

## EXPERIMENTAL INVESTIGATION OF BIOGAS PRODUCTION USING BIODEGRADABLE MUNICIPAL WASTE

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**Abstract.** Waste is undesirable matter, which is most frequently generated by human activity. It is one of the sources of environmental pollution. In the contemporary world, with growing population, the amounts of generated waste are increasing as well. Unsorted municipal waste, including biodegradable waste, is transported to operated landfills. A negative impact of landfills on the environment is determined by waste as well as gas emissions and polluted sewage. Annual increase in amounts of waste is one of the most urgent problems of today, and therefore effective measures have to be employed to address it. In order to apply anaerobic organic waste treatment technologies and minimise the harmful effect on the environment, waste has to be sorted. The article presents the results of experimental investigations performed with fruit, vegetable and meat waste and its mixtures. The concentrations of methane, hydrogen sulphide and oxygen under mesophilic operation of a bioreactor were observed during the experiments. As determined experimentally, meat waste is mostly suitable for the production of biogas while mixtures of other biodegradable municipal wastes with meat also produce good results. Anaerobic digestion of meat waste produces the maximum amount of biogas, which averages to 0.8 m<sup>3</sup>/m<sup>3</sup>d. In this case, the methane content amounts to about 30%. Volume of biogas generated from digestion of meat and fruit mixture of waste was approximately 0.68 m<sup>3</sup>/m<sup>3</sup>d. Methane content in the mixture amounts to 25%. Meat and vegetable waste mixture has an average amount of biogas amounting to 0.54 m<sup>3</sup>/m<sup>3</sup>d, with 25% of methane content.

**Keywords:** biodegradable municipal waste, biogas, methane, anaerobic treatment.

### 1. Introduction

The birth of human society and the development of industry and trade gave rise to the problem of waste handling. Special sites – landfills were established for waste disposal. In 2005, Lithuania had 300 landfills for waste disposal, i.e. one per 10 000 population (Baltrėnas *et al.* 2005). Currently, the system is undergoing reorganization. The total number of 11 landfills is planned. The landfills will be provided with sorting lines for biodegradable municipal waste. This will open up the opportunity for effective use of waste for the production of biogas.

The major problem faced by landfills is negative effects stemming from organic waste decomposition (CO<sub>2</sub> and CH<sub>4</sub> emissions, which cause the greenhouse effect, leachate formation, microbiological and chemical pollution of ground and surface waters, propagation of pathogenic bacteria and unpleasant odours), which negatively affect nature and human health (Zigmontienė and Zuokaitė 2009).

The growing consumption and industrial volumes generate vast amounts of biodegradable municipal waste in Lithuania and in the world. However, this waste is not effectively used and the major part of it is landfilled. Biodegradable municipal waste may be classified as the source of renewable energy and used in energy production.

Fig. 1 provides that in 2007, the amount of municipal waste reached 404 kg per capita, showing an increase of 11 kg compared to 2006. This indicator is closely related to the level of consumption and has been continuously growing since 2004. Even though in Lithuania, the amount of municipal waste per capita is one of the lowest in the EU, the pursued objective of 300 kg of municipal waste per capita per annum, seems even further away.

Every year Lithuania generates around 1.3 million tonnes of municipal waste, including approx. 50% of biodegradable waste. The major part of biodegradable waste is disposed in landfills; however, this is not the only option for handling this type of waste.

The forecast of municipal waste generation and composition is based on six socioeconomic indicators: GDP per capita, infant mortality, the share of population aged between 15 and 59, household size, the average life expectancy, and the share of persons employed in agriculture. Therefore, different amounts of biodegradable waste accumulate in different countries (Kriptavičius 2009).

Lithuania has assumed the obligation to reduce the amount of biodegradable waste disposed in landfills.

According to the State Strategic Plan for Waste Management, Lithuania has to gradually implement Directive 1999/31/EC. From 2010, the biodegradable waste disposed in landfills should account for 75%, from 2013 – 50%, from 2020 – 35% of the amount landfilled in 2000 (Kavaliauskienė 2000). Effective measures are required to

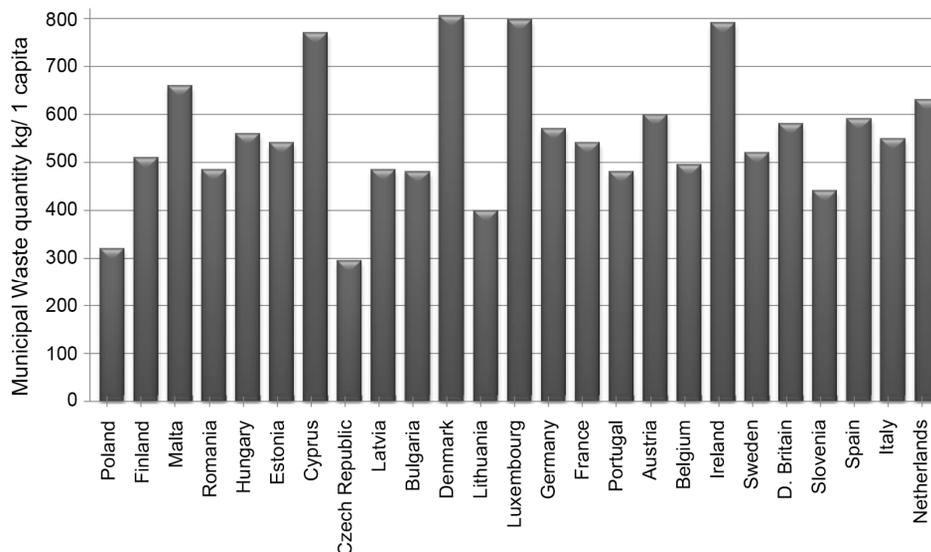


Fig. 1. Municipal waste generation in Europe in 2007, kg per capita (Waste statistics... 2010)

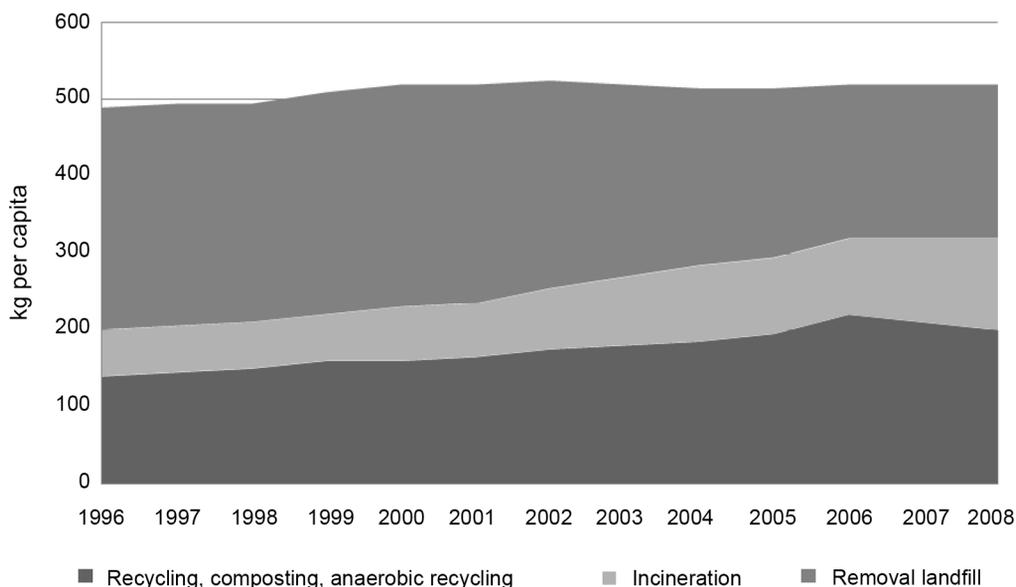


Fig. 2. The tendency of municipal waste utilisation in the European Union (Waste statistics... 2010)

reach these targets. One of the measures could be the anaerobic treatment of such waste. Fig. 2 shows the tendency of municipal waste utilisation in the European Union.

