MOGUĆNOST ISPLATIVOG DOBIJANJA ELEKTRIČNE ENERGIJE IZ MALIH REGIONALNIH DEPONIJA

POSSIBILITY OF COST-EFFECTIVE ELECTRICITY GENERATION FROM SMALL REGIONAL LANDFILLS

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Iskorišćenje deponijskog gasa (DG) kao izvora energije se u poslednjih nekoliko decenija naširoko koristi širom sveta. Deponijski gas se može koristiti za proizvodnju energije na nekoliko različitih načina: za proizvodnju toplote za kotlove (direktno korišćenje zagrejavanja vode) ili izmjenjivača toplote, proizvodnju gasa visokog kvaliteta za upotrebu u gradskim gasovododima za grejanje kuća ili proizvodnju i punjenje komprimovanog prirodnog gasa (KPG) na licu mesta i konačno za proizvodnju električne energije. Iako su moguće različite vrste projekata za proizvodnju električne energije, proces nije efikasan i ekonomičan. Postojanje stotina elektrana širom svijeta samo dokazuje da bi to mogao biti profitabilan proces obnovljive energije samo za velike i duboke deponije. U ovom radu fokus je na manjim regionalnim deponijama koje su karakteristične za Srbiju i širi region (Balkan i Centralne i Istočne Evropa). Razmatra se mogućnost korišćenja električne energije na licu mesta uzimajući u obzir da su regionalne deponije udaljene od naseljenih mesta i niskonaponskih električnih mreža i da je sistem sakupljanja deponijskog gasa i baklje za sagorevanje obavezan iz ekoloških razloga, jer je DG opasan gas staklene bašte.

Ključne reči: *Deponijski gas, obnovljivi izvor energije, regionalne deponije*

Utilization of landfill gas (LFG) as an energy source has been widely used all over the world in the last few decades. LFG can be used for the production of energy in several different ways: for heat production for boilers (direct use of water heating) or heat exchangers, production of high quality gas for the final use as pipeline gas for house heating or onsite compressed natural gas (CNG) production and fueling station and finally for electricity production. Although several different electricity generation project types are possible, the process is not efficient and cost-effective. Existence of hundreds of power plants all over the world just proves that it could be a profitable renewable energy process only for the large and deep landfills. In this paper, the focus is on smaller regional landfills which are characteristics for Serbia and the wider region (Balkan and Central and Eastern Europe). Possibility of the electrical energy use on site is considered taking that regional dump sites are distanced from the populated places and low voltage electric grids and additionally that LFG collection system and flares for its combustion is obligatory from environmental reasons since it is a dangerous greenhouse gas.

Key words: *Landfill gas, renewable energy source, regional landfills*

1 Introduction

Landfilling of waste is the least favorable option in the waste management hierarchy since there are much better options for municipal solid waste (MSW) like waste re-use, recycling, and direct production of the energy. Incineration has a much lower environmental impact and higher energy recovery rate, even when the landfilling gas (LFG) is recovered [1].

Additionally, the management of MSW requires materials and energy with further negative environmental impact. This lead to the high importance of energy recovery from MSWs. LFG is a mixture mainly of carbon dioxide and methane, with approximately 50% of them in total. Other components such as H_2S, NH_3, H_2, N_2O, and CO are in traces. High methane concentration gives

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relatively high calorific value of the LPG, which can be even higher than 18 MJ/Nm^3 [2]. This means that it can be a source of renewable energy production.

Methane has a green house gas (GHG) potential 28 times higher than CO_2, and N_2O 310 times higher which gives a relevant contribution to the LPG as whole even with a very low concentrations [3]. This lead to a high contribution of LFG emissions to the whole anthropogenic greenhouse gas (GHG) production, which is of about 3% in the EU and about 18% of total methane emissions in USA [2-4].

