

Experimental Research of Biogas Yield and Quality Produced from Chicken Manure

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Abstract. Biogas is a fuel, which can be produced from a renewable energy source – biomass. Such a gas can be freely used in small farms or food industry to produce heat or electricity. Two main components of biogas – methane CH₄ and carbon dioxide CO₂. In some case, if biomass has a big amount of proteins, there can be an aggressive to different constructions gas – hydrogen sulphide H₂S in biogas composition. Also, there can be other gases, such as ammonia or hydrogen, but their concentrations are very low. Nowadays it’s extremely important to find a biomass with high energy potential not only to produce “green” energy, but to save the environment from gaseous emissions (greenhouse gases) and soil pollution. The aim of this study – to examine biogas yield and quality, which was produced from chicken manure biomass. To implement research, a small-sized bioreactor of periodic operation (total volume – 30 l, operating volume – 20 l) was used. One of the important parameters of biomass is total quality of volatile solids (VS) and quantity of organic matter in one liter of biomass (organic load – VS/l). In this research, there were examined two chicken manure biomasses with different VS and VS/l. The first one reached relatively 3188 g and 160 g/l. The second’s biomass volatile solids quantity reached 1993 g and organic load was 100 g/l. Both biomasses were of the same type and organic matter (chicken manure with 39.85 % concentration of organic matter). During the experimental research, the temperature of anaerobic digestion was mesophilic (35–37 °C). The operation of bioreactor was periodic, this means, that the biomass was held in anaerobic condition till the complete degasation without any partial refill. The total experiment duration reached 66 days. It was found, that the maximum CH₄ concentration reached 72.2% (biomass with organic load 100 g/l). To compare biogas yield from biomasses with different organic loading, it must be recalculated to an amount of biogas produced per day from 1 kg of volatile solids (l/d/kg VS). By implementing gained data analysis, it was discovered, that the maximum biogas yield is 7.8 l/d/kg VS (biomass with organic load 100 g/l). According to this research, it will be possible to create and use a small-sized bioreactor with chicken manure biomass in small farms to reduce pollution and generate energy.

Keywords: biogas production, biodegradable waste, climate change, energy.

Conference topic: Environmental protection.

Introduction

The world's energy markets rely on fossil fuels, such as coal, biofuel, petroleum, oil and natural gas as a source of energy. Since millions of years are required to generate fossil fuel, their reserves are decreasing as they are consumed. The only other naturally occurring resource known that is possible to use as a substitute of fossil fuels is biomass (Acaroglu et al. 2005). Different type biomass is shown in Figure 1.



Fig. 1. Biomass, generated from fruit waste and chicken manure (IndiaStudyChannel 2014; Poultryhub 2017)

Biodegradation of such waste in landfills of farms generates big amounts of biogas. Anaerobic digestion (AD) is the conversion of organic material directly to a biogas, a mixture of mainly methane (CH₄) and carbon dioxide (CO₂) (Demirbas 2006).

Although biogas energy is more costly than fossil fuel-derived energy, trends to limit CO₂ and other emissions through emission regulations, carbon taxes, and subsidies of biomass energy would make it cost competitive. Methane produced from anaerobic digestion is competitive in efficiencies and costs to other biomass energy forms (Berktaş, Nas 2008). According to scientists (Vorbrodts-Strzałka, Pikoń 2013) the biogas and other fuels calorific value is close to coal (table 1).

Table 1. Biogas and other fuel calorific value and conversion factor (Vorbrod-Strzałka, Pikoń 2013)

Fuel type	Calorific value, MJ/m ³	Conversion factor
Biogas	20–26	1
Natural gas	33.5	0.77
Diesel	41.9	0.62
Coal	23.4	1.10
Biofuel	36.5	0.70
Ethanol	29.6	0.85

Biogas technology offers a very attractive route to utilize certain categories of biomass for meeting partial energy needs (Balat, M., Balat, H. 2009). The growing consumption and industrial development generate vast amounts of biodegradable municipal waste in Lithuania and in the world (Misevičius, Baltrėnas 2011). For example in Lithuania, 0.64 million tonnes of biodegradable waste is generated every year.

