin et al., 2005)*. By the formation of the monosaccharide molecules, the higher organic acids, through the various metabolical processes, also transform with the microbes into simpler organic acids, water, carbon dioxide, ammonia, and hydrogen (H_2).During this phase, in which the enzymatic reaction of acids occurs, CO_2 is generated immediately after the start of the process. According, different studies show different composition of gases: 50-70 % CO_2 after 11 to 23 days, or even 90 % CO_2 after 40 days. In summary, this phase can be represented by the following reaction mechanisms:

Hydrolysis: No gas production. Anaerobic acid enzymatic reaction of glucose (to produce higher emissions of CO_2 and H_2):

$$C_6H_{12}O_6CH_3COOH+C_2H_5COOH+CO_2+H_2 \quad (2)$$

$$C_6H_{12}O_6C_3H_7COOH+2CO_2+2H_2 \quad (3)$$

Phase III - anaerobic, methane, volatile cellulases protease amylase lipase

Phase III of the decomposition starts when certain types of anaerobic bacteria consume organic acids produced in stage II and begin to form acetates. This process causes that the landfill become closer to pH 7 (neutral media) corresponding to the bacteria that produce methane. Methane and acid bacteria have a certain type of symbiotic relationship. Acid bacteria produce the compounds that methane bacteria use for feeding. Methane bacteria are fed with carbon dioxide and acetate, whose large presence is highly toxic to the acid bacteria. The duration of Phase III can start from 180 days of the dumping and continue until 500 days after the deposit.

Phase IV - anaerobic, methane, stable

Phase IV of degradation begins when the composition and production of the landfill gas become relatively constant. Landfill gas then contains about 45-60 % methane, 40-60% carbon dioxide and 2-9 % other gases. Gas is produced constantly in the fourth phase usually for 20 years, while the emission of the gas can continue after 50 years. The production of the gas can last longer, especially if they are present greater amounts of the organic waste.

The management of the landfill gas

This gas is dangerous because it can cause an explosion, the burning of methane, and is very harmful to the environment and the human health.To prevent the harmful effects of the landfill gas (especially methane, which is very dangerous), large perforated pipes are placed into the landfill body and their horizontal connection is performed. Through a compressive installation the landfill gas is sucked, compressed, dried and directed to the gas engine, or methane is used as a fuel in nearby industries. The extraction system is a split system, which means that methane can be used as energy or it can be burned *(Ilić and Milić, 1998)*. For example, a certain municipal landfill, which produces about 1.250 m³ / h of landfill gas can use about 200 m / h gas to start a gas engine that produces 0.3 MW of electricity. The produced electricity is distributed to the public electricity web.

The total amount of landfill gas can be used for combined production of the heat energy and electric energy. The migration of the landfill gas is very harmful, and in many ways damaging to the environment (mainly the explosions). If there is on the landfills oxygen level above 13 percent by volume, the possibility of explosion of methane is high.

In order to achieve a migration of the gas there should be a gradual increase of the concentration in order to allow the diffusion of the vapor phase (a diffuse flow), as well as an increase in the pressure (a viscous flow).

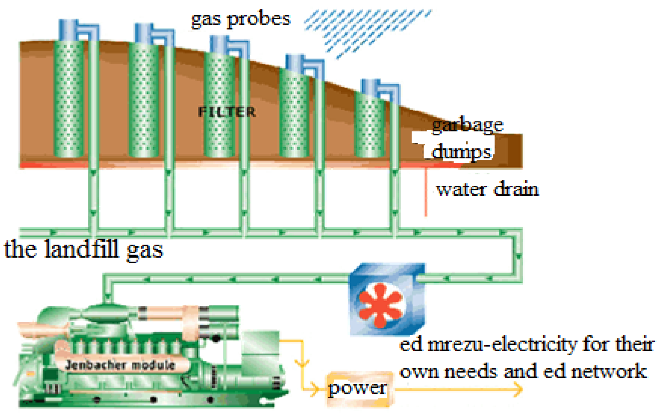

Fig. 1. The treatment of the landfill gas

The migration of the landfill gas is mostly affected by the way of filling landfills. The technique of a thin application with a good compaction and a daily covering with the soil will encourage the (lateral) migration of the gas, particularly where the covering material is of the low permeability, and vice versa. The construction of wells at the landfill will encourage vertical migration of the gas.