Legislative in Serbia follows the trends from developed countries and especially EU legislative. In the law on waste management from 2018, a plan for implementing the reduction of biodegradable waste from landfill is included. It contains measures to achieve the goals of reducing the disposal of this type of waste, especially for recycling, composting, biogas production or reuse of material/energy [5]. Nevertheless, landfilling is a predominant solution in waste management in Serbia, and implementation of regional landfills opening and especially regional waste management system full operation are late [6, 7].

There were build just 7 regional landfills by the end of 2016 and the National Waste Management Strategy 2010-2019 mandates that all municipal solid waste collected must be deposited in 24 to 29 regional landfills by 2025. Achieving this goal would be beneficial for the possibility of energy production since biger (regional) landfills will have a depth higher than 3 meters, which is necessary for being a significant source of methane [7].

Amount of waste collected and deposited by municipal public communal companies in Serbia decreased in the period from 2012 to 2015 but then started to increase and get nearly the same level in 2017 of about 1.8 million tons. The average percentage of waste collection has been constantly increased in the period from 2012 to 2017 [8]. This indicates that gradually increase at a slow rate could be expected in the next decade. Nonetheless, the application of the National Strategy and the decrease in population in the long term could decrease the total amount of municipal waste.

Flaring has been the major way to reduce methane emissions from landfills. The effective impact of flaring on the reduction of methane emissions was and still is significant. Although utilize landfill biogas as a clean and renewable energy source has not been fully utilized, it was determined by economy of electrical energy production from that source. In the United States, electricity generation from reciprocating internal combustion engines is the most prevalent type of landfill electric energy recovery [4].

However, in the areas (globally viewed) with a lower price of electricity, typically LFG generation at threshold levels of more than 750 m^3/h for a minimum of 10 years before active LFG collection would be given any serious consideration for the projects of electricity production [9]. These requirements are suitable only for large regional landfills near the big cities, generally with more than 500,000 citizens. In Serbia, only Belgrade and partly Novi Sad can fitful such criteria. The steady growth of electricity price and the newer environmental criteria, in the meantime, made consideration for the electricity production from smaller regional landfills more realistic. Nevertheless, even recently, a thermal power plant (TPP) is still a strong alternative to electricity production and can be more economic [10].

This paper will aim to present some aspects of the use of modern technologies in the field of electricity production from LFG.

2 Technical and environmental considerations

2.1. Methane quantities and concentration during the time of landfill use

LFG generation from municipal landfills can be determined using several methods. These methods use different mathematical models or on-site measurements, and the best practice is to use a combination of them. LFG quantification is often used by LandGem software which can give a good estimate of the methane quantities during the long period of time. It uses a relatively small number of parameters and is useful even with the use of default values.

US EPA (Environment Protection Agency) Model calculates the volume of methane produced during a year as the sum of a methane volume produced in the year (QTx and T, respectively) form waste mass mx, deposited in subsequent years x prior to the concrete year. Production of the methane in the concrete year can be calculated by the empirical, first-order decay model, which is the relatively simple and straightforward Scholl Canyon Model [11]. The first-order equation can be presented in the following form [11, 12]:

$$Q_{T,x} = k \cdot m_x \cdot L_0 \cdot e^{-k(T-x)} \tag{1}$$

where: x- year of waste deposition; T – year of emission calculation;
k- methane generation rate, L_0 – potential methane generation capacity
with decay in produced methane after the closure of the landfill proportional to the e^{-kt} where t is the year after disclosure.

With the assumption that landfill will be operative 25 years, and that will have 2% of the waste disposal increase in the first decade and then 1% of decrease till disclosure, typical dependence is shown in figure 1.