As per diagram, the amount of municipal waste is slightly increasing in time. Herewith, possibilities of its use are expanding. As more and more waste is utilized usefully, amounts of landfilled municipal waste are decreasing (Waste statistics...2010).

Methanisation is also known as anaerobic digestion. It is one of the most promising methods for converting biodegradable waste into alternative energy through anaerobic digestion in a bioreactor; biodegradable waste is also used for soil fertilisation (Gunaseelan 1997; Kvasauskas 2008).

The production of biogas is a complex process, during which organic matter is treated with different sorts of

bacteria. Under the impact of anaerobic bacteria, conversion of organic matters into biogas occurs in three stages: hydrolysis, acetogenesis and methanogenesis.

Each stage is associated with a certain group of microorganisms having different functions and properties (Bailey 1991). In the process of hydrolysis, bacteria splits complex compounds into fine molecular ones – sugar, carbon dioxide and acetates (Jorgensen *et al.* 2007). In the stage of acetogenesis, soluble acids first convert into acetic acid, carbon dioxide and hydrogen. In the stage of methanogenesis, the methane-producing bacteria can use hydrogen, carbon dioxide and acetates as a substrate for obtaining methane in the process of metabolism. Around 70% of methane is produced from acetates, while 30% – from hydrogen and carbon dioxide (Ghose 2003; Koven 2009).

In nature, methane can be produced in a temperature range from 0 to 100 °C. However, each species of microorganisms participating in the production of methanogenic and other biogases need the optimum specific temperature. In the biogas energy, temperature is normally divided into three groups: psychrophilic (10–25 °C), mesophilic (25–40 °C), thermophilic (50–65 °C). (Feng *et al.* 2007).

The amount of released biogas, including methane, depends on the pH of a substrate. The pH value of anaerobically digested substrate is influenced by the growth of the methanogenesis bacteria. Methane production takes place in a quite narrow interval of pH, in a range of around from 5.5 to 8.5. The pH value of the substrate under treatment also depends on the pH of substrate supplied to bioreactor (Cecchi *et al.* 1993).

Another important element in methane production is the balanced amount of macro elements. The growth and activity of microorganisms in the substrate under treatment depends on the amount of macro elements. The optimum ratio of macro elements, carbon, nitrogen, phosphorus and sulphur (C:N:P:S), in the treated biomass is 600:15:5:1. The shortage of these nutrients can slow down the process.

Wastes suitable for the production of biogas include kitchen waste, food industry waste, slurry, manure, various organic wastes and sewage sludge (Baltrėnas 2008). Biogas production can use various raw materials, including animal manure, plant residues, waste from the food industry and agriculture, sewage sludge, organic municipal waste, waste from public catering establishments and energy plants. Biogas can also be collected with special equipment from landfills (Baltrėnas 2008).

Each type of plants or waste or their mixtures has a specific organic composition. From the viewpoint of anaerobic digestion, biomass is evaluated according to the content of fats, proteins and carbohydrates.

Different proportions of carbohydrates, proteins and fats contained in substrate result in different outputs of biogas and different content of methane in it (Table 1).

**Table 1.** Stoichiometric output of biogas and the content of methane in it (Budrys 2006)

The composition of biodegradable waste	The stoichiometric yield of biogas, m <sup>3</sup> /kg DM	Methane content of biogas, %
Fat	1.4	80–90
Protein	0.6–0.9	75–80
Carbohydrates	0.7–0.8	50–60

DM – dry mass.

A charge is gradually released from continuous operation bioreactors in fixed portions but not in full right away: part de-aerated substrate is removed from it replacing it with the same share of new substrate. Bioreactor's entire charge is replaced within a period of time equal to the duration of exposure (Savickas and Vrubliauskas 1997).

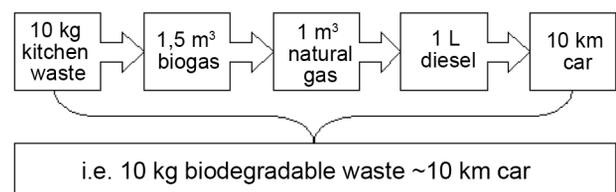
Biogas produced during organic waste treatment in a bioreactor is consumed as fuel but not released to the

environment. Treatment of biodegradable municipal waste helps dealing with environmental problems and at the same time deriving economic benefit and receiving electric and/or thermal power and also reducing the effect of odours released during degradation on the environment, while the digested substrate is used for soil fertilisation (Kvasauskas 2009).

The process of anaerobic digestion kills harmful microorganisms and pathogens, with which industrial and municipal wastes can be polluted.

Waste treatment in a close environment, i.e. a bioreactor, reduces the population of animals feeding on them (insects, rodents, birds) and the risk of disease spread (Baltrėnas *et al.* 2005).

Fig. 3 shows the change and benefit, which can be obtained from 10 g of biodegradable waste.



**Fig. 3.** The energy value of kitchen waste (Budrys 2006)

The main components of biogas produced in anaerobic bioreactors are methane (CH<sub>4</sub>) (40–75%) and carbon dioxide (CO<sub>2</sub>) (25–50%). A much smaller share is constituted of hydrogen sulphide (H<sub>2</sub>S), ammonia (NH<sub>3</sub>), hydrogen (H<sub>2</sub>), nitrogen (N<sub>2</sub>) (6–7%), carbon monoxide (CO), oxygen (O<sub>2</sub>), water vapour (up to 2%) and other compounds (Baltrėnas *et al.* 2006).

**The aim of the work** is to analyse the amounts of biogas and the concentrations of methane emitted from different biodegradable wastes (fruit, vegetable, meat waste and its mixtures) when a bioreactor operates in the mesophilic mode, and to determine the types of waste or their mixtures mostly suitable for the production of biogas.

## 2. Research methods

Experiments were carried out under laboratory conditions. A laboratory bioreactor of continuous operation (see Fig. 4) of 30 l capacity, was filled, via a biomass supply port, with biodegradable waste or its mixtures, which are given below. Anaerobic conditions were created in the bioreactor.

The bioreactor operated in the mesophilic mode. Temperature of 35±1 °C was maintained within. The experiment continued for 30 days.

