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EXPERIMENTAL INVESTIGATION ON BIOGAS PRODUCTION USING PIG MANURE AND SLAUGHTERHOUSE WASTE

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Abstract. The paper presents solution of organic waste from swine-breeding treatment - the anaerobic digestion and biogas production.

The paper presents the findings of experimental investigation of biogas production using pig manure and slaughterhouse wastes were mixed at 95 % : 5 %, 90 % : 10 % and 85 % : 15 % in volume. The paper analyses the quantitative and qualitative composition of biogas: gas content, the concentrations of methane and oxygen.

The highest total biogas output (0.097 m^3 from 0.003 m^3 substrate) was from the mixture of pig manure with slaughterhouse waste at ratio of 19:1. The mixtures of pig manure and slaughterhouse wastes at ratio 9:1 and 17:3 postponed the digestion process in bioreactor. The concentration of methane was reached 60 % after 3 weeks from the beginning the experiment. The highest total amount of valuable biogas (CH_4>60 %), which is useful for combustion and energy production – reached from the mixture with higher portion of slaughterhouse waste – 0.075 m^3. The analysis amount of produced gas and methane concentration in gas shows that the biogas produced from pig manure and slaughterhouse waste mixed at the ratio of 9:1 is the most efficient for use in energy production.

Keywords: biogas, anaerobic digestion, pig manure, slaughterhouse waste, bioreactor.

1. Introduction

The large amount of organic waste generated in the Lithuania is one of the biggest problems today. EU directives and National strategy regulates and promotes waste utilization, but difficult economical situation slows the development (Kvasauskas 2009; Kvasauskas and Baltrėnas 2009).

Swine-breeding is a traditional Lithuanian agriculture activity and pork production is one of the main exports, but its rapid development has affected the environment, especially worst treatment of swine manure, which leads to serious problems: pollution of surface and ground water, pathogens hazardous to human health and wildlife, greenhouse gases emission (methane) and bad odour. Currently, swine farm waste is topical problem, which caused not only by environmentalists but also by local communities, which protests against the piggery activity.

Many nations count on coal, oil and natural gas to supply most of their energy needs, but reliance on fossil fuels presents a big problem. Fossil fuels are a finite resource. Eventually, the world will run out of fossil fuels, or it will become too expensive to retrieve those that remain. Fossil fuels also cause air, water and soil pollution, and produce greenhouse gases that contribute to global warming (Ottinger 2005).

An alternative is creating renewable energy from waste products through anaerobic digestion results in numerous advantages, including capturing and utilizing methane, a greenhouse gas 21 times more powerful than carbon dioxide, decreasing organic loading on receiving waters, and creation of a high-nutrient, low-solid fertilizer (Huttunen *et al.* 2005; Kvasauskas 2009; Lansing *et al.* 2008).

Anaerobic digestion is a microbially mediated biochemical degradation of complex organic material into simple organics and dissolved nutrients. Digesters are physical structures that facilitate anaerobic digestion by providing an anaerobic environment for the organisms responsible for digestion (Kvasauskas 2009; Lansing *et al.* 2008).

The anaerobic digestion – of various organic feedstocks, predominantly animal manures and municipal wastewater sludge, produce a methane rich gaseous mixture called biogas. Biogas generally contains between 40% and 70% methane (CH_4), with the balance of the gas consisting of carbon dioxide (CO_2) and hydrogen sulphide (H_2S). Owing to the high levels of methane, biogas can be used as a heating fuel, and can even be used in an engine to generate electricity (gen-set) (Monteiro *et al.* 2011; White *et al.* 2011).

Large biogas systems are already widely employed in Europe and are gaining traction in North America, but small scale digesters are under construction. Currently, small scale digesters are concentrated in developing countries, with over 5 million household digesters constructed in China and India alone. Digesters built around the world vary in their design complexity, construction materials, and costs (Cuéllar *et al*. 2008; Lansing *et al*. 2010).

Traditionally, anaerobic digestion was a single substrate, single purpose treatment. Recently, it has been realized that anaerobic digestion as such became more stable when the variety of substrates applied at the same time is increased. The most common situation is when a major amount of a main basic substrate (e.g. manure) is mixed and digested together with minor amounts of a single, or a variety of additional substrate (Braun 2002).