During the growth of landfills, each produced gas will be released in the way of the least resistance. Therefore, before the final covering, the largest part of the produced gas will enter the atmosphere. After the final covering, the entering of the gas into the atmosphere will be limited in accordance with the effectiveness of covers. As a result, there will be an increase in the gas pressure within the landfill, which will encourage the migration of the gas. The possibility of the lateral gas migration increases, and the rate and extent of migration will depend on many factors including the characteristics of the environment and climatic and geophysical conditions.

Environmental factors are limited by the conditions of the waste itself, and influence the rate and degree of the decomposition of the waste, as well as the speed and degree of increasing the gas pressure. These are mainly geophysical and climatic factors (the atmospheric pressure and precipitation). Geophysical conditions are also very important and affect differently the migration of the landfill gas.

Depending on the nature of the terrain where the landfill is, as well as what kind the soil layers are (fractured, permeable, porous, spongy, cracked) gas migration will be faster or slower.

When the barometric pressure drops, surface pressures that oppose the migration become weaker thus enabling the movement of a gas. Rainfalls affect the migration of the gas, causing the swelling of the surface material and closing the surface cracks, thereby reducing the vertical migration routes, which results in the increased lateral migration of the landfill gas.

Measuring the rate of the gas flow, and thus measuring the volume of the created gas, and the rate of the creation of the gas, is important for determining the risks associated with the gas *(Vujić et al., 2004)*. The most commonly used method of measuring the flow rate of the gas is a thermal anemometer with a hot wire (a hot-wire detector) and they are very sensitive and can easily break down. Although a good design system tends to minimize the occurrence of failures, it is necessary recognize that the fault occurred in the system and allow the system operator to respond in an appropriate manner and thereby minimize consequences for the system. *(Petković et al., 2015)*.

The measurement is performed by the apparatus for the gas analysis "GEM2000plus" from the producers in the UK – "Geotechnical Instruments", who are specialized for the production of apparatuses for the extraction and analysis of landfill gases."GEM2000plus" is specifically designed with the aim to be used for the purpose of monitoring the state of the landfill gas on biothorns and other systems for the extraction of the landfill gas. The GEM2000 portable landfill gas monitor is designed to analyze landfill gas (LFG) composition and calculating flow. The GEM2000plus ensures consistent data collection for more reliable analysis and also measures and displays Btu content, atmospheric pressures, temperature (using an optional Temperature Probe) relative, and CH4 LEL. The GEM2000 Plus adds CO and H_2S measurements for situations when those capabilities may be necessary. The GEM2000 remains operational for 10–14 hours on a single charge. Certified Intrinsically Safe for use in the landfill. The GEM2000plus measures gas composition, flow, and pressure in gas extraction systems and is a great tool for routine sub-surface migration monitoring of site perimeter landfill probes. The operator can record questions and comments regarding sites and sample point for later display and analysis. The GEM200 ensures consistent collection of data for better analysis and allows balancing of gas extraction systems. GEM2000plus features: Measures % CH_4, CO_2 and O_2 Volume, differential and static pressure; Calculates balance gas, calorific value (kW or Btu), flow (SCFM); Displays % LEL of CH_4 and user-defined site or sample point comments; Records well and site conditions; Provides 10–14 hours of operational use on a single charge; Intrinsically Safe for use in the landfill. http://www.equipcoservices.com/.

The main advantages in the development of expert systems for diagnostic problem solving are: ease of development, transparent reasoning, and the ability to reason under uncertainty and the ability to provide explanations for the solutions provided. There are a number of researchers who have worked on the application of expert systems for problems *(Kanović et al., 2013; Matić et al., 2010)*.

The experimental part

In order to determine the composition of the landfill gas, the sampling of the landfill gas was carried out from the following locations of landfills in the region of Pchinja. The number of samples per a landfill was mostly conditioned by a number of degassers in the landfill. Locations from which the sampling of the landfill gas is made, as well as the number of places for sampling are shown in Table 1.

Table 1. Cities of sampling the landfill gas

The landfill	The mark of the landfill	Number of samples
Vranje	VR	10
Bujanovac	BU	5
Trgovishte	TR	3
Bosilegrad	BO	2
Vladicin Han	VH	5

Samples of the landfill gas are taken from piezometer, due to the absence or defect of vertical degassers.