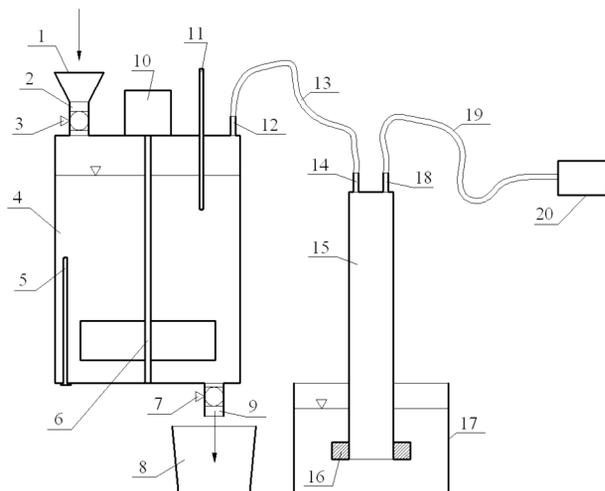
Throughout the experiment, the amount of released biogas and the concentrations of methane, hydrogen sulphide and oxygen as well as their changes were observed on a daily basis.

Bioreactor, its main elements and operation principle:

### *Biomass supply and release branch pipes*

Biomass is supplied to the bioreactor via the biomass funnel and the biomass supply branch pipe with the

valve, which is opened for filling of the funnel and closed once biomass is supplied to the bioreactor. Biomass is released from the biomass release branch pipe with the valve, which is opened during biomass release and closed once the required amount is released. Biomass is released to the biomass collection tank (see Fig. 4).



**Fig. 4.** Scheme of laboratory bioreactor stand:

1 – funnel for biomass, 2 – biomass supply branch pipe, 3 – valve, 4 – bioreactor, 5 – biomass heating element, 6 – biomass mixer, 7 – valve, 8 – biomass collection tank, 9 – biomass release branch pipe, 10 – biomass mixer engine, 11 – thermometer, 12 – branch pipe for gas release, 13 – elastic hose, 14 – branch pipe for hose fixing, 15 – gas accumulation vessel (PVC pipe), 16 – weight, 17 – vessel with water, 18 – branch pipe for hose fixing, 19 – elastic hose, 20 – gas analyser

#### *Biomass heating device and temperature sensor*

Biomass is heated in the bioreactor up to 35 °C. To find out the existing temperature, the bioreactor is supplied with a temperature sensor. If temperature falls or rises, which depends on ambient air, it is automatically increased or decreased to the required value.

#### *Biomass mixer and biomass mixer engine*

A biomass mixer consists of an axis and two blades. The biomass mixer is rotated by a mixer engine, which is mounted on the top to the bioreactor. Mixing duration and frequency are regulated automatically. Mixing takes place for five minutes every hour.

#### *Gas amount measurement*

To measure the gas amount it is necessary to have a gas accumulation vessel of 0.03 m<sup>3</sup> d (PVC pipe), a weight for keeping the vessel in the water, a vessel with water, branch pipes for hose fixing, hoses (see Fig. 4) and a ruler.

#### *Gas composition (methane, hydrogen sulphide and oxygen concentration) measurement*

Measurements were carried out with the analyser INCA 4000, which shows the amount of methane, carbon dioxide and oxygen in %, and the concentration of hy-

drogen sulphide in ppm. Measurement limits of the analyser: 0–25% (error ±1%) for oxygen, 0–100 (error ±5%) ppm for hydrogen sulphide, 0–100% (error ±1%) for methane. Working conditions of the analyser: ambient air temperature –5 °C to +40 °C, relative humidity up to 95%.

#### *pH determination*

The pH meter is used to determine pH. The error of the pH meter is ±0.1.

#### *Operation principle:*

Through the biomass supply opening, the laboratory bioreactor (Fig. 4) is filled with the prepared biomass, the mixtures of which are indicated below. The first stage of each experimental investigation is carried out until the amount of released biogas becomes stable. This should last for around a week. Later, up to 10% of the biomass volume is released and replaced with fresh biomass every five days. During the first week, a small amount of biomass (up to 5 ml) is released from the bioreactor for the purpose of determining its pH. The total amount of biomass released in a week would amount to no more than 35 ml. It is a minor amount as the bioreactor is filled with 28 l of biomass and therefore the mentioned amount of released biomass (35 ml) is not added.

Biomass is supplied through the supply branch pipe by opening the valve. Biomass is also released by opening the valve in the release branch pipe, which is mounted at the bottom of the bioreactor. Temperature and biomass mixing in the bioreactor are ensured automatically.

The experimental investigations used these organic wastes or their mixtures:

- Fruit waste;
- Vegetable waste;
- Meat waste;
- The mixture containing 50% of fruit waste and 50% of vegetable waste;
- The mixture containing 50% of fruit waste and 50% of meat waste;
- The mixture containing 50% of vegetable waste and 50% of meat waste.

Used equipment and devices:

- 30 litre bioreactor;
- Biogas storage;
- pH meter;
- Biogas analyser INCA 4000.

### **3. Research results and their analysis**

One of the most important indicators of effectiveness in anaerobic biodegradable waste treatment is the amount of released biogas. The larger is biogas output at a stable amount of methane, the higher is the benefit (higher energy) obtained during anaerobic digestion of organic waste.

While carrying out experimental investigations of fruit waste, the amount of biogas released at the beginning of the experiment reached 0.36 m<sup>3</sup>/m<sup>3</sup>d and was increasing until the eighth day of the experiment when biogas output amounted to 0.92 m<sup>3</sup>/m<sup>3</sup>d. On the eighth

day the output of biogas was the largest throughout the experiment. Later, the amount of biogas was decreasing and during the remaining time of the experiment ranged from 0.4 to 0.6 m<sup>3</sup>/m<sup>3</sup>d (Fig. 5).

The increase and decrease of the biogas curve results from the following: when microorganisms present in the bioreactor lack nutrients for the production of biogas, the amount of biogas decreases, and in order to prevent the biogas amount from decreasing, more nutrients are added every fifth day of the experiment, which conditions the increase of the biogas amount.

From the start of the experiment, the concentration of methane was gradually increasing until the ninth day when it reached the peak, 0.143 m<sup>3</sup>/m<sup>3</sup>d. From the fourteenth day until the end of the experiment the content of the main biogas component – methane – in gas was falling and at the end reached a mere 0.029 m<sup>3</sup>/m<sup>3</sup>d. A decrease in methane concentration resulted from the instability of the processes of acetogenesis and methanogenesis.

The highest concentration of hydrogen sulphide was registered at the beginning of the experiment as it was decreasing at later stages. Replacement resulted in an insignificant increase, however this is not reflected in the curve.

The concentration of hydrogen sulphide was gradually decreasing in the course of the experiment and reached 1.35·10<sup>-5</sup> m<sup>3</sup>/m<sup>3</sup>d at the end (Fig. 5).

Throughout the experiment, anaerobic conditions were maintained in the bioreactor, i.e. the concentration of oxygen varied from 0.75 to 1.3%.

At the beginning of the experiment, the pH of the substrate amounted to 4.45, meanwhile at the end it was 4.5.

The daily amount of biogas released during anaerobic digestion of vegetable waste was increasing from the beginning of the experiment until the ninth day reaching 0.9 m<sup>3</sup>/m<sup>3</sup>d. Afterward, the amount of biogas was decreasing until the end of the experiment and amounted to 0.24 m<sup>3</sup>/m<sup>3</sup>d (Fig. 6). The amount of biogas released from vegetable waste during the investigations was increasing upon replacing 10% of bioreactor's volume with fresh biomass.

The highest concentration of methane during the experiment, 0.089 m<sup>3</sup>/m<sup>3</sup>d, was recorded on the ninth day. A low concentration of methane in biogas determined substrate's pH below 6 during the experiment.