The effectiveness of the digestion strongly depends on temperature - an increase of temperature in the bioreactor increases the gas output over the same time, and qualitative gas output – higher content of methane, which depends on composition of mixture (Baltrėnas *et al*. 2005; Kvasauskas 2009).

The experiment aimed at analyzing the use of small scale bioreactor in biogas production using mesophilic temperature regime for different of pig manure and slaughterhouse waste mixture proportion.

2. Methods

The research was carried out in laboratory conditions. The qualitative and quantitative analysis of biogas involves the use of a substrate (organic waste) of different composition in mesophilic temperature regime. To recover biogas, piggery and slaughterhouse organic waste of different compositions were mixed at ratio 19:1, 9:1, 17:3 and used for charging the bioreactor. These kinds of organic waste were chosen because their amounts in Lithuania are rather large and previous investigation show that it provides highest biogas production (Baltrėnas *et al.* 2004; Kvasauskas 2009).

The anaerobic digestion processes are carried out in the small scale bioreactors, which are constructed from the closed plastic container with volume of 5 L, in which anaerobic conditions are created. Mesophilic temperature regime is maintained by water tank. The bioreactors are submersed in water tank, where water temperature is maintained at 30 °C. The volume of container is filled up to 3 L (60 %) and the remaining space is reserved for gas to collect. The bioreactors are connected with biogas containers by elastic bowel. Biogas container is constructed from two plastic pipes: one is stable construction of container (diameter of 110 mm), which is immersed in the water to prevent the gas leakage, and another inside tanker (diameter of 90 mm), which shifts up when filled by biogas (Fig. 1).

The investigation consists of three bioreactors, which were charged using piggery and slaughterhouse waste of different compositions: 1) 19:1, 2) 9:1, 3) 17:3. A substrate containing 10 % of dry substance of its total mass was prepared.

Every day the amount of biogas and the content of methane and oxygen in the biogas were measured.

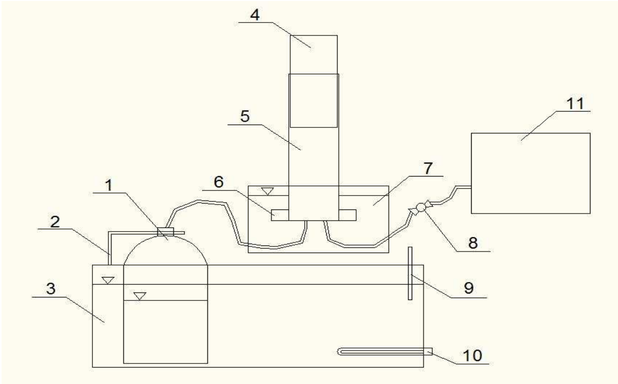

Fig 1. The system of laboratory bioreactor: 1 – bioreactor, 2 - holder, 3 – water tank, 4 – shifting gas container, 5 – stable gas container, 6 – ballast, 7 – water tank, 8 – valve, 9 – thermometer, 10 – heating element, 11 – gas analyzer

The formula, which was used for assessing the produced biogas:

$$Q=\frac{\pi \cdot d^2}{4} \cdot h\,, \tag{1}$$

where Q – amount of produced biogas, m^3; d - diameter of biogas tank m; h – height of tank shifting, m. After the assessment of biogas amount, the gas tank is connected with the gas flow analyzer and the content of biogas is measured.

Measurements of methane, carbon dioxide and oxygen were monitored by gas analyzer.

3. Results and discussion

Main environmental factors which are affecting anaerobic digestion are temperature and pH. Two distinct temperature ranges for anaerobic digestion have been noted. The optimum digestion occurs at 30–35 °C (mesophilic range) and 55 °C (thermophilic range). Most micro-organisms grow best under neutral pH conditions (pH=7.0) (Spinosa *et al.* 1985). The investigations were made under above described conditions.

The experiment continued for 54 days, during June and August of 2010. The mesophilic temperature regime was maintained with heating element. Measurements started from the 3rd day of the experiment, when the first amount of biogas was produced.

