ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 7 2011

Iwona ZAWIEJA[1], Paweł WOLSKI[1]
and Lidia WOLNY[1]

RECOVERING OF BIOGASS FROM WASTE DEPOSITED ON LANDFILLS

POZYSKIWANIE BIOGAZU Z ODPADÓW DEPONOWANYCH NA SKŁADOWISKACH

Abstract: The waste dump as the place, which is burdensome for the environment, can have disadvantageous influence on all its elements. It can affect directly: the air, the ground surface together with the soil, the surface and the underground waters and it can affect indirectly: the health of the population which lives in its surrounding and the animal world. In Poland the waste dumps (together with mines and water treatment plants) have dominant influence on the methane emission from so-called anthropogenic sources. The methane is the second gas, after carbon dioxide, which is responsible for the greenhouse effect. What is more, it is a valuable source of energy carrier, which is produced from the organic substances during the sophisticated process, as regards biochemistry, called oxygen-free stabilization. The content of gas in the vertical structure section of the deposit is not stable. The amount an the quality of waste dump gas depend mainly on the morphology and on the percentage content of the organic parts of the deposited wastes and on their humidity, on their effective concentration and on the insulating cover during the exploitation of the waste dump. According to the literature data, from 100 m^3 of biogas there can be produced about 560–600 kWh of electric energy. The waste dump of the surface: 15 ha can give from 20 GWh up to 60 GWh of energy during a year if the year-long mass of the deposited wastes is about 180 000 Mg. The multilateral and multidimensional character of the renewable energy sources causes that they can have a significant influence both on the development of regional politics of the country, directly affecting the increase of the country energy safety level. They can also have an influence on the keeping to the emission limits which were imposed by European Union (EU), concerning, among others, the production of greenhouse gases. In the Kyoto report ratified in 1997 by Poland, all countries of EU are obliged to reduce the emission of greenhouse gases of 8 % up to 2012. In the article there have been discussed the issue concerning both the biogas energy potential and the management of biogas as well as there have been reviewed the legal acts concerning the usage of biogas which arises on the wastes dumps.

Keywords: biogas, methane, oxygen-free stabilization, waste dump, renewable energy sources (RES)

[1] Institute of Environmental Engineering, Faculty of Environmental Engineering and Protection, Czestochowa University of Technology, ul. Brzeźnicka 60a, 42–200 Częstochowa, Poland, phone: +48 34 325 73 34 ext. 64, email: izawieja@is.pcz.czest.pl

Legal requirements concerning the use of biogas as an alternative energy source

Biogas forming in the process of methane fermentation of biomass or the biodegradable part of waste is one of so-called biofuels. Biofuels provide an alternative to the commonly used fossil fuels. A decided turn in the European Union policy toward the wide utilization of *renewable energy sources* (RES) has been observed for a dozen or so years. The industry involved in the production of renewable energy is one of the most dynamically developing branches of the economy. In the EU legislation, this issue is regulated by the Directive 2001/77/EC on the promotion of electrical energy generated from renewable energy sources [1]. It requires Member States to implement legal measures intended to promote renewable energy sources, remove administrative barriers, and report on the progress of these activities. As the candidate for European Union membership, Poland was required to transpose the regulations of the Directive 2001/77/EC to the national legal system. The EU documents that determine the domestic policy for the development of energy generated from renewable energy sources, such as "The State's ecological policy II" or "The strategy for the development of renewable power engineering" have set the quantitative targets and established the schedule of implementing renewable energy to the domestic electrical energy generation system.

The concept underlying of the oxygen-free stabilization process

Biogas is an energy-valuable fuel which is the product of a specific method of utilization of wastes of plant and animal origin. This method involves the oxygen-free (anaerobic) stabilization of waste. This is a biochemically complex process that proceeds in stages, in an appropriate temperature regime.