Throughout the experiment, the concentration of the undesirable compound hydrogen sulphide varied from 2.3·10<sup>-5</sup> to 3.7·10<sup>-5</sup> m<sup>3</sup>/m<sup>3</sup>d (Fig. 6).

The concentration of oxygen varied in a range of 0.5 to 1.5%, and therefore no anaerobic conditions were ensured.

At the beginning of the experiment, the pH of substrate was 4.42, and amounted to 4.06 at the end.

The production of biogas from vegetables and fruit is ineffective. After carrying out experiments with this type of waste (when bioreactor operated in the mesophilic mode), scientists, such as X. Gómez, H. Bouallagu, F. J. Callaghan, failed obtaining the desired results and therefore mixed fruit and vegetable waste with sewage sludge, cattle and poultry manure.

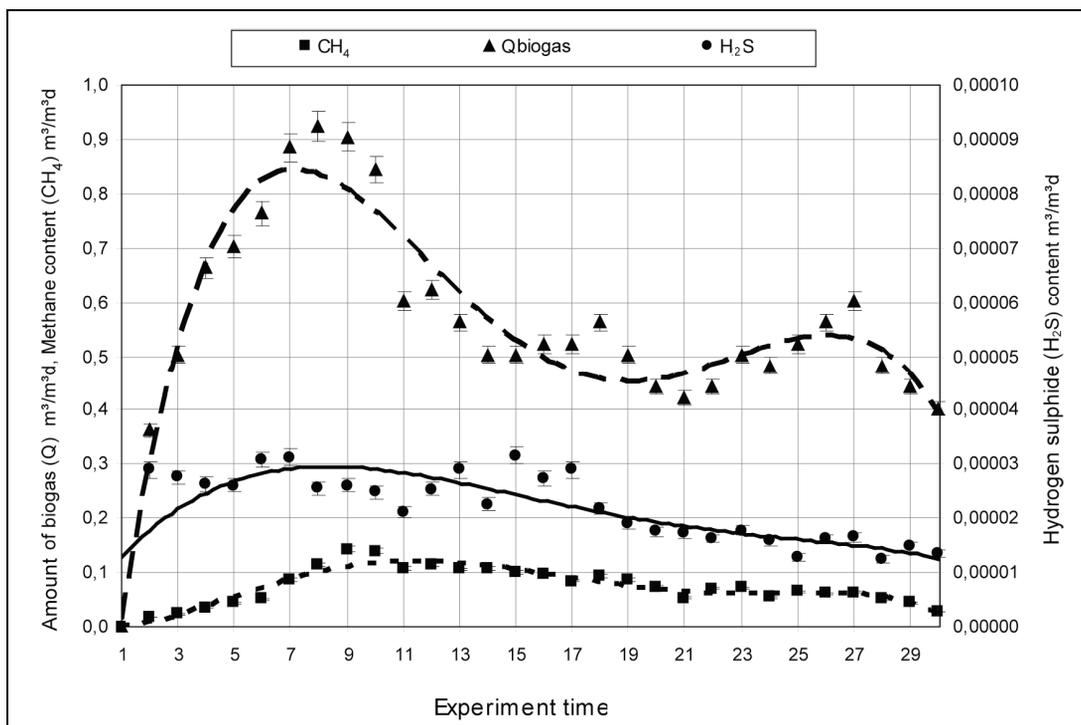
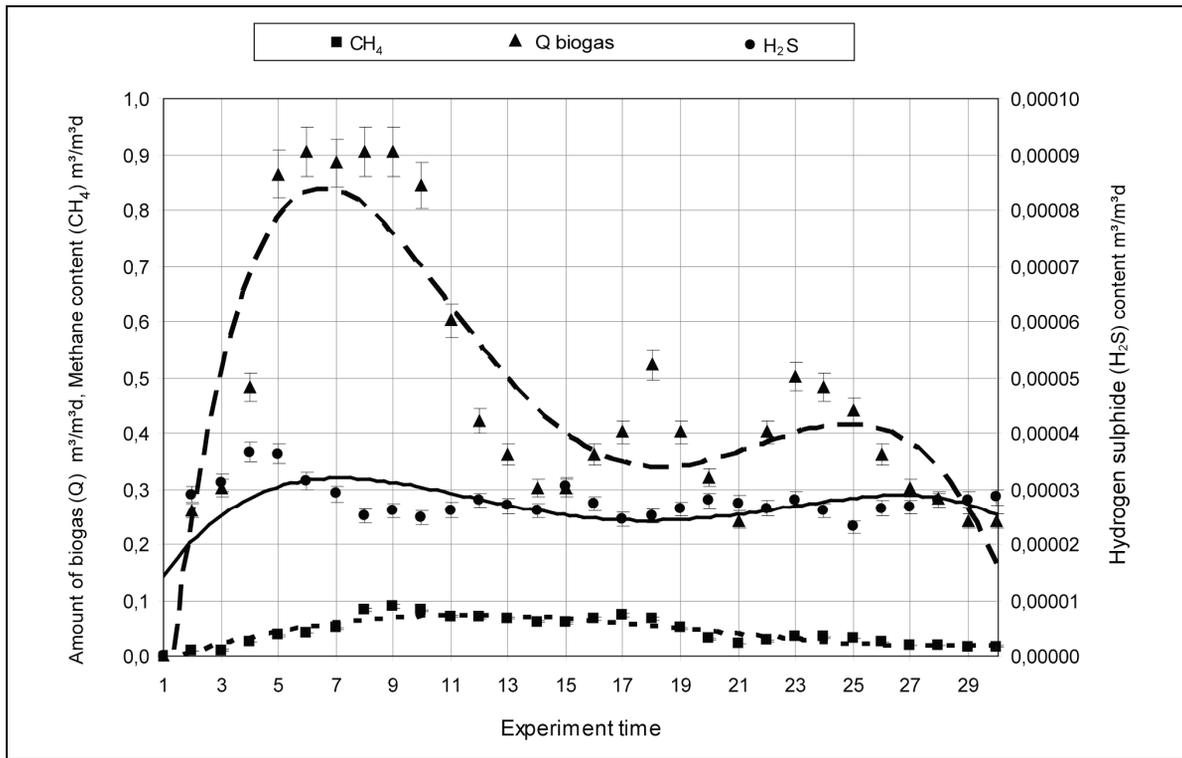
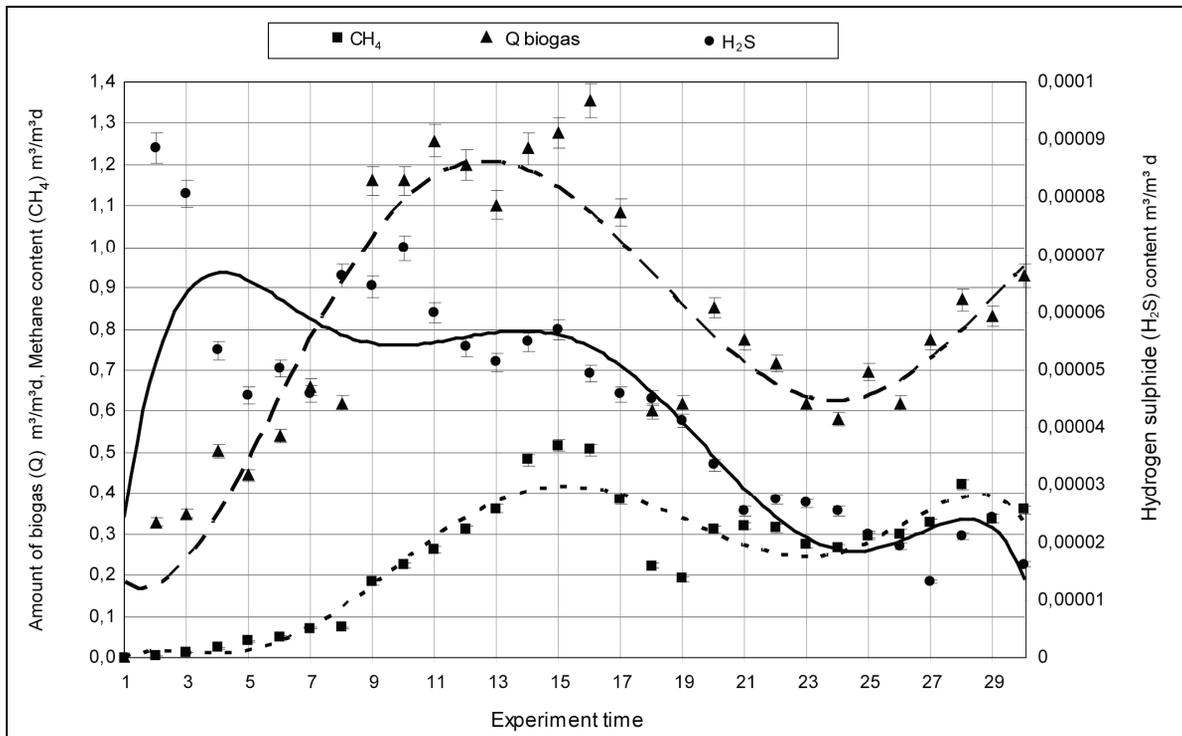


