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THE INFLUENCE OF LEACHATE RECIRCULATION ON BIOGAS PRODUCTION IN A LANDFILL BIOREACTOR

The technology of municipal solid waste treatment in a landfill bioreactor is based on a system of controlled, enhanced fermentation of organic waste, which occurs in a heap having status of bioreactor. The enhancement of biogas production is done by leachate recirculation. In a landfill bioreactor, located in Kosiny Bartosowe, Poland, with capacity of 70 000 Mg of municipal solid waste, the research aiming on the determination of the influence of leachate recirculation on biogas generation was done. Experiments were done in two periods: just one month after bioreactor sealing with hydraulic loading rate (HLR) of 2 mm/d, and one year after bioreactor sealing with HLR of 3 mm/d. Doubling of biogas production from about 100 to 200 m^3/h and the increase of methane content from 60 to 65% has been determined when 2 mm/d of HLR of leachate recirculation was applied. The implementation of HLR on the level 3 mm/d increased biogas production from 148 to 270 m^3/d, and methane content from 62 to 64%. Leachate recirculation improved thermal conditions in bioreactor to typical mesophilic values.

1. INTRODUCTION

From the definition, bioreactor is a device allowing maintaining, controlling, and optimization the microbial process, by measurements, and regulation of parameters [1]. Main objective of bioreactor is the finding the optimum of the objective function, which is the intensification of biological processes in given conditions. In specific conditions landfills may be considered as bioreactors.

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One of the technological solutions of municipal solid waste treatment is biological stabilization in a landfill bioreactor (LB). The technology of LB originates from previous experiences with operation of traditional landfills, and "dry tomb" landfills. The technology, of municipal solid waste (MSW) treatment in LB is based on controlled, enhanced fermentation of organic waste, which occurs in a heap having status of bioreactor. Implementation of landfill leachate recirculation, combined with leachate pretreatment, significantly enhances the decomposition of organic matter, and biogas formation under anaerobic conditions [2]. The duration of stabilization of organic matter in LB is shortened to about 5–10 years, in comparison to traditional landfills, being still active for 30–50 years [3, 4]. LBs usually are dedicated for MSW treatment, and designed for intense generation of biogas, and it is reuse as a renewable source of energy [5]. LBs are used around the world, mostly in USA, Canada, New Zealand, Australia, and also in European countries such as Great Britain, Italy, France, or as recently opened installation in Helsinki, Finland [6]. LB is a self-heating type of bioreactor. Waste, substrate is supplied into the bioreactor once, at the beginning. Next, the leachate recirculation, and biogas extraction systems, and monitoring devices are placed in the landfill body. After the installation, the equipment is closed, and sealed by impermeable mineral layer. From that moment the operation of LB starts, which is related to optimization of fermentation conditions, by gathering, pretreatment, and recirculation of the leachate [2].

Leachate recirculation has several benefits. It allows one to keep waste moisture level close to water holding capacity, and it improves the micronutrients availability for microorganisms [5]. Keefe and Chynoweth [7] showed that leachate recirculation is an effective method of enhancement of biogas productivity by delivering leachate with high alkalinity, containing adopted methanogenic bacteria. Leachate recirculation allows one to maintain a stable water flow through stabilized waste, enhances heap settlement, intensifies biogas production, and organic matter stabilization, increases elution of the contaminants from waste, decreases the risk of fire, and emission of dust to atmosphere [8, 9].

In the year 2013, the first Polish LB with total designed capacity of 200 000 Mg of MSW, was built in Kosiny Bartosowe near Mława in Poland. The first section (cell) of this LB has the capacity of 70 000 Mg. The first section (cell), with the capacity of 70 000 Mg of MSW, has been intensively examined. One of the aims of the study was to determine the influence of leachate recirculation on quantity and quality of generated biogas.