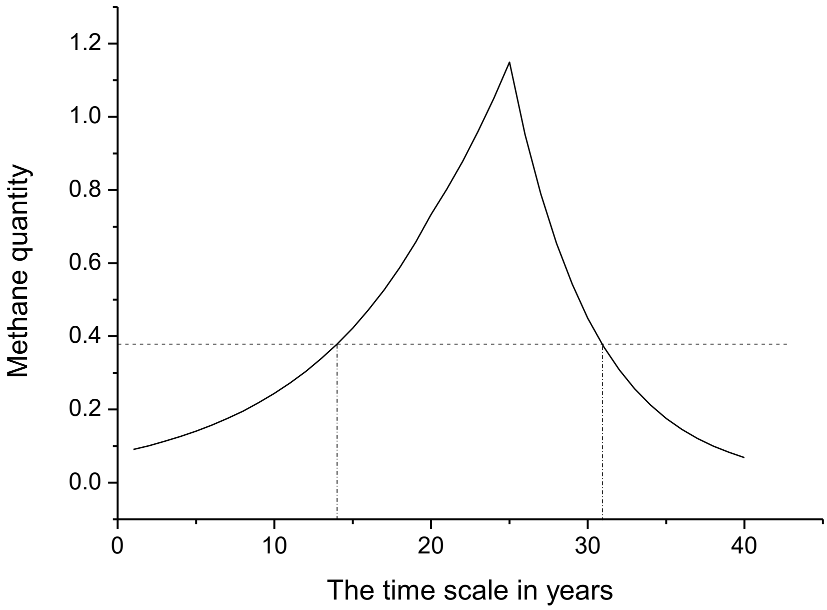

Figure 1 The curve of the methane quantities in the function of the time for the landfill with the parameters given in the text above

As can be seen from figure 1 there is an exponential rise during the exploitation time and similar but sharper decrease after the closure of the facility. It is usual for the small (regional but around small towns) landfills and for the bigger around the cities where the rise in population and quantity of waste per citizen, more balanced curve can be expected. In figure 1 dashed line is the third of the maximal quantity in the graph and dash-dot lines present the limits where more than 33% of the maximum expected quantity can be expected. It is for the example between 14 and 31 years, which is the period of 17 years of total 40 (42.5%). For the production higher than half of the maximum, period is much shorter and last just 10 years, which is just a quarter of the full period in the graph.

An important parameter in addition to the amount is the concentration of methane in the mixture. Typical curve is given in the figure 2.

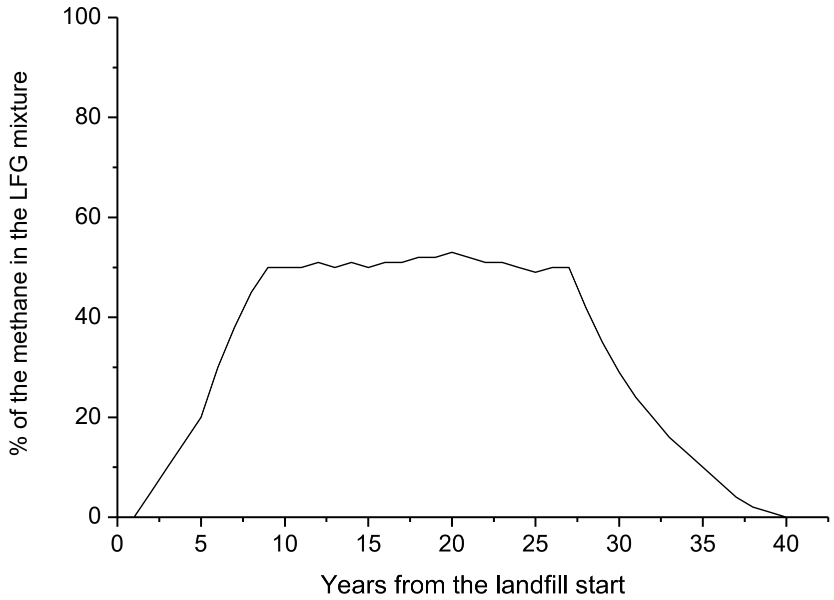

Figure 2 The curve of the methane

Fortunately, after the initial period, the concentration of methane reaches approximately 50% and keeps nearly constant in the long period even a few years after the closure of the dump. The high concentrations of the methane in the gas mixture is essential for the conversion in other energy forms, especially electrical energy. The period with a concentration higher than 40% is usually about half of the total period, for the example is little more than that (about 52.5%).

