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Evaluation of Measurement Methods and Estimation of Biogas Emission from Landfills

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1. Introduction

The biogas coming into existence on landfills on account of its composition isn't indifferent to the environment; therefore one should strain for reconduction in the controlled way. The migrating biogas states a considerable risk for surrounding, because can gather in vacancies such as foundations, basements, creating threatening with the explosion, can be a reason of fires on landfills, threaten with poisoning people and animals by acting of the hydrogen sulphide content and other poisoning compounds. Moreover a methane and carbon dioxide emission influences to global character phenomena as the greenhouse effect. These threats are causing that monitoring of landfill gas emission becomes necessary. It is necessary to conduct monitoring while the landfill, but also after its exploitation is finished. Carrying the monitoring on requires adopting some measurement method of the biogas emission. However, the selection of the right method depends on many factors, e.g. on the kind of the landfill, its size, financial and other availabilities of means. The continuous monitoring of the landfill at an angle of amount and quality of the emitted biogas permits for following up the transformations and taking up the right decisions as for the way of conducting with the biogas, like also to the evaluation of security system effectiveness as well as estimating the threaten scale to surrounding, which is created by the landfill. The need of the continuous inspection of landfill gas emission is resulting not only from desires for expanding knowledge about the threatening, which is connected with the waste disposal. This control is required and established by the Government Order of Environments on 2002 year [7]. The directive defining what parameters on what temporal distances must be examined. However it isn't specifying, what method should be applied for emission examinations. The duty of conducting the emission measurement concerns all organised waste landfills, irrespective of the exploitation phase. However it doesn't announce what are acceptable values of the biogas emission from landfill. British standard allow for emission from active landfills (under the exploitation) on the level of 0.1 mg/m^2·sec, and from closed landfills on the level of 0.001 mg/m^2·sec [Internet 3].

2. Characteristics of the landfill biogas and its process of coming into existence.

The biogas is coming into existence as a result of the biodegradable fraction decay, which contained in waste. This decay is a long-term and multistage process. In natural processes of the organic matter decay running in conditions of the limited oxygen access, the oxygen and oxygen-free phase can be distinguished. In the initial phase of biochemical transformations organic components of waste are surrendering to the hydrolysis, and in the more distant stage are decayed to organic acids in order to undergo a transformation to methane and carbon dioxide at the final phase.

The oxygen phase lasts from 3 to 12 weeks all the way to run reserves of oxygen out in the structure. At that time half of biodegradable substance is being transformed into the carbon dioxide, whereas the rest part is undergoing to the exchange into the biomass of micro-organisms. The oxygen decay is supplying to waste self-overheating, what increase the anaerobic fermentation process by creating good conditions of the development for the anaerobe bacteria, which are mesophile micro-organisms. An anaerobic phase is a complex biological process. During the process about the 95% of decayed organic substances is catabolism decayed to methane and carbon dioxide.

In the first phase of an enzymatic hydrolysis of biopolymers decay is taking place, which means that in the present canailles, proteins, cellulose are undergoing to the decay with the help of enzymes which are being produced by fermentation bacteria. The products of this process are simple sugars, amino acids, aliphatic acids and other compounds as well.

In the further stage higher replaced bacteria are catabolically transforming the hydrolysis products decay to volatile fatty acids (mainly to acetic, butyric and propionic acid) ethanol and gaseous products (of hydrogen and carbon dioxide).

The acetate fermentation is next phase of the degradation, during this process octane bacteria are transforming gaseous aliphatic acids decay to hydrogen, carbon dioxide and acetic acid.

The development of the octane bacteria is depending on the fragmentary pressure of hydrogen in the bacterial culture. They are capable to the development when forming hydrogen is absorbed by bacteria from the methane groups [8].

After all the organic waste decay in the landfill corpus is causing their exchange to:

- ✓ gaseous products, i.e. landfill gas,
- ✓ micro-organisms mass,
- ✓ non-gaseous products remaining in reflux or in waste mass.

In the result of prescribed transformations of organic substances on the landfill a quality of the biogas is changing what permits the chemical evolution of the landfill for singling out a few phases (Fig. 1):

Phase I – aerobic; lasting quite briefly, to the time of reducing oxygen. The organic matter decomposition is taking place with the participation of aero micro-organisms.

Phase II – acid phase; begins in the moment of oxygen depletion. In this phase anaerobic micro-organisms are decomposing hydrocarbons above all, creating organic acids, CO_2 and H_2.

Phase III – anaerobic, methanogenic – unstable; ensues in the moment when CH_4 begins to appear at transformation products.

Phase IV – anaerobic, methanogenic – stable; the methane production velocity is taking the constant comparatively value, what is leading to the percentage composition stabilization of the landfill gas.