Waste disposed of on a landfill is a mix of organic and inorganic materials of different moisture content. If proper landfilling conditions are created, ie compacting followed by covering with a next layer of waste or backfill soil, then the period in which the action of oxygen and light takes place will be very short. This will create conditions for the occurrence of the process of oxygen-free decomposition of the waste. During the deposition of waste, five basic phases of chemical and biochemical processes can be distinguished, which lead to the formation of the fermentation gas, ie: the oxygen phase, the acetogenesis phase, the unstable methanogenesis phase, the stable methanogenesis phase, and the vanishing methanogenesis phase [2].

The energy potential of biogas

Methane is the simplest of the hydrocarbons. The methane molecule has the shape of a tetrahedron. It is a gas that relatively commonly occurs in nature [3]. Methane forms predominantly in the process of deoxidation (reduction) of carbon dioxide with hydrogen, according to the reaction $CO_2 + 3H_2 = CH_4 + H_2O$, and by metabolic decomposition of acetic acid: $CH_3COOH = CH_4 + CO_2$ + energy. In the combustion of methane, carbon dioxide and water forms. This reaction is highly exothermic, therefore methane when mixed with air forms a dangerous explosive mixture with a proportion of the components of 5–15:100 (the lower explosive limit of 5, and the upper explosive limit of 15). By combusting 1 m^3 of methane, approx. 1.6 kg of water in the form of vapour forms. For the combustion of 1 m^3 of methane, approx. 10 m^3 of air are needed [4]. The heat of combustion of methane is 13 264 kcal/kg, or 55.53 MJ/Mg, and its calorific value of is 11 954 kcal/kg, ie 50.05 MJ/Mg. The calorific value of biogas ranges from 18 to 24 MJ/m^3 [5]. The oxygen-free decomposition can theoretically yield [6]:

– from 1 kg of carbohydrates: 456 dm^3 CO_2 + 453 dm^3 CH_4,
– from 1 kg of proteins: 516 dm^3 CO_2 + 547 dm^3 CH_4,
– from 1 kg of fats: 449 dm^3 CO_2 + 1095 dm^3 CH_4.

Knowing the chemical composition of waste, the amounts of methane and carbon dioxide that can be obtained from the unit mass of the waste can be calculated. The percentage content of methane in the landfill gas determines the method of biogas utilization. In the stable phase of methanogenesis, the methane content of gas is approx. 60 %, which, according to the PN-87/C-96001 standard, classifies it to sub-group 30 of natural gases [7]. Detailed requirements for the qualitative composition of biogas are standardized by the manufacturers of equipment using biogas. They refer primarily to the total contents of sulphur compounds, chlorine, fluorine and dust in the biogas. The most important factor determining the method of biogas utilization is the gas potential of landfills. The amount of generated landfill gas ranges from 60 to 180 m^3/Mg of deposited waste.

As shown in Table 1, the level of concentration of main biogas components, ie methane and carbon dioxide, is very diverse, depending chiefly on the type and content of the component, the period of waste deposition, and the method of landfill use [6].

Table 1

Composition of biogas produced in the area of waste dump [8, 9]

Component	Range of occuring	Medium value
	[%]	
Methan, CH_4	30–65	54
Carbon dioxide, CO_2	30–50	40
Nitrogen, N_2	5–40	10
Hydrogen (inflamable gas, H)	0–3 (1–3)	1
Oxygen, O_2	0–5	1
Argon, Ar	0.04	0.1
Hydgrogen sulfide, H_2S	0–0.01	0.003
Total sulphur	0–0.01	0.003
Total chlorine	0–0.005	0.002

Methane has many properties in common with natural gas, however the differences that exist between them are significant (Table 2). This entails the necessity of making a considerable adjustment of the properties of biogas, if it is intended to be pumped into the regional natural gas grid (the same is true for filling steel cylinders intended for motor vehicles) [10].