Fig. 5. The amount of biogas (m<sup>3</sup>/m<sup>3</sup>d), methane (m<sup>3</sup>/m<sup>3</sup>d) and hydrogen sulphide (m<sup>3</sup>/m<sup>3</sup>d) in the anaerobic digestion of fruit waste under continuous bioreactor mesophilic conditions



**Fig. 6.** The amount of biogas ( $\text{m}^3/\text{m}^3\text{d}$ ), methane ( $\text{m}^3/\text{m}^3\text{d}$ ) and hydrogen sulphide ( $\text{m}^3/\text{m}^3\text{d}$ ) in anaerobic digestion of vegetable waste under continuous bioreactor mesophilic conditions



**Fig. 7.** The amount of biogas ( $\text{m}^3/\text{m}^3\text{d}$ ), methane ( $\text{m}^3/\text{m}^3\text{d}$ ) and hydrogen sulphide ( $\text{m}^3/\text{m}^3\text{d}$ ) in the anaerobic digestion of meat wastes under continuous bioreactor mesophilic conditions

Experiments with meat waste produced the best results. The amount of biogas was growing until the fifteenth day of the experiment. On the given day, the gas amount was the largest and amounted to  $1.35 \text{ m}^3/\text{m}^3\text{d}$  (Fig. 7). During the remaining time of the experiment, the

amount of biogas ranged from  $0.58$  to  $0.93 \text{ m}^3/\text{m}^3\text{d}$ . Such good release of biogas amount was determined by the fact that fats and proteins, from which the largest stoichiometric output of biogas is obtained, account for the major part of meat waste.

The content of fats and proteins in a substrate also has a major influence on the amount of methane in biogas as these substances produce the highest concentration of methane. The highest concentration of methane,  $0.517 \text{ m}^3/\text{m}^3\text{d}$ , was recorded on the fifteenth day of the experiment. Nearly throughout the entire period of this investigation, the amount of methane in biogas was regularly increasing. As regards the change of hydrogen sulphide concentration during the experiment, the highest concentration was recorded at the beginning of the experiment and reached  $8.9 \cdot 10^{-5} \text{ m}^3/\text{m}^3\text{d}$ , later it was decreasing and its lowest concentration,  $1.6 \cdot 10^{-5} \text{ m}^3/\text{m}^3\text{d}$ , was recorded at the end of the experiment (Fig. 7). Anaerobic conditions were also maintained during the experiment with meat waste, the concentration of oxygen varied from 0.1 to 0.7%.

The pH of the substrate at the beginning of the experiment was 5.72, meanwhile at the end it amounted to 6.75.

The Korean scientists Jae Kyoung Cho, Soon Chul Park and Ho Nam Chang also investigated biogas output and methane concentrations from biodegradable food waste (meat, rice, cabbage, etc.). As per results of their investigations, the best output and the largest concentration of methane are obtained from anaerobic digestion of meat waste. The stochiometric output of methane amounted to  $0.82 \text{ m}^3/\text{kg}$  of DM.

The experiment with the mixture of fruit and vegetable wastes did not produce better results if compared with those of experiments carried out separately with fruit and vegetable wastes. The highest output of biogas reached  $0.87 \text{ m}^3/\text{m}^3\text{d}$  on the seventh and the eighth day of the experiment (Fig. 8). This could have been influenced

by the activity of the acetogenesis and methanogenesis bacteria as well as low pH of the substrate.

These two reasons also influenced the production of methane. Even though the concentration of methane was growing from the beginning until the twenty-second day of the experiment, it was not large. The highest value,  $0.175 \text{ m}^3/\text{m}^3\text{d}$ , was recorded on the twenty-first day of the experiment. Later, the content of methane in biogas was decreasing and reached  $0.09 \text{ m}^3/\text{m}^3\text{d}$  at the end of the experiment.

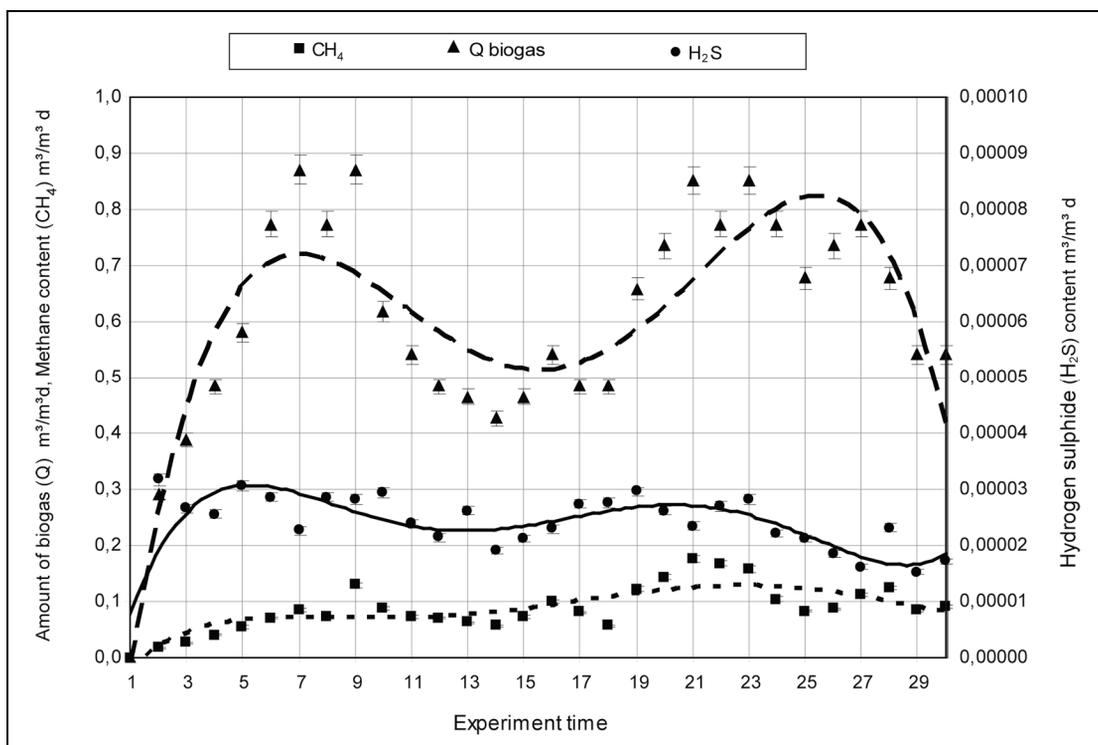
Throughout the experiment, the concentration of hydrogen sulphide in biogas varied within a small interval, from  $1.52 \cdot 10^{-5} \text{ m}^3/\text{m}^3\text{d}$  to  $3.2 \cdot 10^{-5} \text{ m}^3/\text{m}^3\text{d}$ .