The different composition of waste provides large digestion possibilities, in this case co-digestion used. Co-digestion can provide better digestion performance and higher biogas yields. Waste with poor fluid dynamics, aggregating wastes, particulate materials, floating wastes or materials with high disturbing or inhibiting components can be utilized more effectively as co-substrates when co-digest with well performing sewage sludge or liquid manure (Braun 2002).

The gas emission increased till the 16th day of the experiment, decreased from 17th until the 19th day of the experiment and after 22th day of experiment gas emission rapidly increased (Fig. 2).

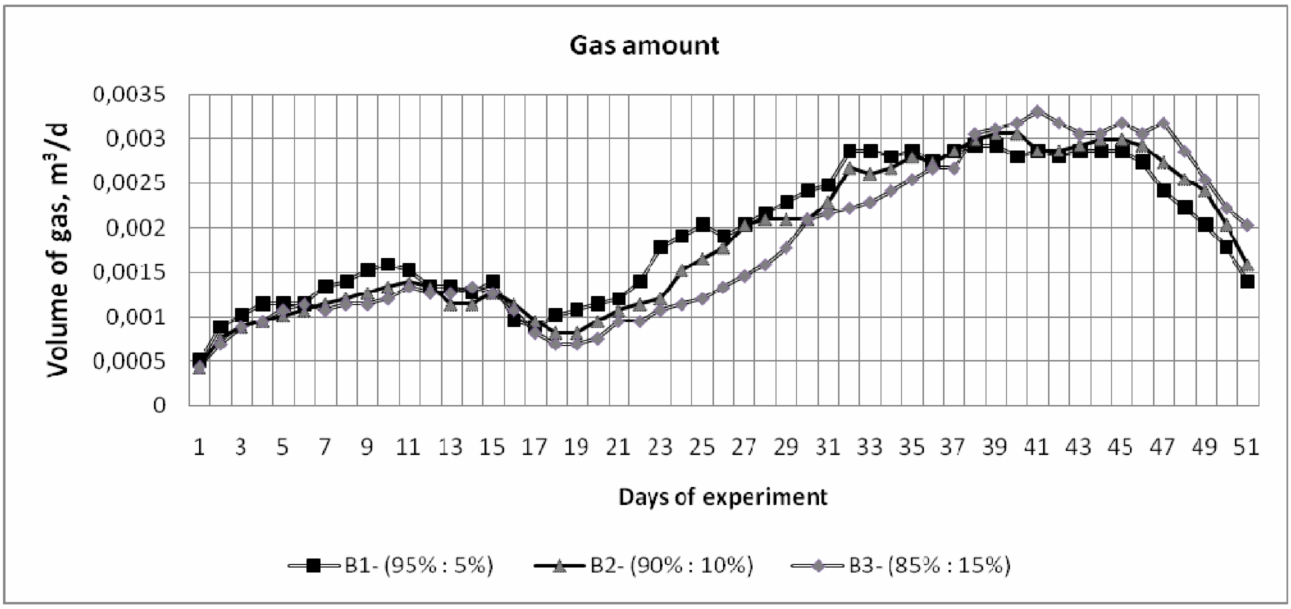

Fig 2. Amount of gas produced during anaerobic digestion of pig manure and slaughterhouse waste