Table 2

Differences between properties of biogas and natural gas distrubuted in the network

Component	Unit	Biogas	Natural gas
Methan, CH_4	% mol	50–70	> 94
Carbon dioxide, CO_2	% mol	25–45	≤ 2
Ammonia, NH_3	mg/Nm^3	≤ 1000	lack
Hydgrogen sulfide, H_2S	mg/Nm^3	≤ 2000	≤ 5
Oxygen, O_2	% mol	≤ 2	≤ 0.5
Nitrogen, N_2	% mol	≤ 8	≤ 5
Calorific value	kWh/Nm^3	6.8–8.4	10.7–12.8

Building of landfills

Landfills are civil engineering structures that are particularly noxious to the natural environment. Therefore, they must be properly designed and made in conformance to the *best available technologies* (BATs). According to the geotechnical classification of building structures, landfills belong to the third geotechnical category due to the environmental hazard that they are likely to cause. Each landfill is required to have a shield that will ensure it to be leakproof and protect the groundwater against contamination by effluent pollutants. The areas of landfills that do not have a sufficiently leakproof geological barrier in the ground must be additionally sealed [11].

The Regulation of the Minister of the Environment [12] on specific requirements for location, construction, operation and confinement, which should be met by particular landfill types, combines landfills for hazardous waste, non-hazardous waste and neutral wastes by stipulating for all of them the same requirements for making the mineral insulation shield. The landfill insulation profile specified in above-mentioned Regulation, corresponds to the minimum requirements of the European Union Directive [13].

A very important insulation layer in landfills is the mineral leakproof layer, ie the "geological barrier", and the clay insulation layer made. The proper method of designing the seals of landfill base and slopes should allow for the geological and hydrogeological conditions, as well as other data on the waste and the landfill surface. Landfill surface sealing shields should be constructed as multi-layered and to be made from natural materials. The thickness of surface seals made (including the land reclamation and draining layer) can reach even 2 to 2.5 m, and depends on the land reclamation method. The cover layer should allow the vegetation growth. Figure 1 shows the surface layer profiles in the land reclamation of landfills, as recommended by the ITB (*Institute for Building Technology*) [14]. It should be noted that the profile does not include the synthetic layer, as in the municipal waste landfills it results in drying up of the landfill and halting gas production. The construction of the landfill surface

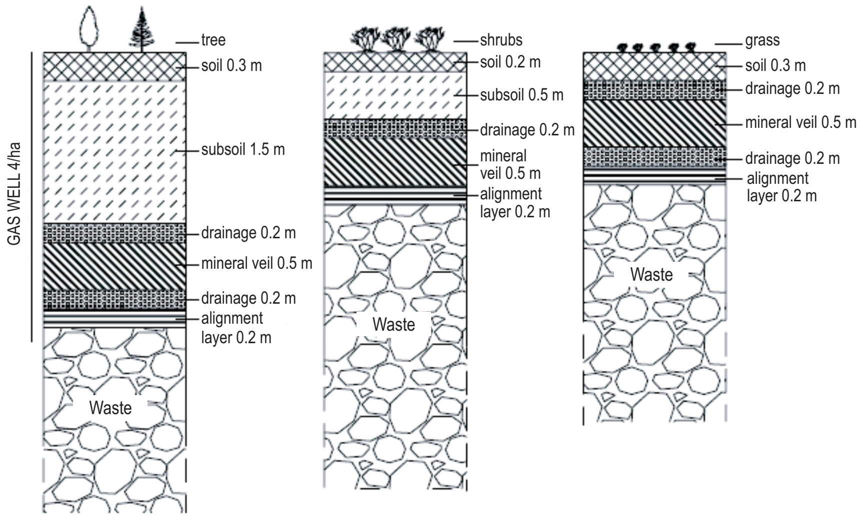

Fig. 1. Landfill surface sealing profiles, as recommended by the ITB [14]

sealing shield most often includes a levelling layer placed on the waste, capped by the following in the consecutive order: a gas draining layer, a mineral shield, a water draining layer, a filtering layer, a biological barrier, and a surface land reclamation layer [15].

Operation of landfills

The operation of a landfill is a very important element of its proper functioning. The aim of landfill operation complying with the regulations is to limit or minimize the emissions of pollutants during and after ending of landfill functioning. For landfill operation to be run properly, it is necessary to prepare an operation plan which should include all essential operation rules, information on landfill body formation, as well as the documentation of technical installations [16].