Phase V – so-called the "calm" phase (not-emphasized in Fig.1), is characterized by a gradual methane production decrease, all the way to complete of its disappearance which is ensuing after the very long period, lasting for even over 100 years.

The amount and the quality of the biogas transmitted from the landfill are depending on the landfill type (organised, unorganized), on existing of the biogas receipt system and its character, on the landfill magnitude, the kind of stored waste (decides about biodegraded faction contents and the biodegradation pace) and from the time which passed from the waste depositing moment (determines the chemical evolution phase).

The fate of the ensuing biogas is depending mainly on character (the kind of stored waste, the type of isolation) and landfill magnitude. The ensued biogas can be captured by the degassing system and next purified in rehabilitation overlap or on the bio-filter, exploited e.g. in the destination of the electric or thermal production of the energy as well as burnt in torches. However the biogas often migrates directly to the atmosphere, whether these are from the entire landfills surface area or from the passive degassing system, becoming the factor threatening to the purity and the safety of the environment.

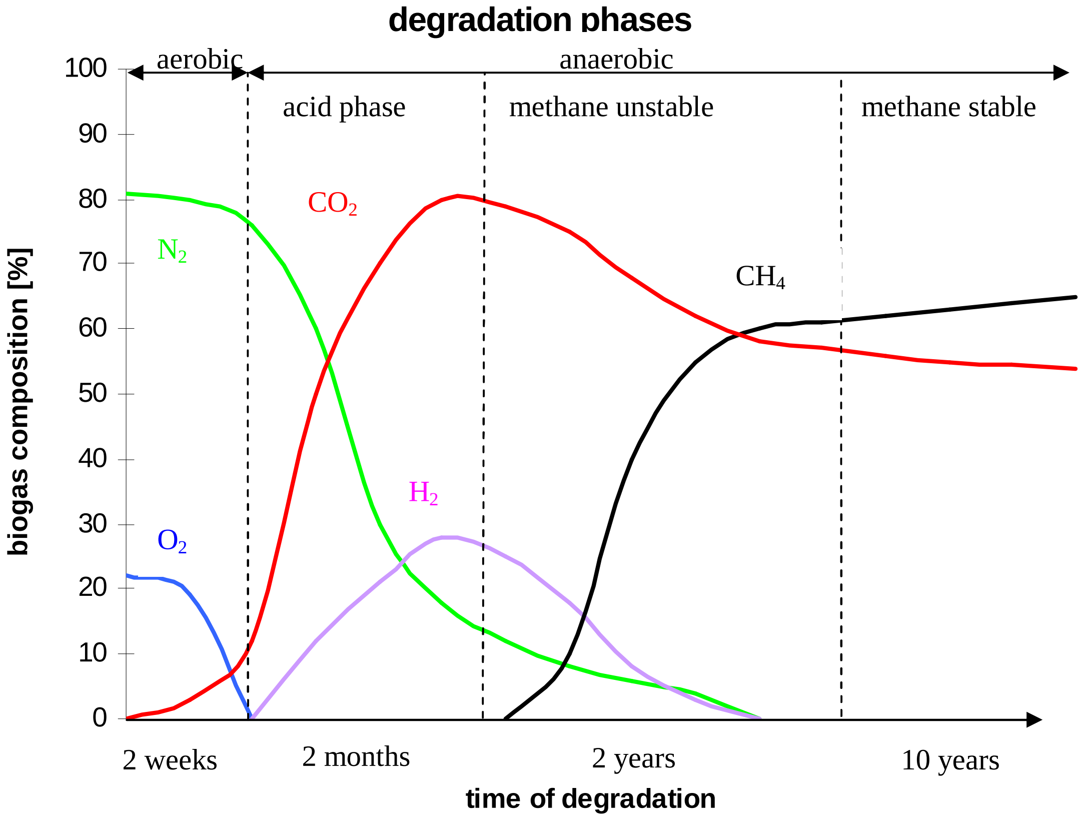

Fig.1. Composition of landfill gas (in % volume) presented in time as a function according to [3]
Rys. 1. Skład gazu składowiskowego (w % objętościowych) w funkcji czasu wg [3]

3. Estimation methods of biogas emission

Estimation of landfill gas emission is not a method of its measurement, but it permits for theoretical estimating the stream of biogas emission from landfills. Biogas emission is being estimated taking the advantage of the standard IPCC method (it concerns to methane) or the triangle method. Then it can be compared with results obtained on the way of direct measurements.

3.1. Standard method

The developed countries are obliged for the stabilization of greenhouse gases emission with the General Convention of United Nations. Among other things this agreement requires conducting the all-year-round register of the greenhouse gases emission according to guidelines of the Intergovernmental Panel on Climate Changes – IPCC.