Just as with other investigations, the concentration of oxygen in the continuous operation bioreactor working in the mesophilic mode did not exceed the norm, which meets anaerobic conditions and varied from 0 to 1.5%.

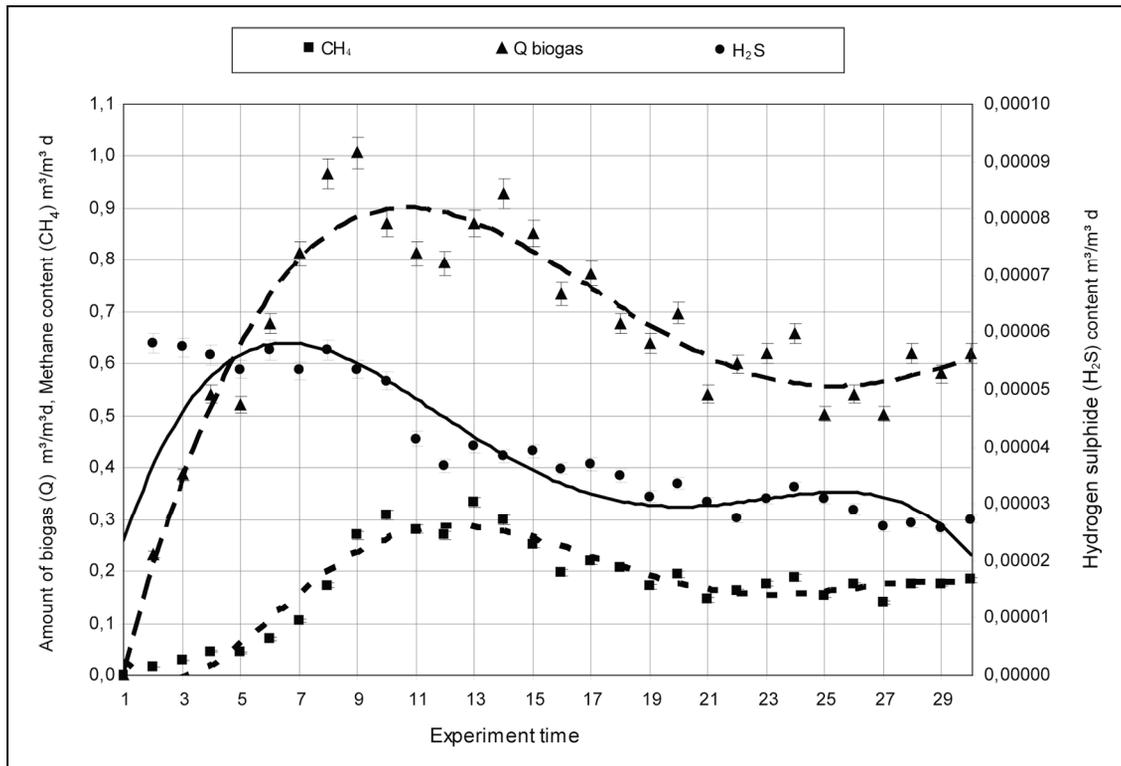
The pH of the substrate at the beginning of the experiment was 4.42, and amounted to 4.71 at the end.

The results obtained by scientist M. Kvasauskas from the experiment with vegetable and fruit waste with the bioreactor working under psychophilic conditions, were by 5 times worse, and therefore the production of biogas during the digestion of this waste in the bioreactor working in the mesophilic mode is more effective.

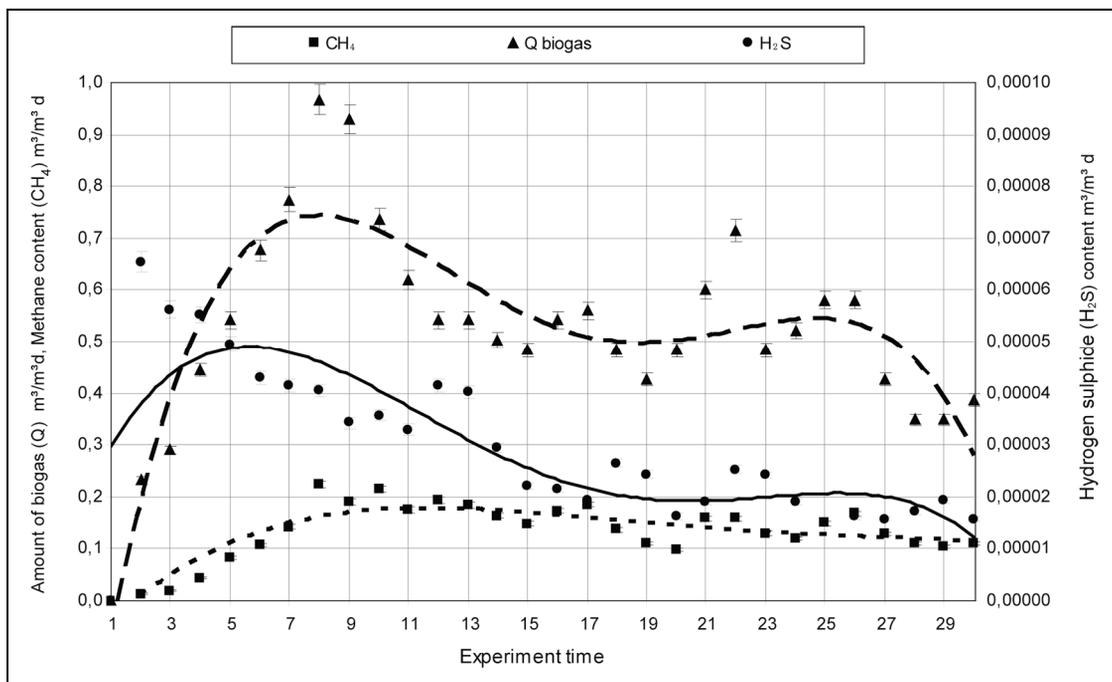
As the investigations of meat waste demonstrate, this waste produces the best output of biogas and methane content when the substrate contains fats and proteins. Bearing this in mind, two mixtures were composed: one – of vegetable and meat waste, and the other – of fruit and meat waste, both on the fifty-fifty basis. The results of these investigations are presented in Figs. 9 and 10.