According to the information gained from Statistical Office of the European Union (Eurostat), about 60% of total waste amount generated in Lithuania, is being landfilled. For example, in Germany it's only 1 % (Eurostat 2016). This tendency shows, that potential of usage of biomass in Lithuania is far from ideal.

To produce biogas, different organic material can be used as a bioreactor's loading: sewage sludge, biodegradable waste, food industry waste, agricultural waste, animal by-products and etc. (Vorbrod-Strzałka, Pikoń 2013; Appels *et al.* 2008; Nasir *et al.* 2014; Demirbas *et al.* 2016; Demirer 2016). As it was already mentioned, biogas mostly consists of methane CH₄ and carbon dioxide CO₂, but there are other gases, which concentration is usually very low (Jingura, Matengaifa 2009; Yaldiz *et al.* 2011; Biogaz-russia 2016) (Fig. 2). The concentration of biogas components may differ depending on used biomass.

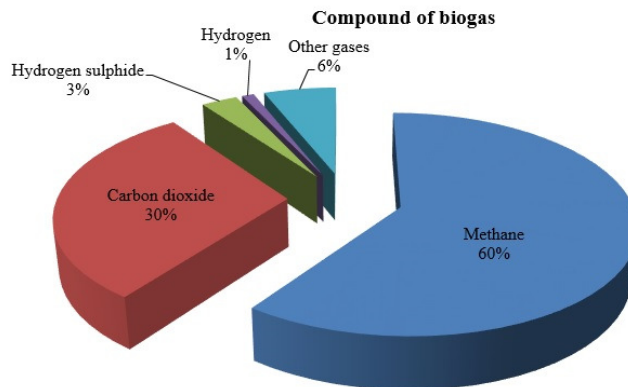


Fig. 2. Compound of biogas

In Lithuania livestock farms occupy about 50% from all farming sector. 6.2% of this amount is poultry farming. Every year, about 10 million birds are grown (Lietuvos Respublikos žemės... 2017). It is determined, that one bird generates about 55–73 kg of manure per year (Ptitcevod.ru 2013). So, this means, that Lithuanian poultry farms have minimum 550 thousands of tones of manure per year. Part of it is processed to fertilizers (Fig. 3), other part – stored on opened platforms.



Fig. 3. Chicken manure fertilizer (Newstyle live 2017)

During the digestion of chicken manure, a big amount of biogas emissions is released in the environment. This process causes greenhouse effect, which has negative impact on ecosystems (Konate' *et al.* 2013). So, chicken manure

must be treated to save our environment and to produce energy. This can be achieved by using special biogas production device – bioreactor (Fig. 4).



Fig. 4 Bioreactor (Author’s picture)

Device has mechanical mixer and heating element inside the camera. Usually the optimal for biogas production temperature conditions are mezophylic (about 35 °C).

Scientists from Antalya, Turkey (Yaldiz *et al.* 2011) studied biogas yield from chicken manure. Two organic loading were used. The first one was generated from chicken manure and vegetables loading (mixing ratio: 50% and 50%). The second fermentation material was grass and grass silage, covered marketplace wastes, rumen waste, chicken manure, and cattle manure with a rate of 57.62, 18.17, 3.81, 17.29, and 3.1%. respectively. The maximum concentration of methane during the experiment reached 40.28% and 52.88%. The yield of biogas is shown in figure 5 (Yaldiz *et al.* 2011).

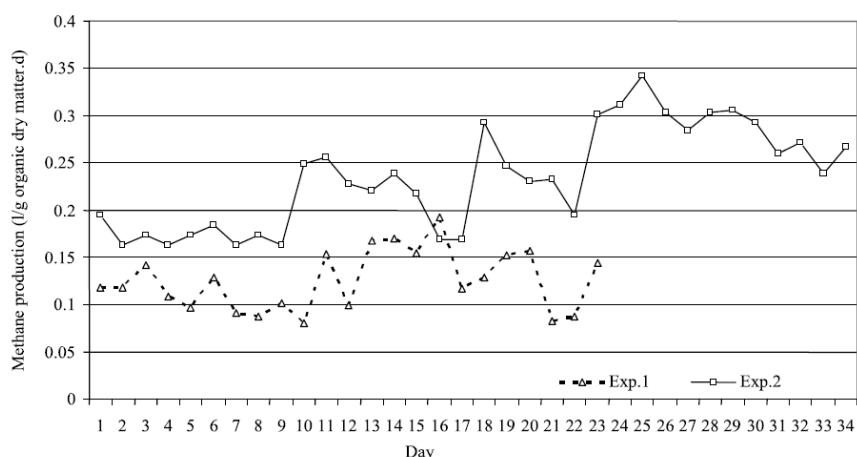


Fig. 5. Methane production process (Yaldiz *et al.* 2011)