The standard method gives the reliable annual assessment to potential emission, when mass of deposited waste is keeping steady or is changing slightly during a several decades of years. The other permitting condition for applying this way of calculations relies in so that the morphology of deposited waste have been changed slightly in the period of several dozen years. If a notable reduction of bio-degradable carbon in waste appeared, with the standard method the methane emission will be determined as too high potential. However appearing of notable reduction of bio-degradable carbon in the investigated duration is possible only in the situation of the radical change in the waste disposal in the scale of the country.

Potential methane emission according to the standard method is being calculating from the following equation:

$$Emission CH_4 = \left[\left(MSW_T \cdot MSW_F \cdot L_0\right) - R\right] \cdot \left(1 - OX\right) \text{ [Gg/yr]} \tag{1}$$

$$L_0 = MCF \cdot DOC \cdot DOC_F \cdot F \cdot \frac{16}{12} \text{ [GgC/Gg waste]} \tag{2}$$

where:

MSW_T – total mass of council waste coming into existence within the year, [Gg],

MSW_F – the part of council waste happening upon landfills, the absolute fraction,

L_0 – productivity of generating methane, [GgC/Gg of waste],

MCF – corrective factor for methane, the absolute fraction,

DOC – content of carbon in organic compounds undergoing to decay, [GgC/Gg of waste],

DOC_F – weights fraction of carbon undergoing to the methane transformation, the absolute fraction,
F – voluminal fraction of methane in the biogas, the absolute fraction,
R – amount of extracted methane, [Gg/year],
OX – factor considering oxidizing methane in soil or other materials, which covered waste is, the absolute fraction.

Data about total mass of council waste produced on the given landfill within the year (MSW_T), they are getting thanks to statistical data. Mass of council waste taken away to landfills (MSW_F) is calculating deducting from total mass of produced waste within the year, mass of selected or subjected to neutralizing harmless in the different way.

In accordance with the applying law the amount and kinds of stored waste should be registered. The IPCC method is recommending in order facilitating getting of data concerning waste participation are succumbing the methane genesis process and of participation of waste decayed in oxygen processes; one should divide landfills into four groups and to assign the factor determining the methane genesis participation to each of it in decomposition processes. In accordance with IPCC the waste landfills are being divided into the following groups:

- ✓ organized - the value of the corrective factor equal 1,
- ✓ disorganized deep-seated, about the larger than 5 m depth - the value of the corrective factor equal 0.8,
- ✓ disorganized shallow, about the smaller than 5 m depth the value of the corrective factor equal 0.4,
- ✓ not-classified, the value of the corrective factor equal 0.6.

Accordingly one of two solutions can be accepted: to take an assumption of data deficiency and to judge landfill or landfills as not-classified or else to classify it on the basis of the possessed information.

Solid wastes are making council wastes up from households and the social infrastructure, e.g. hospitals, enterprises, offices. The composition of waste is diversified and depending on the living level and style. In accordance with guiding principles of the IPCC, carbon contained in degradable organic compounds is being appointed for the following of four waste groups:

A – waste fraction constituting paper and textiles,
B – waste fraction of parks, gardens and other organic waste except for food,
C – waste fraction of food,
D – waste fraction of waste constituting wood or straw.

On the basis of the masses of individual fractions knowledge, the carbon value is being calculated in organic compounds undergoing to decomposition:

$$DOC = 0{,}4 \cdot A + 0{,}17 \cdot B + 0{,}15 \cdot C + 0{,}3 \cdot D \text{ [GgC/Gg waste]} \qquad [3]$$

where:

A, B, C, D – content of individual fractions [weight %].

The DOC_F factor is an assessment of the carbon amount, which is ultimately biodegraded and liberated from landfills. IPCC guidelines are recommending default factor value of DOCF equal 0.77. It is necessary to accept this value on account of literature data deficiency concerning the problem.

Fraction of amount of the methane contained in landfill gas can assume values from 0.4 to 0.6. According to IPCC recommendations the molar fraction (F) is entertaining one another as value equal 0.5.

Determining the value of extracted methane one should know the volume of the biogas used at energy purposes, next with the help of the minor methane fraction in landfill gas a value of extracted methane is being determined.

Methane can became oxidized to $CO_{2,}$ during its migration through the oxygen-rich layers, which are situated closely to the surface area. The exothermic course of oxidizing the methane is undergoing thanks to the presence of methanotrophs bacteria. The oxygenation process is causing that the value of molar ratio of methane to carbon dioxide is decreasing, in the biogas migrating beyond the landfill area. Researches are proving that on organised landfills the rank of oxygenation is higher than on disorganized landfills. Default value of this factor according to IPCC guidelines amounts at zero. This method was described in detail by both: [1] and [4, 5].

3.2. Triangular method

This method confirms that assessing emission dependent on time, matches true model of degradation process in the time. Be going to define biogas emission on the basis of this method one should have data concerning waste amount and its composition, as well as storing techniques applied on the given landfill of around a few decades.