2.2. Electricity production from the LFG

There are several ways to use landfill gas as an energy source. The primary intention in EU and US is to utilize it for electricity. Electicity can be generated using different technologies, and the mostly used are [12]:

- Internal combustion engines,
- Gas turbines,
- Microturbines.

The first two are in wider use, and the microturbine technology is in expansion for the small landfills. The use of the internal combustion engines is the far most common LFG utilization technology for small to relatively large LFGE projects. Internal combustion engines (ICE) as electric generators are available in various sizes. Their electrical outputs ranging from less than 0.2 MW to more than 3.0 MW per unit and with a total installed power of more than 20 MW [13]. High efficiency is a significant advantage and can be increased when the heat is recovered. They also have low investment cost. Nevertheless, they have relatively high maintenance costs and higher air emissions compared to turbine technologies. This technology also requires primary and sometimes secondary treatment of LFG [13]. ICEs also require high quality of the gas fuel for the

Gas turbine technology is more resistant to corrosion and often need just a primary treatment of LFG. This technology has good efficiency, but it is influenced by the load, which increases it. Gas turbines are generally larger than internal combustion engines and are available in various sizes from 1 MW to more than 10 MW [13]. Larger output also requires a high and sustainable flow of LFG, which disqualify them for the smaller regional landfills.

Microturbines (MT) are the first choice for the electricity production from the low-grade fuel which is typical for smaller LF. Although it is desirable to include some degree of hydrogen sulfide removal from this kind of gas fuel, MTs are highly hydrogen sulfide tolerant. While internal combustion engines operate best when hydrogen sulfide is maintained below 100 ppm and even typical boilers cannot withstand concentrations higher than 1000 ppm, MT can withstand concentrations up to 7% when parts in the microturbine have been acid-resistant treated [11]. There are two major types of microturbine generators: unrecuperated and recuperated. The first has only 15% of efficiency and the second has conversion to electrical energy in the range of 20 to 30%; waste heat recovery can also be used with these systems to achieve efficiencies greater than 80% [14]. The size range for micro turbines available and in development is from 30 to 250 kW [14]. The low maintenance cost and lower emissions than ICEs made them more and more popular recently.

3 Basic economic issues

Internal combustion engines have low investment costs and no need for highly trained workforce. They have a lower cost per installed kW capacity basis when compared with gas turbines and microturbines. Electricity cost can reach as low as 0.06 $/kWh without collection and flaring system costs when minimum total costs increase to 0.09 $/kWh for the medium-sized projects [15]. The smaller electric energy projects, like for regional LF, with the use of ICE, would have some higher costs. For the optimal LFG Electricity Project with the use of gas turbine technology installed power has to be at least 3 MW, which would require LFG flow over 1500 m^3/h. In that, ideal scenario, capital costs as well as operating and maintaining costs per kW could be even lower than for internal combustion engines. However, for the regional LF, this technology is not feasible.

Microturbines can be the best option for the small regional LF with the flow rate of 100 m^3/h up to few hundreds cubic meters per hour. The results of a recent study show that electricity production based on biogas with micro-turbine of 30 kW power can be economically and technically reasonable for the small size landfill area. Calculate Levelized costs of electricity for such a system was between US$0.079 and US$0.091/kWh and total costs with maintenance, were considered varies between US$0.091 and US$0.116/kWh [16]. Taking in mind that capital costs are only 20% higher than for the small internal combustion engine [15], microturbines becomes very competitive technology at the end of the second decade of the century.

4 Conslusion

The results of this study show that electricity production from LFG can be technologically feasible. The technologies that are most used include internal combustion engines, gas turbines, and microturbine technology. They can be combined with heat recuperation when reaches very high energy conversions coefficients.

Even small regional landfills can be used for the project of electricity production when small ICEs and microturbines are the most promising technologies. Although small ICES has some lower initial costs, microturbines are more suitable for the lower quality of the gas fuel (LFG) and have much lower emissions. The cost of the flaring is also lower. This sets the microturbines as a relevant choice for the energy production projects.