The operation of a landfill should ensure the minimization of the exposure of deposited waste surface to the elements, if it is necessary for reducing air contamination, including waste carry-over by wind.

In addition, it should prevent the accumulation of effluents and ensure that they undergo treatment to the extent that allow them to be received by the waste treatment plant or discharged to the surface water or to the ground, and also it should guarantee the geotechnical stability of the waste deposited [12]. Quarters shall be sectioned off on the landfill, each of the volume as specified in the building design of the landfill. The surface area of the quarters intended for the storage of hazardous waste should not exceed 2500 m^2. In the case of storing biodegradable waste, the operation of the next quarter may only be started upon obtaining the approval for the closure of the separated part of the landfill. Non-hazardous and neutral wastes originated from waste neutralization processes, which are listed in the Catalogue of Wastes forming the Annex to the Regulation of the Minister of the Environment of 27th September, 2001, on the Catalogue of Wastes in sub-groups 19 01, 19 02, 19 03, 19 04 and 19 10, shall be stored in a separated quarter. In the process of closing a landfill or its part, land reclamation work shall be done in a manner that will prevent any harmful impact of the landfill on surface and underground waters and air, integrate the landfill area with the surroundings, and enable the observation of the landfill's influence on the environment [15]. Several technologically proven and economically viable systems of the recovery and utilization of biogas from selected municipal wastes of organic origin or from refuse deposited in the form of heaps on landfills are now functioning in Europe and in the world. The best developed technologies based on the oxygen-free fermentation process include the following: BTA (Germany), Dranko (Belgium), Rollweil (Germany), SWECO (Sweden) WABIO (Finland), Valorga (France) and others. The formation of gases in a waste bed is the result of the biochemical process that causes an increase in temperature and pressure. As a result of convective movements, these gases are released from the waste bed to the atmosphere, and in the case where the bed is not sufficiently sealed, the gases migrate also to ground base of the landfill. The current state of technology offers two basic methods of extracting gas from a landfill, ie the passive and the active degassing methods. Passive degassing is generally used in the operation of older landfills, but only when the gas systems are appropriately prepared for specific conditions. In new, well sealed landfills, active degassing is exclusively used. This is true in particular, where more than 10 thousand Mg (tonnes) of waste are disposed of on landfills, which is adequately compacted with heavy studded rolls, and when the individual layers of the waste being compacted are adequately backfilled with insulating soil. In so made beds, horizontal draining pipelines and vertical gas extraction shafts are gradually developed.

Poland's first implementations related to the use of landfill gas as a valuable energy source concerned plants generating solely electrical energy, with the power installed on particular landfills generally not exceeding 200 kW. There is currently a trend towards building larger plants (above 1 MW in power) or retrofitting existing ones to increase their power. Thermal energy produced in the co-generation process is most often used to meet the landfill operator's own needs, or is sold to municipal heat distribution services or other users. Moreover, after prior adjustment of its physicochemical parameters to those of natural gas, the biogas can be distributed to the municipal gas grid. The combustion of gas in gas engines coupled with generators contributes to the generation of mechanical energy that is used for driving compressors, pumps, generators and other mechanical equipment operated on the landfill site. In the case of having high methane content (on a level of 40–70 %), the biogas forming during the biological conversion of biomass is a particularly attractive energy medium for CHP (*Combined Heat and Power*) systems. The extraction of landfill gas from the landfill and its energy utilization prevents the free emission of the gas, which results in a reduction of the adverse environmental impact of the landfill.