Biogas emission is presented in the triangle's form (Fig. 1), where the surface area of the triangle is equivalent to amount of biogas being liberated from each ton of deposited wastes in the entire period of the chemical activity.

The assumption is taken in this method, which says that degradation process is running for two stages. The first stage is divided also in two phases.

The first stage is starting after the year from the beginning of deposition, since then the scale of gas production of is increasing and the increase is staying to the 6th year. Next, the second stage is being begun, in the time period when the gas production is going down and fading out after several dozen years.

The "h" point is the emission peak value. In each case the biogas emission is being calculated, knowing the volume of gas and the time, which passed since starting depositing [4, 5].

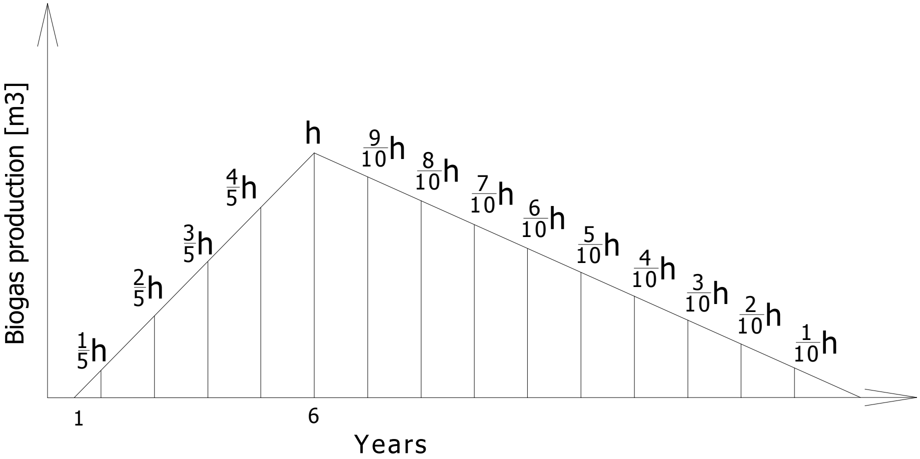

Fig. 2. Triangular graph showing the biogas production scale in particular years of the biochemical evolution of the landfill [4, 5]

Rys. 2. Trójkątny wykres przedstawiający wielkość produkcji biogazu w poszczególnych latach ewolucji biochemicznej składowiska [4, 5]

4. Review measurement methods of biogas emission.

One perfect method which allows determining biogas emission from waste landfills precisely does not exist. However a few methods exist, which were probed in the different conditions. Some of them are being used for assessing biogas emission from small areas, while other permits to judge the emission from large surface area, e.g. from the entire landfill. The first group of methods represents: chamber method, method of subsurface vertical gradient of the concentration; counts among the second group of methods: micrometeorological methods, the isotope ratio technique, the tracer method and the IR spectroscopy. In the further part of the paper above methods are presented and characterised.

4.1. Chamber technique

The measurement method using chambers is based on an acquaintance of air volume, where the increase of the landfill gas concentration passing across the familiar surface area of soil pile is being observed in the definite time [2]. The surface area over which the chamber is being placed, isn't usually larger than 1m^2, however the minimum time for the sample collection is taking the less than 1 hour out [Internet 1].

The chambers applied for measuring biogas emission from landfills are divided to static and dynamic chambers. The static chambers are filled up with familiar air volume, in which the change of the examined gas concentration is being measured from 4 till 6 times in the short duration, usually from 30 min. till a few hours (Fig. 3a). The gas flow is caused mainly by diffusion, therefore when a steady-state is setting between the gas concentration in a chamber and concentration in pores of material covering the landfill, the net emission is going down to zero.

The quantity of gas flow in static chambers can be defined applying the formula:

$$Q = \frac{V}{A} \cdot \left(\frac{dc}{dt} \right) \quad [\mathrm{mg/m^2 \cdot s}] \tag{4}$$

where:

Q – gas flow [mg/m^2·s],
V – chamber volume [m^3],
A – field of chamber base [m^2],
dc/dt – gas concentration flux over time [mg/m^3·s].

In dynamic chambers a familiar air volume is flowing through the chamber (Fig.3b). The concentration of gas in the air is being measured up before and behind the chamber, however the emission value is being calculated from the difference of the concentration and the flow. The gas flow assures that air is mixing up inside the chamber. The quantity of the gas flow on the entrance and on the exit should be defined precisely. Differences of the pressure in different parts of the chamber system can have the influence on the flow magnitude of the gas being researched.

The chamber technique has noteworthy advantages, in particular its low cost, the possibility of using for assessing emission of many gasses and the option of applying chambers in the different conditions by the right adapting their volume [2]. Chambers are being exploiting for the measurement of the biogas emission from council waste landfills as well as for the measurement of emission from boggy lands, contaminated areas or from perilous waste landfills. The chamber technique of biogas emission measurement is permitting to get the information concerning factors having the influence on the gas flow; the information of among others humidity of soil pile and landfill structure.