Total costs for such projects are still high and can be profitable only in countries with high electricity prices or government subsidies for sustainable energy sources and environmental subventions. In the aim to achieve higher economic electricity production can be easily combined with direct thermal applications such as boilers, dryers, furnaces, and kilns. Further improvement should be for the use for the electric vehicles chargers, with not just on-site use but also for the communal waste transport to the landfills.

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5 References

[1] **Jeswani, H.K., Azapagic A.,** Assessing the environmental sustainability of energy recovery from municipal solid waste in the UK, *Waste Management*, 50: 346–363 (2016).

[2] **Desideri U, Di Maria F, Leonardi D, Proietti S.,** Sanitary landfill energetic potential analysis: a real case study, *Energy Conversion and Management*, 44: 1969–1981 (2003).
[3] **Sisania F., Continia S., Di Maria F.**, Energetic efficiency of landfill: An Italian case study, *Energy Procedia*, 101: 66–73 (2016).
[4] **Broun R., Sattler M.**, A comparison of greenhouse gas emissions and potential electricity recovery from conventional and bioreactor landfills, *Journal of Cleaner Production*, 112: 2664–2673 (2016)
[5] Zakon o upravljanju otpadom, „Sl. glasnik RS“, br. 95/2018.
[6] **Stanisavljevic N., Vujovic S,, Zivancev M., Batinic B., Tot B., Ubavin D.**, Application of MFA as a decision support tool for waste management in small municipalities – case study of Serbia, *Waste Management & Research*, 33: 550–560 (2015).
[7] **Mandić-Rajčević S., Stevanović D,, Jovanović J., Karanac M., Mihajlović M., Dajić A., Jovanović M.**, Analysis of the Regional Landfill System Effects on Green House Gas Emissions in The Republic of Serbia, *IV MKOIEE*, Belgrade 2016.
[8] Upravljanje otpadom u Republici Srbiji od 2011. do 2017. godine, Ministarstvo zaštite životne srdine Agencija za zaštitu životne sredine, http://www.sepa.gov.rs/download/otpad2011-2017.pdf (Accessed in July 2019).
[9] **Mundial B.**, Handbook for the Preparation of Landfill Gas to Energy Projects in Latin America and the Caribbean. World Bank–ESMAP (Energy Sector Management Assistance Programme) Prepared by: Conestoga-Rovers & Associates. 2004; 651.
[10] **Silva T.R., Barros R.M., Filho G.L.T., Santos I.F.S.**, Methodology for the determination of optimum power of a Thermal Power Plant (TPP) by biogas from sanitary landfill, *Waste Management*, 65: 75–91 (2017).
[11] United States Environmental Protection Agency, Landfill Gas Management Facilities Design Guidelines; 2010 https://www.epa.gov/lmop/list-publications-tools-and-resources#publications-b (Accessed in July 2019).
[12] **Dudek J., Klimek P., Kolodyiejak G., Niemcyewska J., Zaleska-Bartosz J.**, Landfill Gas Energy Technologies, Instytut Nafty i Gazu, Krakow 2010.
[13] International Best Practices Guide for LFGE Projects–2012, Landfill Gas Energy Utilization Technologies, https://www.globalmethane.org/documents/toolsres_lfg_IBPGch4.pdf (Accessed in July 2019).
[14] **Lav C., Singh R.K., Kaul C., Rai A.**, Potential of Micro Turbines for Small Scale Power Generation, *International Journal of Advanced Information Science and Technology*, 13: 35–39 (2013).
[15] EPA LFG Energy Project Development Handbook, 2017, https://www.epa.gov/lmop/landfill-gas-energy-project-development-handbook (Accessed in July 2019).
[16] **Gökçek M.**, Waste to Energy: Exploitation ff Landfill Gas in Micro-Turbines, *Omer Halisdemir University Journal of Engineering Sciences*, 6: 710–716 (2017).