The economics of a plant using landfill gas

Renewable energy sources are local sources that can increase the level of energy security in a national scale and provide appropriate standards in the protection of the atmosphere and the entire natural environment against pollution, as well as to create new jobs [17]. It has been established from model laboratory tests and practical measurements of biogas carried out on landfills that 1 Mg (tonne) of moist waste collected from households and businesses yields 80–160 m^3 of landfill gas. Considering the average calorific value of biogas being equal to 4.5 kWh/m^3 and the amount of recovered biogas being > 50 m^3/h, it turns out that domestic refuse landfills constitute economically viable sources of renewable energy [18]. It is estimated that the energy utilization of landfill gas is economically viable for landfills with the total mass of deposited waste being at least $0.5 \cdot 10^6$ Mg. An analysis of landfills carried out by the Research & Development Centre for the Ecology of Towns (Ośrodek Badawczo--Rozwojowy Ekologii Miast, OBREM) in the aspect of economical viability of landfill gas utilization has found that such investment projects are cost-effective for landfills of an area above 3 ha and a minimum bed thickness of 5 m. Depending on the landfill size, the biogas utilization method, the biogas recovery technology used, the fuel properties of the biogas being recovered, and on the market prices of recovered heat or electricity, the incurred investment outlays give a return within 2 to 10 years [19]. It should be noted that landfill gas will be produced intensively for 10 to 15 years after the ending of landfill operation. This provides an unquestionable argument for the opinion that the energy utilization of landfill gas can bring about both environmental advantages, as well as measurable economic benefits.

Conclusions

The necessity of organic waste utilization is the main aim of biogas technologial application, whereas the secondary aim is biogas production. Biogas is treated as accessory product of anaerobic stabilization of waste, being simultaneously valuable energetically fuel. Degassing of waste dump, in the ecological aspect, is equally important, as protection of its structure against migration of water leachates to the groundwater medium. Suitable system of waste dump degassing testifies its exploatational safety. According to the recommendations of the European Union, the waste dumps of total storaged waste mass over 10 thousand Mg (ton) must own degassing instalation.

Acknowledgement

This work was financially supported by BW-401/202/07.

References

[1] Directive 2001/77/EC of the European Parliament and of the Council of 27th September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market.

[2] Kempa E.S.: Gospodarka odpadami na wysypiskach, Wyd. Arka Konsorcjum s.c., Poznań 1993.
[3] Metan, Encyklopedia WIEM, http://portalwiedzy.onet.pl.
[4] Matuzik M.: *Biogazownie w zachodniopomorskim – patent na paliwo i lepszy zapach*. Energia Gigawat 2005, http://www.gigawat.info/archiwum/index.php/article/articleview/590/1/55/index.html
[5] Rosik-Dulewska Cz.: Podstawy gospodarki odpadami, Wyd. Nauk. PWN, Warszawa 2006.
[6] Skorek J. and Kalina J.: Gazowe układy kogeneracyjne. WNT, Warszawa 2005.
[7] Czurejno M.: *Biogaz środowiskowy, jako źródło alternatywnej energii*. Energet. Ekol. 2006, **10**, 777–781.
[8] Willmunsen H.C. *Energy recovery from landfill gas in Denmark and worldwide.* Międzynarodowe Sympozjum, Utilization of landfill gas for energy production. Lithuanian Energy Institute, Print of Kaunas University of Technology, Kaunas, Lithuania 2001.
[9] Manczarski P.: Systemy odgazowani składowisk odpadów komunalnych – zagadnienia procesowe i technologiczne, www.drewnozamiastbenzyny.pl
[10] Kotowski W.: *Wyłapać metan*. Energia Gigawat 2006, http://www.ekoenergia.pl/index.php?id_art=404&cms=108&plik=Biogaz_-_biogazownie.html.
[11] Wysokiński L.: *Przegląd problemów związanych ze składowaniem odpadów*. Mater. Budowl. 2006, **11**(411), 34–36.
[12] Rozporządzenie Ministra Środowiska z dnia 24 marca 2003 r. W sprawie szczegółowych wymagań dotyczących lokalizacji, budowy, eksploatacji i zamknięcia, jakim powinny odpowiadać poszczególne typy składowi skodpadów (DzU 2003, nr 61, poz. 549).
[13] Zawisza M.: *Geosyntetyki na składowiskach odpadów komunalnych*. Mater. Budowl. 2006, **11**(411), 45.
[14] Wysokiński L.: *Projektowanie i wykonywanie przesłon izolacyjnych z materiałów mineralnych na składowiskach odpadów komunalnych.* Instrukcja ITB nr 337. Wyd. ITB, Warszawa 1996.
[15] Projektowanie i budowa nowoczesnego składowiska odpadów, Internet, http://odpady.org.pl/plugins/content/content.php?content.1665.2
[16] Bilitewski B., Hardtle G. and Marek K.: Podręcznik gospodarki odpadami. Wyd. Seidel-Krzywecki, Warszawa 2003.
[17] Wiśniewski G.: Odnawialne źródła energii jako element rozwoju lokalnego, Przewodnik dla samorządowców terytorialnych i inwestorów. Wyd. EC BREC/IMBER, Warszawa 2003.
[18] Stępniak S.: *Ustalenie potencjału gazowego, metody określania prognoz wysypisk komunalnych*, Przegl. Energet. 2006, **4**, 33–35.
[19] Czurejno M.: *Energetetyczne wykorzystanie gazu składowiskowego*. Ekonatura 2005, **3**(16), 20–22.