The main fault of this method constitutes its labour intensity and the results strong dependence on the temperature fluxes. Deficiency in right isolation in the coincidence of static chambers is causing significant temperature fluxes of chamber interior. The temperature flux at range of 10 ºC can lead for decreasing the gas volume for 3 - 4%, what in a row is influencing for concentration of individual compounds of the biogas. The labour intensity of the method is resulting from necessity of performing series of measurements in many points of the landfill in the little temporary compartment [Internet 1].

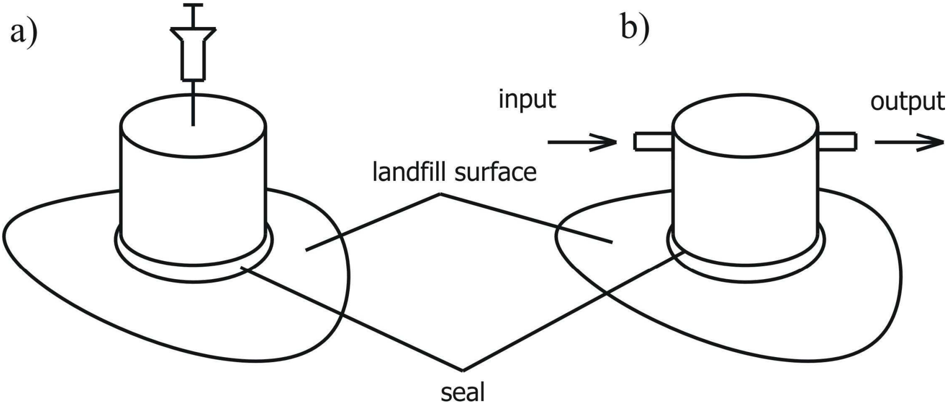

Fig. 3. Chamber methods: a) static chamber b) dynamic chamber
Rys. 3. Metody komór pomiarowych: a) komora statyczna b) komora dynamiczna

4.2. Sub-surface vertical gradient method

This method was described by Rolston in 1986, and is based on the Fick's Law of Diffusion. In order to apply this method at defining the landfill gas emission magnitude, one should know the value of gas diffusion rate in the soil and the gas concentration gradient in soil air. The gas emission is calculated using formula:

$$F = -D_s \cdot \left(\frac{dc}{dx} \right) \quad [\mathrm{g/m^2 \cdot s}] \tag{5}$$

where:

D_s – gas diffusion coefficient in soil [m^2/s],
dc – gas concentration difference within vertical distance x [g/m^3],
dx – depth difference [m],
F – gas emission velocity [$g/m^2 \cdot s$].

The gas concentration gradient is measured by dipping in soil the measurement probes containing one or a few holes, by which gaseous samples are being taken up on different depths of probed profile.

The subsurface vertical gradient method, even that is an easy and cheap method, wasn't extensively described in any literature. Compared with the chamber method, permits to estimate the spot emission only, as it is main disadvantage of this method. Application of this method gives larger values of gas emission than in case of applying other methods. It can be caused by oxygen diffusion into soil top-layers covering waste. Flows can be also over measured, if analysed gas was partly oxidized, during its migration through soil pile, which concerns methane in the particular. The next disadvantage of this method is fact, that only diffusion is accounted to consideration. Differences of the pressure and temperatures which are also provoking the gas flow aren't being taken into consideration.

4.3. Micrometeorological methods

These methods are being applied for indicating gas flows above the surface area of researched object. They are based on the assumption, that gas emission is being measured in the low-lying layer of the atmosphere named planetary boundary layer - PLB. These methods are being applied, when soil pile is homogeneous and biogas flow is steady in time. The PLB thickness differs in time, it is caused by heating and cooling processes, topographical survey, winds and other atmospheric factors (Fig. 4).

Different variants of this method are known:

Above – ground gradient technique

The vertical flow of landfill gas in atmospheric air is being calculated with the aid of data concerning the gas gradient in the atmosphere and its diffusion rate. Main disadvantage of this technique is difficulty of estimating rate diffusion, various for individual biogas component. The limitation of applying this method is also fact, that the topography of a land, where the measurements are being taken should be homogeneous.