**Fig. 8.** The amount of biogas ( $\text{m}^3/\text{m}^3\text{d}$ ), methane ( $\text{m}^3/\text{m}^3\text{d}$ ) and hydrogen sulphide ( $\text{m}^3/\text{m}^3\text{d}$ ) concentrations when vegetable and fruit waste mixture are anaerobically decomposed under continuous bioreactor mesophilic conditions



**Fig. 9.** The amount of biogas ( $\text{m}^3/\text{m}^3\text{d}$ ), methane ( $\text{m}^3/\text{m}^3\text{d}$ ) and hydrogen sulphide ( $\text{m}^3/\text{m}^3\text{d}$ ) concentrations when fruit and meat mixture are anaerobically decomposed under continuous bioreactor mesophilic conditions



**Fig. 10.** The amount of biogas ( $\text{m}^3/\text{m}^3\text{d}$ ), methane ( $\text{m}^3/\text{m}^3\text{d}$ ) and hydrogen sulphide ( $\text{m}^3/\text{m}^3\text{d}$ ) concentrations when vegetable and meat waste mixture are anaerobically decomposed under continuous bioreactor mesophilic conditions

The investigations of these two mixtures show that the mixture of fruit and meat waste produced more biogas than fruit waste alone. During this investigation, the largest amount of released biogas,  $1.01 \text{ m}^3/\text{m}^3\text{d}$ , was recorded on the ninth day of the experiment. Even though the

amount of biogas was lower during the remaining days of the experiment, it still produced better results than the experiment with fruit waste. From the ninth day until the end of the experiment, the amount of biogas varied from  $0.5$  to  $0.93 \text{ m}^3/\text{m}^3\text{d}$  (Fig. 9). The better release of biogas

was determined by the presence of fatty substances in the mixture, while the same situation was observed during the experiment with the mixture of vegetable and meat waste.

Anaerobic digestion of the mixture of vegetables and meat waste also shows better results compared to those obtained from vegetable waste treatment. The highest amount of biogas,  $0.97 \text{ m}^3/\text{m}^3\text{d}$ , was recorded on the eighth day of the experiment. During the remaining time of the experiment, the amount of biogas ranged from  $0.43$  to  $0.93 \text{ m}^3/\text{m}^3\text{d}$  (Fig. 10).

The mixtures composed with meat waste produced noticeable results in methane production. From the beginning until the thirteenth day of the experiment, the content of methane in biogas was increasing during the treatment of fruit and meat waste mixture. The highest concentration of methane was identified on the thirteenth day and reached  $0.333 \text{ m}^3/\text{m}^3\text{d}$ . Until the end of the experiment the concentration of methane ranged from  $0.196$  to  $0.298 \text{ m}^3/\text{m}^3\text{d}$  (Fig. 9).

Methane production also improved when treating the mixture composed of vegetable and meat waste. In this case, the highest concentration of methane,  $0.224 \text{ m}^3/\text{m}^3\text{d}$ , was determined on the twelfth day of the experiment. Until the end of the experiment, the concentration of methane ranged from  $0.105$  to  $0.214 \text{ m}^3/\text{m}^3\text{d}$  (Fig. 10).

During the treatment of fruit and meat waste mixture the concentration of the undesirable component hydrogen sulphide varied within the interval of  $2.6 \cdot 10^{-5}$  to  $5.8 \cdot 10^{-5} \text{ m}^3/\text{m}^3\text{d}$ , while during the treatment of vegetable and meat waste – from  $64.0 \cdot 10^{-5} \text{ m}^3/\text{m}^3\text{d}$  at the beginning to  $14.6 \cdot 10^{-5} \text{ m}^3/\text{m}^3\text{d}$  at the end of the experiment.

Anaerobic conditions necessary for the production of biogas were ensured in bioreactors throughout both experiments.

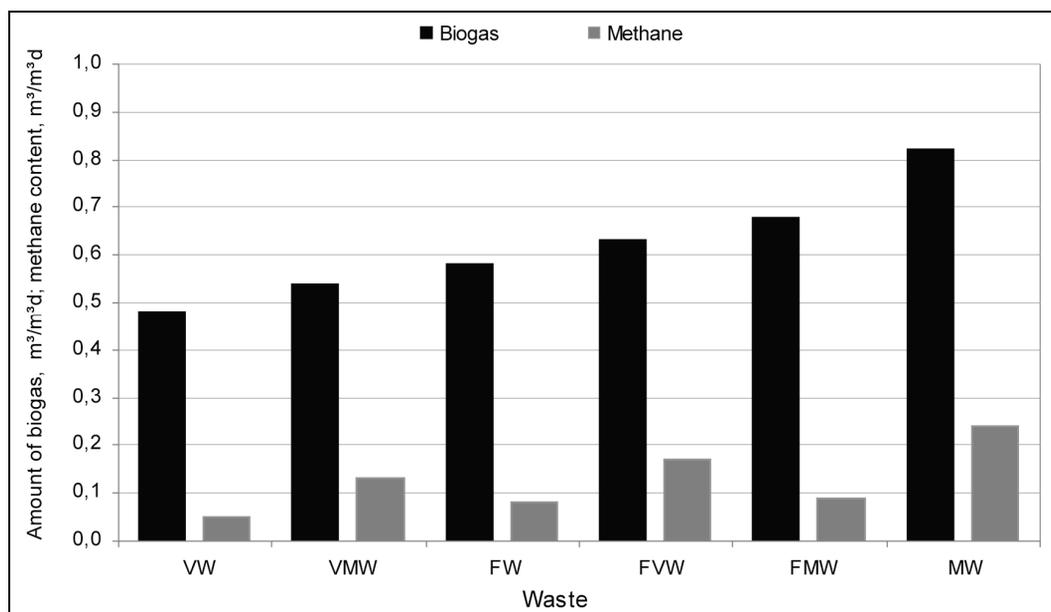
At the beginning of the experiment, the pH of the substrate (FMW mixture) was  $4.85$ , and amounted to  $5.75$  at the end. Digestion of vegetable and meat waste the beginning of what the pH indicator pursue  $4.81$ , at the end  $5.38$ .

#### 4. General results

The experimental study on biogas from biodegradable municipal waste was undertaken, the results of which are presented in Fig. 11. Figure shows the average amount of biogas and methane in the anaerobic degradation of biodegradable waste. The study revealed that the best results can be achieved from bio-degradation of meat waste. The average amount of biogas was  $0.82 \text{ m}^3/\text{m}^3\text{d}$ . Anaerobic decomposition of other waste and their mixtures has lower volume of biogas FMW – 17%, FVW – 22%, FW – 29% VMW – 34% in VW – 41%. Such difference in the quantity of biogas due to the pH indicator, a mixture of protein, fat and refined carbohydrates content acetogenesis and methanogenesis and the density of bacteria, microbial population as well as the release of biogas could be influenced by macronutrients carbon, nitrogen, phosphorus and sulphur content of the recycled biomass.