POZYSKIWANIE BIOGAZU Z ODPADÓW DEPONOWANYCH NA SKŁADOWISKACH

Instytut Inżynierii Środowiska, Wydział Inżynierii Środowiska
Politechnika Częstochowska

Abstrakt: Składowisko jako obiekt uciążliwy dla środowiska może oddziaływać niekorzystnie na wszystkie jego elementy, bezpośrednio na powietrze, powierzchnię ziemi wraz z glebą, wody powierzchniowe i podziemne oraz pośrednio na zdrowie ludności zamieszkałej w jego otoczeniu, jak również świat zwierząt. W Polsce składowiska odpadów (wraz z kopalniami i oczyszczalniami ścieków) mają dominujący wpływ na emisję metanu z tzw. źródeł antropogennych. Metan jest drugim po ditlenku węgla gazem odpowiedzialnym za zjawisko cieplarniane. Ponadto jest wartościowym nośnikiem energii, wytwarzanym z substancji organicznych podczas złożonego pod względem biochemicznym procesu, jakim jest stabilizacja beztlenowa. Skład biogazu w pionowym przekroju złoża nie jest stały. Ilość i jakość gazu składowiskowego zależy głównie od morfologii i procentowej zawartości części organicznych deponowanych odpadów oraz od ich wilgotności, efektywnego zagęszczania, a także przykrycia izolacyjnego w trakcie eksploatacji składowiska. Jak podają dane literaturowe, ze 100 m^3 biogazu można wyprodukować około 560–600 kWh energii elektrycznej. Ze składowiska o powierzchni około 15 ha można uzyskać od 20 do 60 GWh energii w ciągu roku, jeżeli roczna masa składowanych odpadów to około 180 tys. Mg (ton). Poprzez swoją wielostronność i wielowymiarowość odnawialne źródła energii mogą znacząco przyczynić się zarówno do rozwoju polityki regionalnej kraju, wpływając bezpośrednio na zwiększenie poziomu bezpieczeństwa energetycznego, jak również dotrzymanie wprowadzonych przez Unię Europejską (UE) limitów emisyjnych, dotyczących m.in.

wytwarzania gazów cieplarnianych. W ratyfikowanym przez Polskę protokole z Kioto z 1997 r., kraje UE zobowiązały się zredukować do roku 2012 emisję gazów cieplarnianych o 8 %. W artykule podjęto problematykę dotyczącą zarówno potencjału energetycznego biogazu, instalacji służących do ujmowania biogazu oraz jego zagospodarowania, jak również dokonano przeglądu aktów prawnych dotyczących wykorzystania biogazu powstającego na składowiskach odpadów

Słowa kluczowe: biogaz, metan, stabilizacja beztlenowa, składowisko odpadów, odnawialne źródła energii (OZE)