Figure 5 shows, that methane yield is too low, and this amount of biogas, as well as methane concentration, requires more experimental research.

The aim of this research – to determine the optimal organic matter amount in chicken manure loading to produce high quality biogas for further usage in small farms.

Methods

Experimental studies were carried out using a biogas production device – small-sized bioreactor of periodic operation. Bioreactor’s volume: total volume 30 l and operation volume – 20 l. Process temperature – 35 °C.

Preparation of organic load.

Before the biogas production process, it’s necessary to determine the dry mass and volatile solids amount in certain biomass. To implement this, organic matter must be heated for 3–5 hours (at temperature 100–110 °C) to remove water from the sample and to gain the dry mass (hereinafter – *DM*).

$$DM = n_0 - n_{H_2O}, \quad (1)$$

where DM – dry mass of the sample, g.; n_0 – mass of the sample before drying, g.; n_{H_2O} – mass of water removed from the sample, g.

DM is composed of organic and inorganic matter. To calculate their content, sample (DM) is being burned for 3–5 hours at a temperature of 500–530°C. Secondly, the burnt mass of the sample is weighed, the content of the inorganic matter of DM is determined, and the content of organic matter is calculated:

$$n_{org} = DM - n_n, \quad (2)$$

where n_{org} – content of the organic matter of the DM of the sample, g.; DM – dry mass of the sample, g.; n_n – content of the inorganic matter of the DM of the sample, g.

Considering the mass of the sample before and after incineration, a share of the burnt organic matter from the initial mass of the sample (before drying) is calculated:

$$n_1 = \frac{n_{org}}{n_0} \times 100\%, \quad (3)$$

where n_1 – share of the organic matter of the sample from the common mass of the sample before drying, g.; n_{org} – content of the organic matter of the dry mass of the sample, g.; n_0 – sample mass before drying, g.

After implementation of VS calculation, it was found, that the VS of chicken manure was equal to 39.85%. In order to determine the required number of biomass of chicken manure for preparing the loading of bioreactor, an organic load rate (VS/l), indicating the content of organic matter in grams per litre of operating volume, is applied. The implemented investigation focused on examining two types of the biomasses having different VS/l:

- 1) Biomass number 1: VS/l = 160.0 g/l;
- 2) Biomass number 2: VS/l = 100.0 g/l.

Calculated biomass is mixed with water, until operating volume reaches 20 l. Then, heating elements and mixing are turned on on the bioreactor is ready for biogas production process.

Results and Discussion

The changes of biogas methane concentration was examined to set which of two biomasses is more suitable for biogas production (Fig. 6).