The analysis of the resulting methane content in biogas shows that  $\text{CH}_4$  is mainly formed as well as anaerobic decomposition of waste in the meat. Its content in biogas amounted to 32%. Methane decomposition at least split the fruit and vegetable waste 13% and 9%. Digestion VMW, FVW and FMW waste methane were 25%, 28% and 14%. Factors that affect biogas emissions also affect methane emissions.

Neither of the tested organic wastes and their mixtures were is not suitable for energy recovery as the methane content of biogas does not exceed 55%. However, once mixed with other combustible gases, the derived biogas can be used for fired boilers.



**Fig. 11.** The amount of biogas ( $\text{m}^3/\text{m}^3\text{d}$ ) and methane ( $\text{m}^3/\text{m}^3\text{d}$ ) anaerobic digestion of biodegradable waste under continuous bioreactor mesophilic conditions (VW – vegetable waste, VMW – vegetable and meat waste, FW – fruit waste, FVW – fruit and vegetable waste, FMW – fruit and meat waste, MW – meat waste)

Foreign scholars such as Li Rongping, Chen and Li Shulin Xiujiu investigated the production of biogas from food waste and mixtures with cattle dung at different ratios. The biogas production process of biodegradable municipal waste was studied by German scientists G. Busch, J. Grossmann, M. Sieber and M. Burkhardt, Nigerian scientists A. Hilkiyah Igoni, M. J. Ayotamuno, C. L. Eze, Italian scholars such as M. Pognani, G. D'Imporzano, B. Scaglia and F. Adana studied biogas release when biodegradable municipal waste was mixed with the agriculture crop waste. Biogas processes in mesophilic conditions were studied by Indian scholars D. Elango, M. Pulikesi, P. Baskaralingam, V. Ramamurthy, S. Sivanesan; they mixed biodegradable waste with household sewage.

## 5. Conclusions

1. The highest released amount of biogas,  $1.35 \text{ m}^3/\text{m}^3\text{d}$ , and the highest amount of methane,  $0.517 \text{ m}^3/\text{m}^3\text{d}$ , were determined during anaerobic digestion of meat waste.

2. Greater biogas output and higher concentration of methane were obtained from digestion of substrate with predominant fats and proteins but not carbohydrates.

3. Anaerobic treatment of vegetable and fruit waste in a bioreactor does not produce the desired results, i.e. methane amount is low, around  $0.1 \text{ m}^3/\text{m}^3\text{d}$ , which has an influence on low quality of biogas.

4. The results obtained from investigations of fruit and meat waste mixture shows that the amount of biogas increased by 1.2 times, while the content of methane doubled compared to results from fruit waste investigations.

5. The results obtained from investigations of vegetable and meat waste mixture show that biogas amount increased by 1.3 times, while the content of methane rose by 2.8 times compared to results from vegetable waste investigations.

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## BIODUJŲ GAMYBOS EKSPERIMENTINIAI TYRIMAI NAUDOJANT BIOLOGIŠKAI SKAIDŽIAS KOMUNALINES ATLIEKAS

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Santrauka

Atliekos – nepageidaujamos medžiagos, kurios dažniausiai susidaro dėl žmogaus veiklos. Jos yra vienos iš aplinkos teršimo šaltinių. Šiuolaikiniame pasaulyje didėjant žmonių skaičiui, didėja ir susidarančių atliekų kiekiai. Nerūšiuotos komunalinės atliekos, tarp jų ir biologiškai skaidžios, patenka į eksploatuojamus sąvartynus. Sąvartyno neigiamą poveikį aplinkai lemia ne tik pačios atliekos, bet ir iš jų sklindančios dujos, užterštos nuotekos. Kasmet didėjantys atliekų kiekiai yra viena iš svarbiausių šių dienų problemų, todėl reikia imtis efektyvių priemonių šiai problemai spręsti. Norint pritaikyti anaerobinio organinių atliekų apdorojimo technologijas ir kuo labiau sumažinti kenksmingą poveikį aplinkai, atliekas būtina rūšiuoti. Straipsnyje pateikiami eksperimentinių tyrimų su vaisių, daržovių bei mėsos atliekomis ir jų mišiniais rezultatai. Eksperimentų metu stebėtos metano, sieros vandenilio ir deguonies koncentracijos bioreaktoriui veikiant mezofiliniu režimu. Tyrimų metu nustatyta, kad geriausiai biodujų gamybai tinka mėsos atliekos. Šias atliekas anaerobiškai perdirbant gaunamas didžiausias biodujų kiekis. Vidutiniškai  $0,8 \text{ m}^3/\text{m}^3\text{d}$ , o metano kiekis siekia apie 30 %. Taip pat kitas biologiškai skaidžias komunalines atliekas maišant su mėsos atliekomis gaunami geresni rezultatai. Skaidant mėsos ir vaisių atliekų mišinį biodujų kiekis siekė vidutiniškai  $0,68 \text{ m}^3/\text{m}^3\text{d}$ , metano kiekis 25 %, skaidant mėsos ir daržovių atliekų mišinį biodujų kiekis buvo vidutiniškai  $0,54 \text{ m}^3/\text{m}^3\text{d}$ , metano – 25 %.

**Reikšminiai žodžiai:** biologiškai skaidžios komunalinės atliekos, biodujos, metanas, anaerobinis perdirbimas.

## ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ПО ПРОИЗВОДСТВУ БИОГАЗА С ИСПОЛЬЗОВАНИЕМ БИОРАЗЛАГАЕМЫХ МУНИЦИПАЛЬНЫХ ОТХОДОВ

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Резюме

Отходы – нежелательные материалы, являющиеся в основном результатом деятельности человека. Это один из источников загрязнения окружающей среды. В современном мире с увеличением числа людей увеличивается и количество отходов. Неотсортированные муниципальные отходы, в том числе и биоразлагаемые, попадают на эксплуатируемые свалки. Негативное воздействие на окружающую среду оказывают не только сами отходы, но и выделяющиеся из них газы, загрязненные сточные воды. Ежегодное увеличение количества отходов является одной из основных проблем в наше время, требующих принятия эффективных мер для их решения. Для того, чтобы применить анаэробную технологию для обработки органических отходов и свести к минимуму неблагоприятное воздействие на окружающую среду, отходы необходимо сортировать. В работе представлены экспериментальные исследования, касающиеся отходов фруктов, овощей и мяса, а также их смесей, и их результаты. Во время эксперимента наблюдались концентрации метана, сероводорода и кислорода в мезофильном режиме работы биореактора. Исследования показали, что наиболее приемлемыми для производства биогаза являются мясные отходы. Благодаря анаэробной переработке мясных отходов можно получить максимальное количество биогаза (в среднем  $0,8 \text{ м}^3/\text{м}^3\text{д}$ ) и около 30 % метана. Хорошие результаты были получены также при переработке смесей из других биоразлагаемых муниципальных отходов и мясных отходов. От переработки смеси из мясных и фруктовых отходов получено среднее количество биогаза ( $0,68 \text{ м}^3/\text{м}^3\text{д}$ ) с содержанием 25 % метана, а от переработки смеси из мясных и овощных отходов – в среднем  $0,54 \text{ м}^3/\text{м}^3\text{д}$  биогаза с содержанием 25 % метана.

**Ключевые слова:** биоразлагаемые муниципальные отходы, биогаз, метан, анаэробная переработка.

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