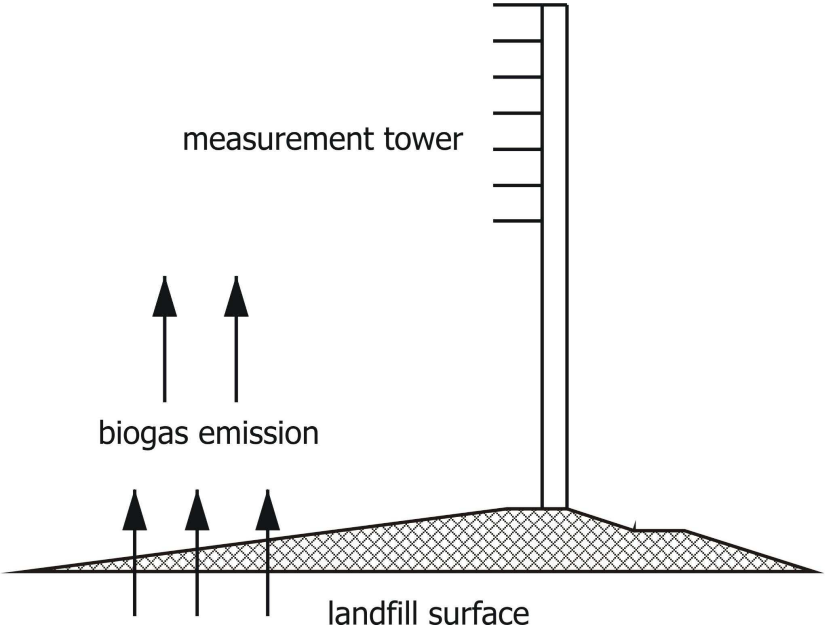

Fig. 4. Scheme of the micrometeorological measurement method research stand
Rys. 4. Schemat stanowiska badań metodą mikrometeorologiczną

Eddy Correlation technique

A dominating mechanism in gas transport above the soil surface area is a turbulent wind movement. Deliberating to use this method for biogas emission measurement from landfills one should know two parameters. First from them is the vertical wind velocity and the other is trace gas concentration above appropriately large area.

Gas emission is calculated in accordance with the equation below:

$$F = W_v \cdot C_g \ [m^3/m^2 \cdot s] \tag{6}$$

where:

W_v – vertical wind velocity [m/s],
C_g – concentration of trace gas above the landfill surface area [m^3/m^3],
F – magnitude of biogas emission [$m^3/m^2 \cdot s$].

The main advantage of this technique is that emission from large area a can be estimated, e.g. from the entire landfill. The method is automated process; therefore it is also used for research on emission differences in time (periodic emission). The disadvantage of the rotary correlation technique is that it requires very complicated and expensive equipment. Moreover the lay of the land that research is carried out should be flat [2].

4.4. Isotopic fractionation

This technique is a variety of the model addition technique. It is based on the measurement of isotope ratio. A substance being added is known amount of compound, which is different from analysed in isotopic composition only. During the organic compounds contents are indicated, as it is in the case of methane; the appropriately isotope marked analogues are applied, concluding very often deuterium (heavy hydrogen) atoms instead of hydrogen or ^{13}C instead of ^{12}C.

The isotopic composition of methane is variable and dependent on its origin. Methane originating from the microbiological decay of organic matter in anaerobic conditions is enriched with ^{12}C, however contains low amounts of ^{13}C. It was also proven that bacteria are oxidizing ^{12}C faster than ^{13}C, what in consequence is causing that methane migrating from waste landfills is enriched in^{13}C, while the oxidation processes occurs in top-layer.

The measurement of isotopic methane composition isn't a measurement alone in just of its emission. It can be a base for emission calculations, although attempts to apply this technique for estimating emission of methane emission were conducted using carbon stable isotopes in order to estimate participation of different methane sources in its annual global emission into the atmosphere. This technique of indicating methane emission as the principal biogas component can be helpful in explaining methanotrophs processes of methanogenesis as well as in the estimation of global emission of this relation from all sorts' sources. However it is not distributed and applied to the broad scale.

The advantage is a great precision of this technique. The issues such as high expense, the limited availability of isotopic marked models and high exploitation of apparatus being used, are related among disadvantages.

4.5. Tracer method

Tracer measurement method of biogas emission relies on releasing neutral gas, most often in SF6, from points placed along one line in direction against the wind. When released neutral gas is well mixed up with the emitted biogas creating the so-called cloud, value of the landfill gas emission can be traced. The emission of individual biogas compounds is calculated from gasses proportion in the cloud, knowing the volume of integrated gas:

$$Q_G = Q_{SF_6} \cdot \left(\frac{C_G}{C_{SF_6}} \right) \quad [\mathrm{m^3/h}] \tag{7}$$

where:

Q_G – magnitude of trace gas flow [m^3/h],

Q_{SF_6} – magnitude of SF_6 flow [m^3/h],

C_G – measured concentration of trace gas [m^3/m^3],

C_{SF_6} – measured concentration of sulphur fluoride hexane (SF_6) [m^3/m^3].

Concentration of trace gas and sulphur fluoride hexane are being measured with the aid of the gaseous chromatography, e.g. the methane concentration can be determined by the flame-ionizing detector (FID), however the sulphur fluoride hexane concentration can determined by the electron capture detector (ECD).