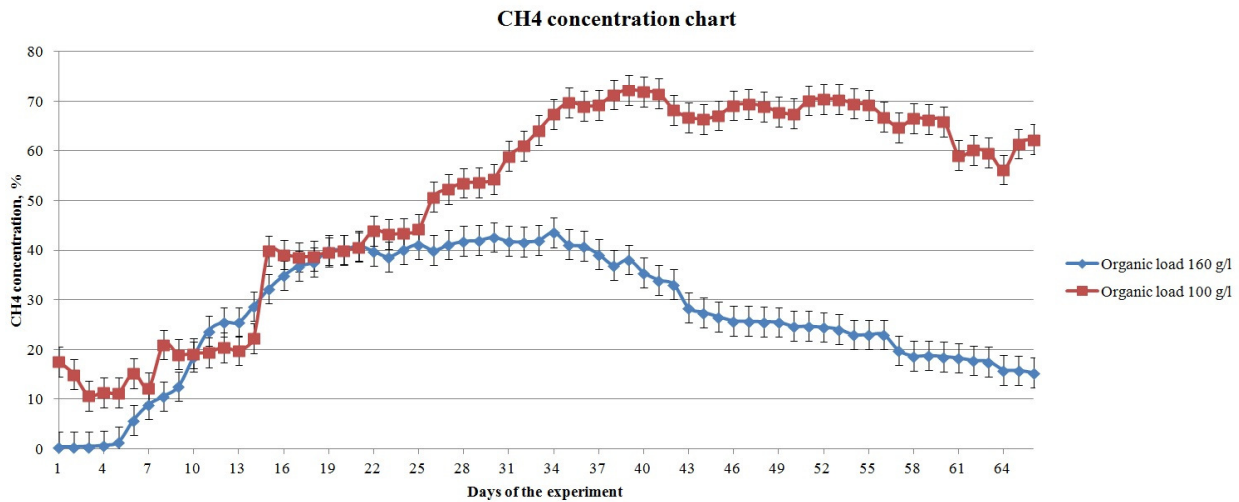


Fig. 6. The dependence of methane concentration on experiment duration

Figure 6 shows, that chicken manure biomass with organic load 100 g/l is more suitable for usage, because of its higher methane concentration, which reaches more than 70%. During the first two weeks of the experiment, CH_4 concentration was not stable (it was fastly increasing). Active methanogenesis process started after 14th day of the experiment, when CH_4 concentration reached more than 40%. After 37th day of experiment, methane concentration in biogas, produced from biomass with 160 g/l organic load, started to decrease, while biomass with organic load 100 g/l was still producing high quality biogas (during the whole period of time of the implemented experiment). In order to evaluate biogas quality by second indicator, CO_2 concentration was measured (Fig. 7).

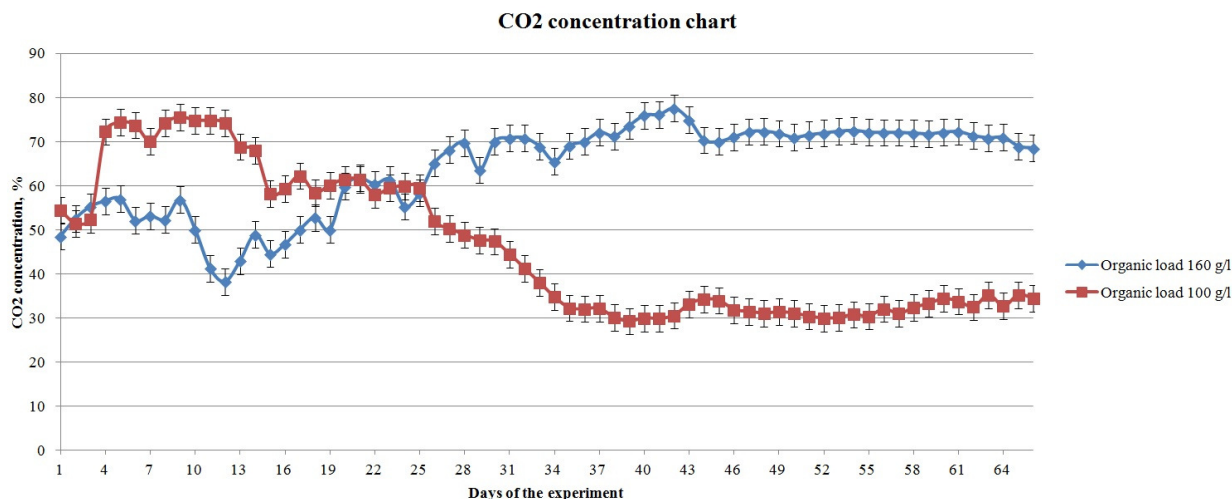


Fig. 7. The dependence of carbon dioxide concentration on experiment duration

In energetically effective and valuable biogas carbon dioxide concentration should be about 30–35%. Figure 7 shows, that biomass with organic load 160 g/l has CO₂ concentration, which is higher than 30–35% during the whole experiment (it's average concentration reaches 64%). This fact means, that microbiological balance in biomass is unappropriate (not methanogenic, but acid bacteria predominate). On the other hand, in biomass with organic load 100 g/l, CO₂ concentration after bacteria adaptation period (1–14 days from experiment start) changes between 30–35%, which means that such organic load is more suitable for bacteria's reproduction.