Table 2. The results of the measurement of the concentration of the landfill gas at the landfills in Vranje, Bujanovac, Trgoviste, Bosilegrad and Vladicin Han

The mark of the biothorn	Coordinates	date	CH_4 %	CO_2 %	O_2 %	Min O_2 %	P mb	CO Ppm	H_2S Ppm	H_2 ppm	CH_4/CO_2 %
Vranje	42° 33′ 15″ NGW, 21° 53′ 50″ EGL	05.03.2013	0.2	2.3	7.6	4.8	1001	0	0	LOW	0.1
		24.03.2013	1.8	1.9	10.2	8.9	1001	0	0	LOW	1.2
		07.04.2013	1.2	0.5	8.4	14.5	1000	0	0	LOW	1.4
		30.04.2013	0.9	1.6	6.7	14.9	1002	0	0	LOW	0.7
		08.06.2013	4.2	3.7	17.5	12.6	1007	0	0	LOW	0.9
		27.06.2013	6.1	2.4	13.7	5.7	1010	0	0	LOW	2.1
		15.10.2013	2.8	1.1	20.1	15.5	1001	0	0	LOW	2.7
		12.02.2014	1.9	0.4	16.9	17.4	1003	0	0	LOW	3.0
		05.04.2014	5.7	4.8	9.4	11.7	1001	0	0	LOW	2.5
		23.05.2014	7.3	4.9	14.8	10.8	1002	0	0	LOW	1.7
Bujanovac	42° 24′ 04" NGW, 21° 41′ 20" EGL	16.04.2013	0.6	2.3	10.8	5.8	1001	0	0	LOW	2.8
		28.06.2013	1.9	1.9	8.9	8.6	1002	0	0	LOW	1.2
		06.09.2013	3.7	0.5	13.9	13.8	1010	0	0	LOW	0.5
		04.03.2014	6.2	3.5	17.4	16.4	1001	0	0	LOW	2.6
		25.05.2014	2.9	4.9	20.1	18.9	1001	0	0	LOW	2.9
Trgovishte	42° 21′ 31" NGW, 22° 04′ 34" EGL	29.05.2013	2.7	2.8	11.7	10.8	1003	0	0	LOW	2.6
		17.10.2013	4.1	1.6	15.9	12.9	1001	0	0	LOW	1.7
		15.02.2014	0.8	0.1	10.3	17.1	1001	0	0	LOW	0.4
Bosilegrad	42° 29′ 31" NGW, 22° 28′ 04" EGL	15.04.2013	0.7	3.8	8.9	4.7	1004	0	0	LOW	0.8
		23.10.2014	5.3	2.7	17.8	8.1	1010	0	0	LOW	1.9
Vladicin Han	42° 42′ 17" NGW, 22° 03′ 29" EGL	05.06.2013	1.5	1.6	11.7	7.8	1001	0	0	LOW	0.8
		16.07.2013	3.5	3.4	16.4	10.6	1000	0	0	LOW	0.7
		25.11.2013	2.8	0.8	10.8	15.9	1001	0	0	LOW	1.7
		19.06.2014	6.3	2.3	9.6	20.1	1003	0	0	LOW	2.4

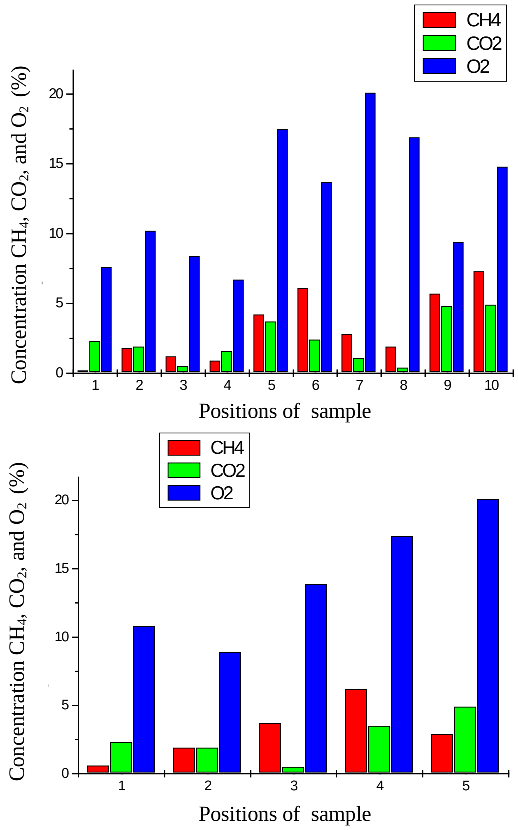

Fig. 2. The concentration of methane, carbon dioxide and oxygen at all measuring points in Vranje on the landfill "Meteris" (left) and Bujanovac (right)