The alternative in using SF_6 is applying N_2O as neutral gas. Nitrous oxide was applied as gas for indicating methane emission from landfills in Sweden by Galle in 1999 [2].

The advantage is less expensive of tracer method than micrometeorological method. It permits to estimate emission from local sources e.g. lagoons. The main disadvantage is that SF_6 has influence on deepening the greenhouse effect.

4.6. Infrared spectroscopy - IR

Infrared spectroscopy (IR) is a simple and easy in applying measurement method of the gas flow. Spectral methods permit to indicate the concentration of different gasses, e.g. CH_4, CO_2, CO, they are the methods based on the infrared adsorption. Certain value of the infrared bundle is emitted from the source to the detector. The detector is measuring the infrared light intensity and then is calculating radiation losses and differences. The measuring procedure is repeated several times in different distances in order to get more precise results. The infrared spectroscopy method is not a very credible method. In order to estimate the gas flow one should relate the measurement results to results obtained in laboratory conditions and juxtapose in special tables. In these tables is presented indicated bundle intensity for known CH_4 concentrations (e.g. the 50%, the 55%, the 60%, the 65%) measured with the aid of the same spectrometer, as well as for atmospheric air measured in different distances from the emission source [2].

Then results obtained directly from landfill measurements are being compared with results obtained in laboratory conditions. The infrared spectroscopy method can be used as the verification of the results obtained with the aid of applying other methods. The disadvantage is strong dependence of obtained results on atmospheric factors such as humidity of air, atmospheric falls and wind.

The variety of IR spectroscopy is FTIR spectroscopy which improves its selectivity. The principle for using the FTIR spectroscopy requires decomposition of infrared light on to two light beams with the use of Michaelis's diadelphous interferometer. When the light beams are integrated in the infrared detector, interference is causing the modulated signal which among these beams is a function of the optical way difference. In the FTIR spectroscopy the adsorption in the infrared of individual gasses permits to determine their concentration.

The FTIR spectroscopy is coming to spacious diversity problem by fusing entire flow area. This method is frequently chosen for determining methane emission from the entire landfill. However this technique is limited by costs.

5. Conclusions

Analysing the mixed blessing, of each characterised measurements method of landfill gas emission, considering economic factors and the availability of given technique, a chamber method is an optimal method. It is cheap and can be applied on large surface areas e.g. on the entire landfill. Thanks to the availability of chambers about the different volume, this method can be conducted in the different conditions. Uneven lie of the land, changeability of atmosphere conditions does not exclude the option for using this method, however this factors permits for getting the information concerning its influence on the emission magnitude. The static and dynamic chamber technique is used universally. The chamber technique was applied by inter alia Jager and Petersen in 1985 in order to determine biogas emission from landfills in Germany as well as Börjessonaka and Svensson in 1999 in Sweden [Internet 2].

The FTIR spectroscopy is the second of recommended methods. In spite of this method is much more expensive than the chamber method, gives more credible results.

References

1. **Barański A.:** *Methane emisision from landfills.* Protection of environment and natural resources, no. 25/26, 2003.
2. **Fisher C., Maurice C., Lagerkvist A.:** *Gas Emission from Landfills – An overview of issues and research needs.* Swedish Environmental Protection Agency, Stockholm, 1999.

3. **Hoeks J.:** *Significance of biogas production in waste tips.* Waste Management & Research, 1, 1983. 323÷335.
4. **Kumar S., Gaikwad S.A., Shekdar A.V., Kshirsagar P.S., Singh R.N.:** *Estimation method for national methane emission from solid waste landfills.* Atmospheric Environment 38, 2004. 3481÷3487.
5. **Kumar S., Mondal A.N., Gaikwad S.A., Sukumar Devotta, Singh N.R.:** *Qualitative assessment of methane emission inventory from municipal solid waste disposal sites: a case study.* Atmospheric Environment 38, 2004, 4921÷4929.
6. **Smith K.A., Bogner J.:** *Measurement and Modeling of Methane Fluxes from Landfills.* IGA Ctivites, Newsletter No. 10, 1997.
7. The order established by the Minister of Environments on 9th December 2002 in the matter of the scope / time / way / and the conditions for monitoring on waste landfills; Journal of Law, no. 220, position 1858.
8. **Żygadło M.:** *Municipal waste management.* Publication of Kielce University of Technology, 2002.