Moreover, after an anaerobic digestion of biomass with high amount of proteins (high amount of volatile solids), such as chicken manure, hydrogen sulfide H₂S can be generated (Fig. 8).

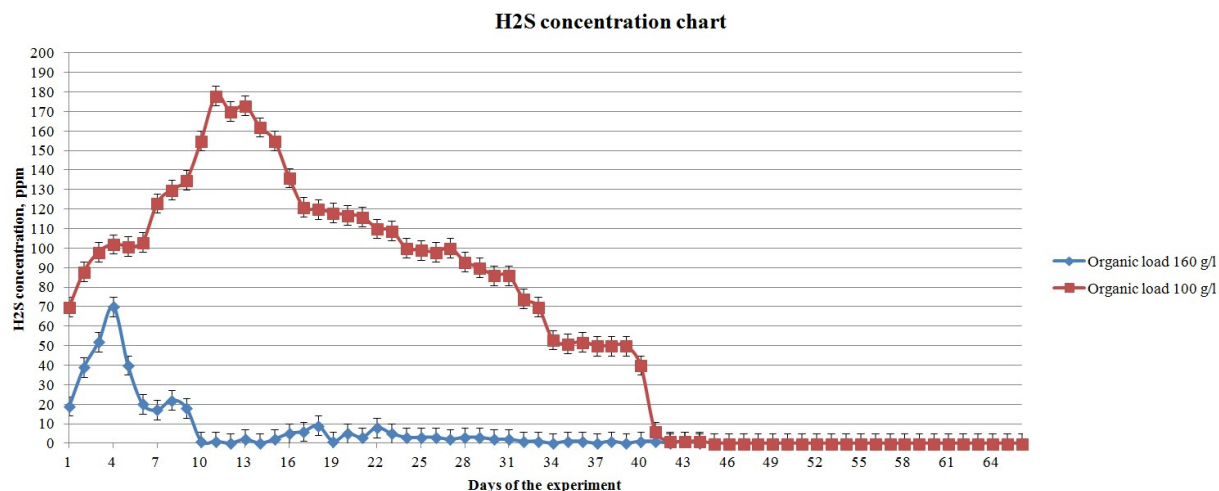


Fig. 8. The dependence of hydrogen sulfide concentration on experiment duration

H₂S – aggressive gas, which destructs biogas production constructions: pipes, compressors and cameras. It produces at two conditions: 1) biomass has a big amount of proteins; 2) digestion process of such biomass is implemented in appropriate for biogas production conditions, when proteins are decomposed into simpler compounds, which are food source to methanogenic bacteria. Figure 8 shows, that despite the big enough amount of proteins in biomass with organic load 160 g/l, H₂S concentration is very low. It could mean, that proteins are not fully decomposed because of too high amount of food sources (too high organic load 160 g/l). It directly effects biogas quantity and quality (methane concentration). Experiment with organic load 100 g/l is more effective, because of high concentration of H₂S (more than 170 ppm), which means, that microbiological processes are balanced well, but such biogas should be treated in order to produce energy without negative impact on biogas plant's construction elements (for example adsorption filters can be used to "capture" H₂S).

Last, but not less important parameter of biomass effectiveness is biogas yield, because bigger amount of biogas means more produced energy. Biogas yield from chicken manure biomasses is shown in Fig. 9.