2. MATERIALS AND METHODS

Leachate recirculation system in LB. The research was executed at the section 1, containing 70 000 Mg of MSW, filled up during 8 months. The mean depth of the LB heap is 15 m. The leachate from LB is caught by a bottom drainage system, and directed into a pump station, from where it is pumped to 4 tanks, having the total working volume of

220 m^3. The outflow from underground retention tanks is gravitational. It is controlled by a slide, which opening allows one to outflow of leachate into the next pump station, from where leachate is pumped into an opened retention tank. In the opened retention tank, the system of leachate aeration has been placed. The working volume of the tank is 400 m^3, and its depth is 2.6 m. Leachate aeration is done by air pumping with a compressor. This system is mostly dedicated for ammonia nitrogen stripping. Leachate from an opened retention tank gravitationally flows out into the next pump station. From that point, the leachate is pumped intermittently into two shallow constructed wetlands with a horizontal subsurface flow. During winter season, it is possible to bypass a hydrophyte systems. Two parallel shallow constructed wetlands with a horizontal subsurface flow system were constructed, one with reed, and the other with willow. Each of the systems has the area of 324 m^2, and working depth of 40 cm. Leachate is supplied to constructed wetlands intermittently, but the frequencies of dosing are regulated by work regime of a final recirculation pump. As a constructed wetlands fulfilment, the light expanded clay aggregates are used.

From constructed wetlands, leachate flows gravitationally through a sequence of two joining wells, and finally into the final recirculation pump. From there, leachate is pumped into a manifold chamber, from where 8 pumping lines were led out. After the leading out from the manifold, each of the pumping pipes, on the distance between manifold to the beginning of infiltration zone was placed on the surface, and mounted into the ground by a holder on every 5 m of the pipe. On that distance, PE pipes have no perforations. In the infiltration zone, perforated PE pipes were lined down in the trench (D20×W40 cm) with a gravel filling. The total length of pipes in the infiltration zone is 605 m. In the infiltration zone, the sealing clay layer of LB was placed. The infiltration zones are designed with at least 9 m distance from gas wells, to reduce problems with gas wells flooding.

Experimental procedure. After the starting of the prototype LB's control system, the research on the influence of leachate recirculation on processes occurring in LB, with special consideration of quantity, and quality of produced biogas was done. Research was executed if two runs. The first experiment was done one month after LB sealing, with leachate hydraulic loading rate (HLR) 2 mm/d. The second experiment was done one year after LB sealing but with leachate HLR 3 mm/d. Between both experiments, leachate recirculation was stopped, due to decision of the bioreactor landfill operator, to avoid unnecessary overproduction of biogas before CHP installation.

As a response of LB for a given leachate recirculation HLR, the quantity and quality of biogas were measured. The flow rate of gathered biogas, the content of CH_4 and CO_2, and the temperature were measured. The biogas flow rate and temperature were measured at the end of the biogas collection system before the flare, with using Pitot's tube joined with KIMO meter. The biogas composition was determined with a biogas analyzer GA2000. During the first experiment, the measurements were done daily for 20 days, while in the second experiment daily for 30 days.

3. RESULTS AND DISCUSSION

Measurements done during the first experiment showed that the gas flow before the recirculation was on the level about 100 m^3/h (Fig. 1). It has been determined that if LB had such biogas production for the whole operation period – 5 years, the total amount of generated biogas would be on the level 4 380 000 m^3 of gas. In relation to waste mass in the first section of LB – about 70 000 Mg, it gives 5 year biogas potential 62.7 m^3/Mg. For the gas flow of 148 m^3/h measured one year after LB sealing but also before the recirculation, the biogas potential 93 m^3/Mg has been estimated. Those values are typical of traditional MSW landfill. Many authors presented wide range of biogas potential for traditional landfills. Usually, values are in range between 35 and 180 m^3/Mg, but in some reports wider range may be found from 6 to 270 m^3/Mg [10].

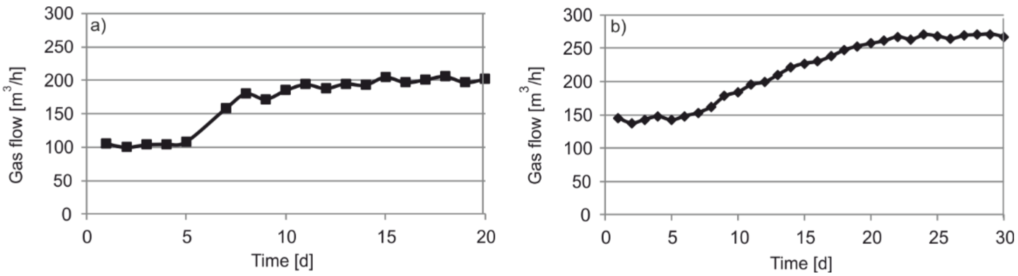

Fig. 1. Time dependences of biogas flow during leachate recirculation:
a) hydraulic loading rate 2 mm/d, one month after LB sealing,
b) with hydraulic loading rate 3 mm/d, one year after LB sealing