Internet
1. http://www.ima.kth.se/lm/3c1350/Text/Grp9.doc - *Investigation of standard methods for analysis of methane emission from landfills;*
2. http://www.tema.liu.se/people/gunbo/Waste2000 - Börjesson G., Galle B., Samuelsson J., Svensson B.H., *Methane emissions from landfills: options for measurement and control;*
3 http://environment-agency.gov.uk/commondata/acrobat/lfg_surface_emissions_0303.pdf - *Guidance on monitoring landfill gas surface emissions.*

Ocena metod pomiaru i szacowania emisji biogazu ze składowisk odpadów

Streszczenie

Ocena ładunku zanieczyszczeń gazowych dostających się do atmosfery ze składowisk odpadów zawierających frakcję organiczną dokonywana być może na podstawie rzeczywistych pomiarów szybkości emisji lub na podstawie oszacowań teoretycznych, przy przyjęciu pewnych założeń. Obie metody nie są niezawodne. Przyjęcie uśrednionych wartości parametrów stosowanych w oszacowaniach teoretycznych pociąga za sobą błędy. Zmienność emisji biogazu w czasie i w przestrzeni oraz niedoskonałość metod jej pomiaru, sprawia, że wyniki mają charakter chwilowy lub są niedokładne, a obliczenia ilości biogazu dostającego są do atmosfery w długim czasie są również obarczone błędem. Dokładność pomiaru, choć nie eliminuje błędów to jednak znacząco je redukuje. Przyjęta metoda nie pozostaje więc bez wpływu na uzyskany wynik końcowy obliczeń. Wybór właściwej pod względem dokładności metody jest ważnym krokiem w ocenie oddziaływania składowiska na atmosferę. Nie zawsze jed-

nak dokładności jest najważniejszym kryterium wyboru metody. Często przewagę nad nim mają względy ekonomiczne. W pracy przedstawiono przegląd i ocenę najważniejszych metod pomiaru emisji biogazu (lub tylko metanu) ze składowisk odpadów.

Estymacja emisji gazu składowiskowego nie jest metodą jego pomiaru, ale pozwala na teoretyczne oszacowanie strumienia emisji biogazu z składowisk odpadów. Emisja biogazu jest szacowana przy wykorzystaniu standardowej metody IPCC (dotyczy metanu) albo metodą trójkąta. Późnie może to być porównane z rezultatami uzyskanymi na drodze bezpośrednich pomiarów.

Kraje rozwinięte są zobowiązane do stabilizacji emisji gazów cieplarnianych za Konwencją Generalną Narodów Zjednoczonych. Między innymi ta umowa wymaga prowadzenie całorocznego rejestru emisji gazów cieplarnianych zgodnie z zaleceniami Międzyrządowego Panelu nt. Zmian Klimatu – IPCC.

Metoda standardowa daje niezawodną coroczną ocenę potencjalnej emisji gdy masa zdeponowanych odpadów jest stała lub zmienia się nieznacznie podczas kilku dziesięcioleci.

Trójkątna metoda potwierdza, że oceniając emisję zależną od czasu, pasuje do prawdziwego model procesu degradacji w czasie. Zamierzając definiować emisję biogazu na podstawie z tej metody, powinno się dysponować danymi dotyczącymi ilości odpadów i ich składu, jak również metody składowania na danym składowisku odpadów z około kilku dziesięcioleci.

Jedna doskonała metoda, która pozwala dokładnie określić emisję biogazu ze składowiska odpadów nie istnieje. Jakkolwiek, istnieje kilka metod, które zostały przetestowane w różnych warunkach. Niektóre z nich są używane do oceny emisji biogazu z małych obszarów, podczas gdy inne pozwalają określić emisję z dużych powierzchni, np. z całego składowiska odpadów. Pierwsza grupa metod to: metoda komór, metoda podpowierzchniowego pionowego gradientu stężenia; wśród drugiej grupy metod są: metody mikro-meteorologiczne, metoda izotopowa, metoda wskaźnikowa i spektroskopia IR.

Metoda pomiaru korzystająca z komór opiera się na znajomości objętości powietrza, gdzie wzrost stężenia gazu składowikowego przechodzącego przez znajome pole powierzchni gleby jest obserwowane przez określony czas.

Metoda podpowierzchniowego pionowego gradientu została opisana przez Rolstona w 1986 i opiera się na prawie dyfuzji Ficka. Aby stosować tę metodę przy określaniu rozmiar emisji gazu składowiskowego, trzeba znać wartość prędkości dyfuzji gazu w glebie i gradient stężenia gazu w powietrzu w glebie. Emisja gazu jest obliczona na podstawie wzoru.

Metody mikro-meteorologiczny są stosowane dla oznaczania przepływów gazów nad powierzchnią badanego obiektu.

Izotopowe frakcjonowanie jest odmiana metody modelu addytywnego. Opiera się ona na pomiarze stosunku izotopu.

Spektroskopia w podczerwieni (IR) to prosty i łatwy w stosowaniu sposób pomiaru przepływu gazu. Metody widmowe pozwalają oznaczyć stężenie różnych gazów, np. CH_4, CO_2, CO. Są metodami opartymi na adsorpcji podczerwieni.