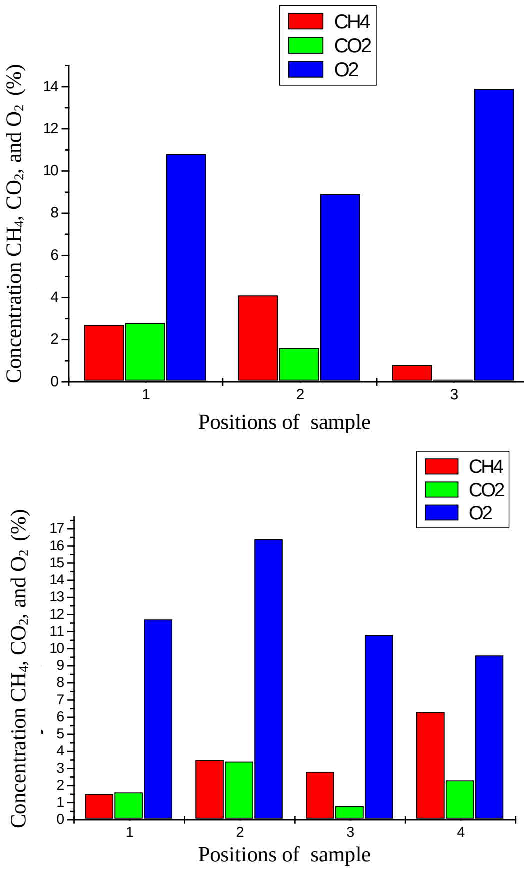

Fig. 3. The concentration of methane, carbon dioxide and oxygen at all measuring points in Trgovishte, (left) and Vladicin Han (right)

On figures 2 and 3 the results of measurements of the concentration of various concentrations of methane (CH_4), carbon dioxide (CO_2) and oxygen (O_2) are schematically shown in landfills in different places in the region of Pchinja.

The results shown in Tables 1 and 2 present that on the landfills in the region of Pchinja where biothorns are correctly placed and in function, there is a significant presence of landfill gases, and high concentrations of methane. On landfills where are no biothorns or it was not possible to take a sample from the biothorns, sampling was done with piezometers, which proved to be inadequate. The concentrations of landfill gases on samples from piezometers were completely different from the samples with biothorns.The fact is that at all landfills where biothorns exist there were significant amounts of methane, indicating the necessity of setting up biothorns at all landfills in order to prevent accumulation of methane in the landfill body and the environment, and to prevent the possibility of formation of explosive mixtures *(Vujić et al., 2003)*. Various concentrations of oxygen in the same landfill indicate insufficient insulation measures on the landfill compared to the atmosphere. The lack of isolation, especially in the upper layers of covering, can inhibit the biological processes of chemical degradation of waste, thus the formation of the landfill gas, and the process of generating the landfill gas is significantly extended. Significant quantities that were detected on the landfill "Meteris" in Vranje, point to the necessity of setting up a sufficient number of adequate biothorns, as well as the minimal measures of protection from an explosion and fire. In the future it is necessary to implement solutions that will prevent the landfill gas to freely leave the landfill body and goes into the atmosphere, and it is necessary to do the shift from passive to active systems of extraction of the landfill gas.

CONCLUSION

On the landfill "Meteris" in Vranje, the process of managing with the landfill gas is not fully regulated. For this reason, the landfill gas goes into the atmosphere, and also goes in the crevices on the ground thus damaging the wildlife. What is very important for the landfill “Meteris” is that her life is about to expire, but even after the closing and covering with the soil, there is the possibility that the landfill gas will still be “created”, and also the possibility of an explosion still exists. For this reason they make new sanitary landfills that will have a better system of the regulation of a landfill gas, in order to preserve the environment and prevent from the explosive consequences of methane gas which is mostly contained in the landfill gas.

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