After implementing recirculation with HLR of 2 mm/d, it has been observed that after about 5 days, the gas flow rate started to increase, and after 15 days it reached the level of 200 m^3/h (Fig. 1). Implementation of intense leachate recirculation doubled the gas year potential, which was 125.1 m^3/Mg per unit waste weight. Similarly, implementation of recirculation of leachate with a higher hydraulic loading of to 3 mm/d, one year after LB sealing, caused the increase of gas flow rate from 148 m^3/h to 270 m^3/h (Fig. 1). It has been achieved after 23 days of recirculation. In relation to waste weight, 5 year biogas potential counted about 169 m^3/Mg.

In the present study, the implementation of leachate recirculation into the bioreactor body significantly increased the biogas potential to 125 m^3/Mg during 1 month after LB sealing, and to 169 m^3/Mg after 1 year after LB sealing, when methanogenesis was more stable, and matured. The research clearly showed that the waste moisture is a key parameter for anaerobic degradation of organic matter. Similar effects were achieved by Warith et al. who recirculated landfill leachate with HLR 200 dm^3/(Mg·y), what caused the increase waste moisture from 15% to 35%, finally resulting in doubling of the biogas generation rate.

In the research, two HLR of recirculated leachate were used: 2, and 3 mm/d, corresponding to 104 dm^3/(Mg·y), and 156 dm^3/(Mg·y), respectively. HLR of leachate level depends on the results to be achieved. When the main purpose of leachate recirculation is to maintain equal conditions inside the landfill body during the whole year seasonal changes, then HLR 5 dm^3/(Mg·y) should be maintained. When flush landfill is designed, and operated, where the main purpose of leachate recirculation in maximizing the pollutants elution HLR should reach the level of 3000 dm^3/(Mg·y). For typical landfill bioreactors, where fermentation is optimized, HLR should be in the range from 100 to 200 dm^3/(Mg·y) [3], what was confirmed in our study.

During the first experiment, the content of methane exceeded 60%, and after 10th day, it increased from 60% to 65% (Fig. 2). This high value remained constant to the end of the experiment. In the case of second experiment, after one year of LB sealing, initial methane content was on the level of 62%. Implementation of leachate recirculation slightly increased the methane content to 64%, after twelve day of the recirculation.

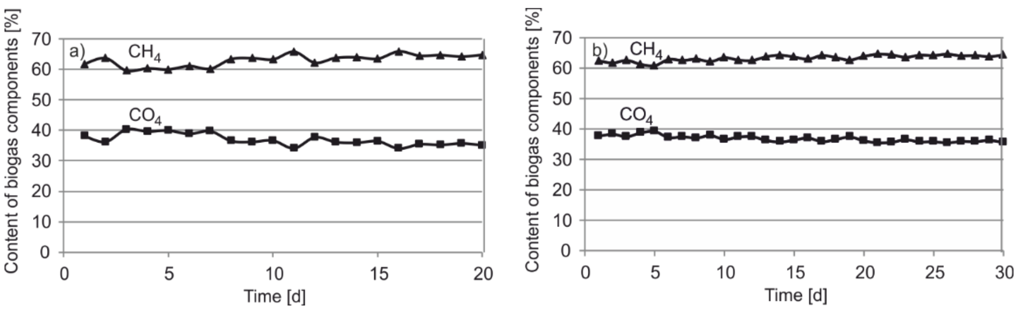

Fig. 2. Time dependences of biogas composition during leachate recirculation:
a) hydraulic loading rate 2 mm/d, one month after LB sealing,
b) with hydraulic loading rate 3 mm/d, one year after LB sealing

Biogas is one of the products of biological processes running inside the MSW landfill body. It is an effect of decomposition of biodegradable organic matter, and the rate of its generation and its composition changes during the landfill life cycle. It is based on a combined model of the bacterial decomposition of waste (phases I–X) and the model for the long-term behavior of landfill gas from old waste deposits [11, 12]. According to [12], the phases I–III of the landfill gas production of non-pretreated waste last for a half up to three years. In phase I, the aerobic phase, aerobic bacteria decompose long molecular chains of complex carbohydrates, proteins and lipids by oxidizing them into carbon dioxide. The emitted gas consists mainly of nitrogen and oxygen.