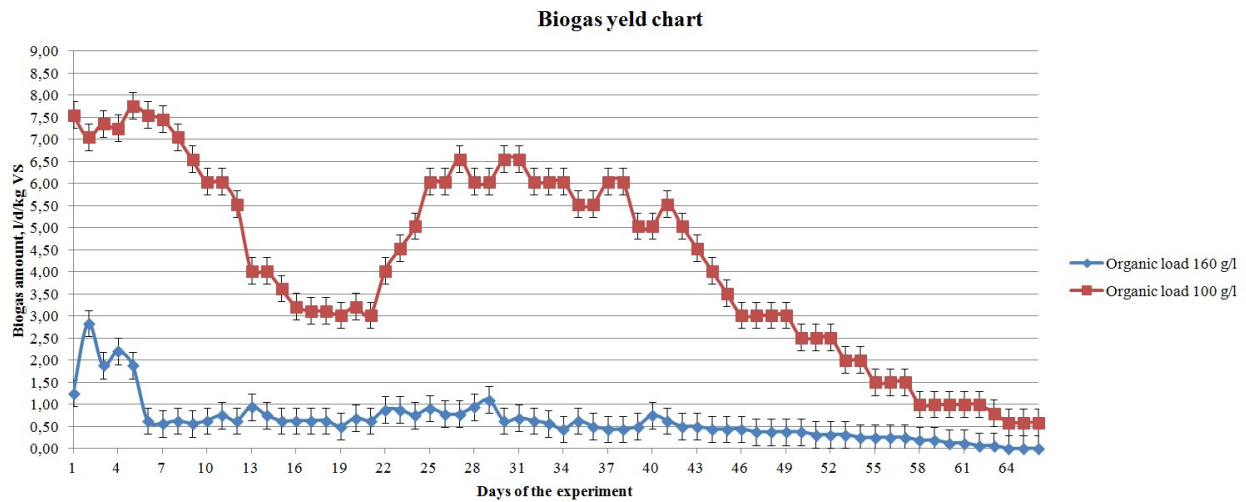


Fig. 9. The dependence of biogas yield on experiment duration

Figure 9 shows, that biomass with organic load 100 g/l produces much bigger amount of biogas than biomass with organic load 160 g/l. Difference between yields is obvious, which reaches ratio of 1:7. Biogas production from biomass with 100 g/l is effective from the beginning of the experiment, but during the adaptation period (1–14th day of experiment), such biogas consists mostly of CO₂, so it's not valuable for first two weeks. After 14–19th day of the experiment, when methane concentration is high, biogas yield increases for the second time, because the other (methanogenesis) process takes place. Biogas yield from biomass with organic load 160 g/l do not requires detailed analysis, as it is obvious, that such amount of biogas is not enough and can't be used for production of energy.

Conclusions

Based on the research results, it can be said that the optimal organic load of chicken manure biomass is 100 g/l. Biogas, produced from such a biomass, has high concentration of methane (more than 60%), optimal CO₂ concentration (30–35%). Because of active decomposition of proteins there are H₂S in biogas. H₂S generates when proteins are effectively decomposed. This gas must be treated in order to prevent metallic constructions from destruction. For example, adsorbent filter with activated carbon, biochar, metal oxides, zeolites or other porous material can be used to purificate biogas. What is more, to decrease CO₂ concentration in biogas, water-based filters with slaked lime filling can be used. As regards the other biomass (with organic load 160 g/l), biogas yield is too low, as well as low concentration of methane (maximum 40%) and too high concentration of carbon dioxide (about 70%). Such biogas yield can not be used to produce energy because of its little amount and low energetic value. Such effect is actual because of too high amount of food source for bacteria, which can not physically increase the number of their colonies so fast to decompose proteins in time. As a result, microbiological balance is impaired and biogas production process stops at all or becomes ineffective.

In order to produce high quality biogas for local usage in small farms, it is recommended to use chicken manure biomass with 100 g/l organic load. If such a farm has other waste material, more experimental studies must be implemented. For example, analysing gained data of other authors (Yaldiz *et al.* 2011), it was set, that their best result was achieved by using biomass of grass and grass silage, covered marketplace wastes, rumen waste, chicken manure, and cattle manure with a mixing rate of 57.62, 18.17, 3.81, 17.29, and 3.1%. respectively. Maximum methane concentration, which was gained by the scientists reached only 52.88% and biomass was totally decomposed per 34–35 days. So, after implementing experiments with chicken manure without any additives, the authors of this work (Kolodynskij and Baltrėnas) set, that chicken manure biomass (having organic load 100 g/l) can produce high quality biogas (CH₄ concentration above 60%) for about 66 days. That means, that in some case, additives of chicken manure biomass (for example grass or rumen waste) decrease methane concentration by increasing biogas yield. In such a case, more studies must be implemented to set the better mixing ratio of chicken manure biomass with other additives and to stabilize the process.

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