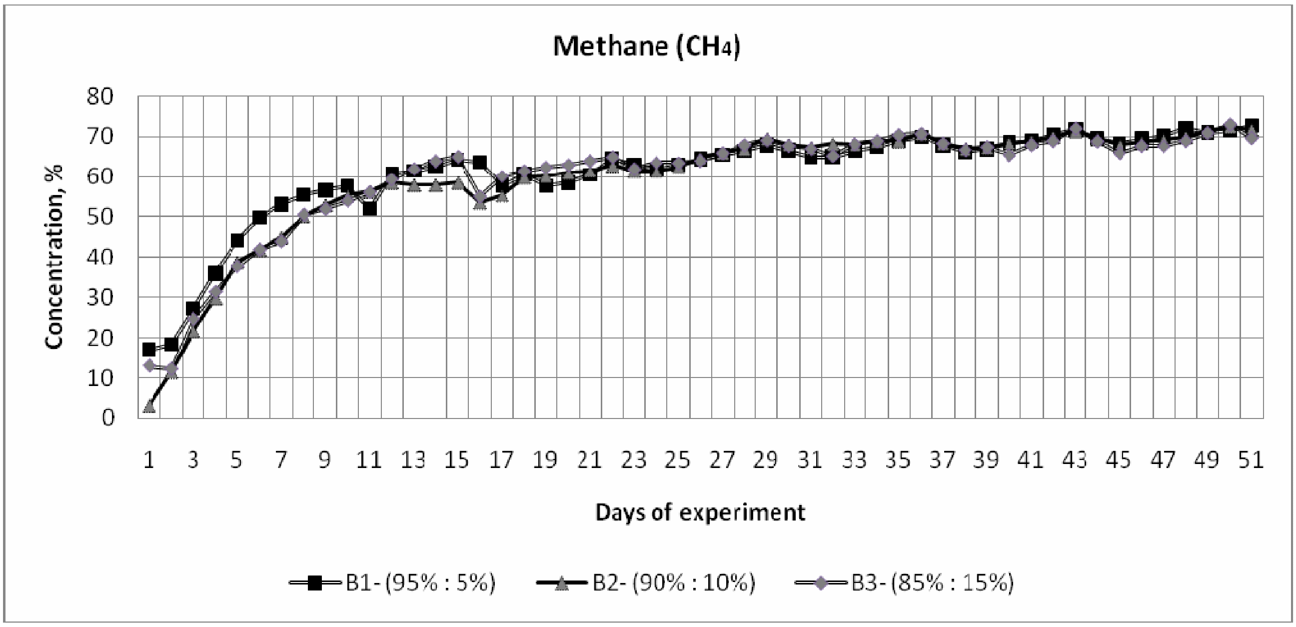

Fig 3. Concentration of methane in produced biogas during anaerobic digestion of pig manure and slaughterhouse waste

The highest total biogas production – 0.097 m^3 ($1m^3$ – 323 l) – was achieved using the mixture of pig manure and slaughterhouse waste at ratio of 19:1, amount of 0.094 m^3 ($1m^3$ – 313 l) was achieved using the mixture at ratio of 9:1 and lowest biogas amount – 0.091 m^3 ($1m^3$ – 303 l) – from mixture at ratio of 17:3. It is substantiated by slaughterhouse waste composition, which mostly consists of proteins and hydrocarbons.

Researches in the anaerobic co-digestion reported that one of the main predictions of anaerobic process is substrate C/N ratio in the reactor (Desai *et.al.* 1994).

During biological degradation of pig manure and slaughterhouse (the ratio of 19:1) the amount of gas evolved was 0.5 L/d and it gradually increased until the 11th day of the experiment, when the gas output totaled 1.5 L/d. Then the gas output rapidly declined, reaching 0.8 L/d on day 17th, although later gas output rapidly increased until it reached 2.9 L/d on 38th day of experiment and later the amount of biogas decreased with time.

Second bioreactor charged with mixture of pig manure and slaughterhouse waste at ratio of 9:1 produced less amount of biogas than the first bioreactor – 0.094 m^3. The amount of gas evolved was 0.4 L/d and the later process was the same as described above: the amount of the produced gas increased till 11th day of the experiment and the gas output totaled 1.4 L/d. Then the amount of gas decreased till 0.8 L/d on 18th day of the experiment. From 19th day of experiment the amount of produced biogas rapidly increased till 40th day when reached maximum output – 3 L/d, and was constant for a week and then rapidly decreased.