The amount of carbon dioxide increases as the conditions for the microorganisms improve.

Phase II is the anaerobic acidic phase in which the oxygen in the landfill has been used up and anaerobic bacteria convert compounds produced in phase I into acetic, lactic and formic acids and alcohols. The landfill becomes highly acidic. The landfill gas consists mainly of hydrogen, carbon dioxide, and residual nitrogen. Phase II is highly unstable and the reactions will stop if oxygen contacts the waste. During phase III, the acids from phase II are decomposed into acetate. Thus, the acidity of the landfill decreases. Methane producing bacteria establish in the landfill body. Therefore, the production of methane increases and reaches about 60%. The carbon dioxide production decreases from 70% to 40%. The landfill gas production in this phase is large. A long phase IV follows short phases I–II. It could last for more than twenty years in typical MSW landfills. In this phase, the gas production is relatively constant. The methane–carbon dioxide relation is about 1.25:1. The landfill gas production decreases in comparison to phase III but it is still high enough to prevent ambient atmosphere to infiltrate the landfill body. Conducted experiments, indicated that LB was in phase IV, but the methane–carbon dioxide ratio ranged 1.5–1.85:1, being higher than that for typical MSW landfills. Increase of CH_4/CO_2 ratio in LB may be caused by high rate of waste deposition – 8 months, and final sealing, in contrary to traditional landfills, where deposition of waste takes years, and due to lack of mineral sealing conditions which are not suitable for methanogenic organisms. Next phases of landfill life cycle (V–IX) are related to final depletion of organic compounds and transition of conditions from anaerobic to aerobic [12].

The leachate recirculation improved thermal conditions. In the case of the first experiment, when HLR was 2 mm/d, temperature of biogas started to increase, and achieved typical mesophilic values at the 8th day of the experiment (Fig. 3).

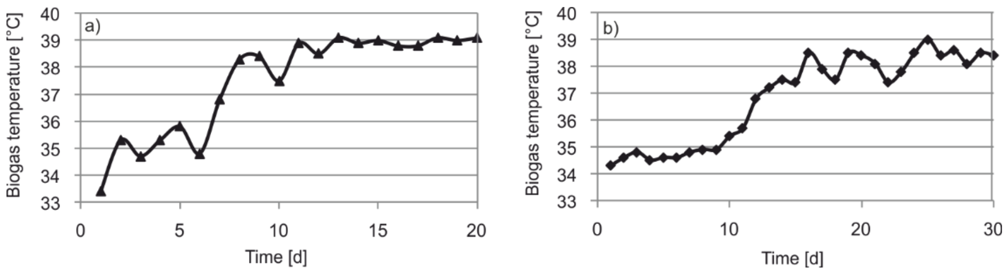

Fig. 3. Time dependences of biogas temperature during leachate recirculation:
a) hydraulic loading rate 2 mm/d, one month after LB sealing,
b) with hydraulic loading rate 3 mm/d, one year after LB sealing

During the set of the experiment with HLR of 3 mm/d, the temperature of biogas started to increase from 34 °C, and after 12–13 days of recirculation it achieved 37–39 °C. In both cases of HLR, temperature after reaching the mesophilic values remained at this level to the end of the experiment.

Biochemical processes occur under specific conditions. Methane fermentation may occur under psychrophilic range of temperatures from 5 to 25 °C, the mesophilic one from 25 to 45 °C, and the thermophilic one from 45 to 60 °C. In practice, due to the highest efficiency, mesophilic, and thermophilic fermentation is used [13]. Leachate recirculation is one of the methods of temperature controlling in the landfill bioreactor. Mehta et al. [14] examined the influence of leachate recirculation on the temperature course during fermentation with or without recirculation. Initially, the temperature increased in both variants to 50–55 °C due to residual oxygen depletion. However shortly after stabilization of anaerobic conditions, it stabilized at the level of 25–32 °C in the system without recirculation, and at the level of 35-40 °C in system with recirculation. This difference was caused by higher microbial activity in variant with higher waste moisture. Similar results were obtained in this study, where in both experiments temperature increased from 32–34 °C to 37–49 °C after about 1–2 weeks of recirculation.

4. SUMMARY

The research with leachate hydraulic loading rate of LB on the level 2 mm/d, and 3 mm/d showed a positive influence of leachate recirculation on conditions in LB. The increase of methane content from 60 to 65% in the case of the hydraulic loading rate of 2 mm/d has been determined. These results were obtained during initial stage of LB operation, after one month of LB sealing. Implementation of leachate recirculation with the hydraulic loading rate of 3 mm/d, one year after LB sealing increased the flow rate from initial value of 148 m^3/h to 270 m^3/h. Methane content increased slightly from 62% by about 2%. Recirculation positively influenced thermal conditions in the bioreactor. Observed phenomenon confirmed the chosen technological assumptions considering leachate recirculation. The observations show that controlling the biogas production by leachate recirculation is possible both during initial phase of LB operation, and during stable methanogenic phase.

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REFERENCES

[1] CHMIEL A., *Biotechnology. Microbiological, and biochemical principles*, Wydawnictwo Naukowe PWN, Warszawa 1998 (in Polish).

[2] WARITH M., LI X., JIN H., *Bioreactor landfills. State-of-the-art review*, Emirates J. Eng. Res., 2005, 10 (1), 1.

[3] TOWNSEND T., KUMAR D., KO J., *Bioreactor Landfill Operation. A Guide for Development, Implementation and Monitoring*, Hinkley Center for Solid and Hazardous Waste Management, Gainesville, FL, 2008.

[4] POHLAND F.G., *Landfill Bioreactors: Historical Perspective, Fundamental Principles and New Horizons in Design and Operations*, [in:] *Landfill Bioreactor Design and Operation*, EPA Seminar Publication, 1995.

[5] BENSON C.H., BARLAZ M.A., LANE D.T., RAWE J.M., *Practice review of five bioreactor/recirculation landfills*, Waste Manage., 2007, 27, 13.

[6] SORMUNEN K., VALTARI M., TASKINEN J., UUSIHAKALA M., LAURILA T., ETTALA M., *Leachate quality and water balance in a new bioreactor landfill*, Proc. 13th International Waste Management and Landfill Symposium, S. Margherita di Pula, Cagliari, Italy, 3–7 October 2011.

[7] KEEFE D.M., CHYNOWETH D.P., *Influence of phase separation, leachate recycle and aeration on treatment of municipal solid waste in simulated landfill cells*, Biores. Technol., 2000, 72, 55.

[8] KNOX K., BEAVEN R.P., ROSEVEAR A., BRAITHWAITE P., *A technical review of leachate recirculation*, Proc. 11th International Waste Management and Landfill Symposium, S. Margherita di Pula, Cagliari, Italy, 1–5 October 2007.

[9] REINHART D.R., TOWNSEND T.G., *Landfill Bioreactor Design and Operation*. Lewis, New York 1998.

[10] US EPA, *A Landfill Gas-to-Energy Project Development Handbook*, US Environmental Protection Agency, 1996.

[11] FARQUHAR G.H., ROVERS F.A., *Gas production during refuge decomposition*, Water Air Soil Poll., 1973, 2, 483.

[12] BOCKREIS A., STEINBERG I., *Influence of mechanical-biological waste pre-treatment methods on the gas formation in landfills*, Waste Manage., 2005, 25, 337.

[13] BLAKEY N.C., BRADSHAW K., REYNOLDS P., KNOX K., *Bioreactor landfill a field trial of accelerated waste stabilization*, Proc. 6th International Landfill Symposium, Sardinia 1997, 1, 375.

[14] MEHTA R., BARLAZ M., YAZDANI R., AUGENSTEIN D., BRYARS M., SINDERSON L., *Refuse decomposition in the presence and absence of leachate recirculation*, J. Environ. Eng., 2002, 128 (3), 228.