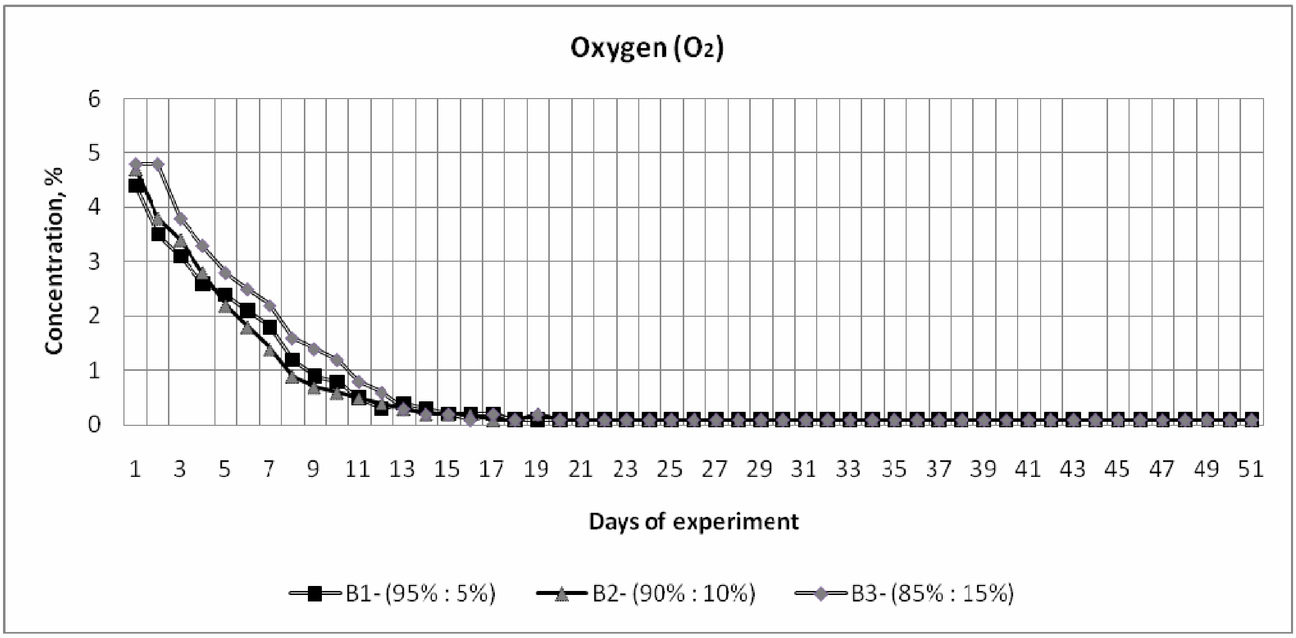

Fig 4. Concentration of oxygen in produced biogas during anaerobic digestion of pig manure and slaughterhouse waste

Third bioreactor charged with mixture of pig manure and slaughterhouse waste at ratio of 17:3 produced the lowest amount of biogas – 0.091 m^3. The tendency of biogas production was similar to the previous bioreactors. At the beginning of the experiment the amount of gas evolved was 0.4 L/d and it increased till 1.2 L/d on 15^{th} day, later it decreased till 0.7 L/d on 20^{th} day. From 21^{th} day of the experiment the amount of produced biogas increased till 42^{th} day and reached maximum output – 3.1 L/d which was almost constant for a week and then rapidly decreased.

The tendency of biogas production from different mixture showed that higher concentration of slaughterhouse waste in bioreactor postpones gas emission flow and reduces total produced gas amount.

The intensity of biogas flow was affected by the substrate mixing. During the experiment substrates have not been mixing. In this condition after two weeks of the experiment gas flow decreased and later increased up to the maximum. It is reasoned due to substrate layering, when the upper layer of substrate slows down the biodegradation of the lower layer.

Mostly important component of biogas is concentration of methane (CH_4), which is essential for biogas use in energy production. Biogas is useful for combustion, when methane concentration is higher than 60–65 % (White *et al.* 2011).

The concentration of methane from start to 14^{th} day of the experiment was rapidly grown and later till the end of the experiment despite small fluctuations gradually increasing (Fig. 3).

At start of the experiment in biogas there was 12–18 % of methane, highest concentration – 73 % of methane reached at the end of experiment.

Production of valuable biogas (CH_4>60 %) started after 3 weeks from the beginning of the experiment. The highest amount of total valuable biogas produced in bioreactors Nr.2 and Nr.3 – 0.075 m^3, where was digesting mixture of pig manure and slaughterhouse waste at ratio 9:1 and 17:3. The lower amount of total valuable biogas produced in bioreactor Nr.1 with substrate mixture at ratio 19:1.Another important measurement of produced biogas is concentration of oxygen (O_2), which identify anaerobic process (Fig. 4).

Throughout the experiment the concentration of oxygen in produced biogas was decreasing from 7.4 % at the beginning to 0.1 % at the end of the experiment.

In comparison with the result of investigation made in anaerobic digestion of swine manure at 17 °C (Masse *et al*. 2007) and 22 °C (Kvasauskas 2009) cumulative biogas production was 121 L and 321 L from 1 m^3 substrate. The mixture of pig manure and slaughterhouse waste at 30 °C produced from 303 to 323 L from 1 m^3 substrate. It means that slaughterhouse waste reduces yield of biogas, but investigations showed, that it increases the methane concentration.

The experiment clearly showed the benefit of co-digestion. Low degradable slaughterhouse waste can be handled with the manure and co-digest for biogas production. Co-digestion of both wastes solves waste management and renewable energy production questions.

4. Conclusions

1. Throughout the experiment, the highest biogas production – 0.097 m^3 – was achieved using the mixture of pig manure and slaughterhouse waste at ratio of 19:1.
2. Output of biogas rapidly increased after 3 weeks from the beginning of the experiment and depended on the composition of the substrate. Higher portion of slaughterhouse waste in mixture with pig manure postpones digestion process in the bioreactor.

3. Methane concentration in biogas reached 60 % on the 21st day of the experiment and later gradually increasing till the end of the experiment.
4. The highest amount of total valuable biogas (CH_4>60 %) – 0.075 m^3 reached from the higher portion of slaughterhouse waste in the substrate.
5. The analysis amount of produced gas and methane concentration in gas shows that the biogas produced from pig manure and slaughterhouse waste mixed at the ratio of 9:1 is the most efficient for use in energy production.

References

Baltrėnas, P.; Raistenskis, E.; Zigmontienė, A. 2004. Experimental investigation of biogas emissions during organic waste biodegradation process. *Journal of Environmental Engineering and Landscape Management,* 12(1): 3–9.

Braun, R. 2002. (online). Potential of Co-digestion. (cited on 2011 03 07). Available on the Internet: <http://www.novaenergie.ch/iea-bioenergy-task37/Dokumente/final.PDF>.

Cuéllar, A. D.; Webber, M. E. 2008. Cow power: the energy and emissions benefits of converting manure to biogas. *Journal of Environmental Resource Letters,* 3: 034002.

Desai, M.; Patel, V.; Madamwar, D. 1994. Effect of temperature and retention time on biomethanation of cheese whey-poultry waste-cattle dung. *Environmental Pollution,* 83: 311–315.

Huttunen, S.; Lampinen, A. (Eds.), 2005. *Bioenergy Technology Evaluation and Potential in Costa Rica*. University of Jyva¨skyla¨ Printing House, Jyva¨skyla¨, Finland.

Kvasauskas, M. 2009. *Mažų gabaritų bioreaktoriaus tyrimai ir kūrimas* [Research and design of small scale bioreactor]. Vilnius: Technika ISBN 978-9955-28-426-0.

Kvasauskas, M.; Baltrėnas, P. 2009. Research on anaerobically treated organic waste suitability for soil fertilization. *Journal of Environmental Engineering and Landscape Management,* 17(4): 205–211.

Lansing, S.; Botero Botero, R.; Martin, J. F. 2008. Waste treatment and biogas quality in small-scale agricultural digesters. *Journal of Bioresource Technology,* 99: 5881–5890.

Lansing, S.; Martin, J. F.; Botero Botero, R.; Nogueira da Silva, T.; Dias da Silva, E. 2010. Methane production in low-cost, unheated, plug-flow digesters treating swine manure and used cooking grease. *Journal of Bioresource Technology,* 101: 4362–4370.

Masse, D. I.; Croteau, F.; Masse, L. 2007. The fate of crop nutrients during digestion of swine manure in psychrophilic anaerobic sequencing batch reactors. *Journal of Bioresource Technology,* 98: 2819–2823.

Monteiro, E.; Mantha, V.; Rouboa, A. 2011. Prospective application of farm cattle manure for bioenergy production in Portugal. *Journal of Renewable energy,* 36: 627–631.

Ottinger, R. L., 2005. Experience with promotion of renewable energy. *Journal of Renewable energy,* 30: 425–460.

Spinosa, L. 1985. Technological characterization of sewage sludge. *Waste Management and Research,* 3: 389–398.

White, A. J.; Kirk, D. W.; Graydon, J. W. 2011. Analysis of small-scale biogas utilization systems on Ontario cattle farms. *Journal of Renewable energy,* 36: 1019–1025.