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EXPERIMENTAL INVESTIGATION OF BIOGAS PRODUCTION USING FATTY WASTE

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Abstract. The paper presents the findings of experimental investigation of biogas production using hen manure and sewage sludge with fatty waste (from margarine production). The following mixtures were made using this organic waste: hen manure and sewage sludge were mixed with fatty waste at 75% : 25%, 50% : 50% and 25% : 75% in volume. The paper analyses quantitative and qualitative composition of biogas: gas emission content, the concentrations of methane, sulphuretted hydrogen and oxygen in it as well as temperature and pH change during the experiment.

Mixing hen manure with fatty waste at 75% : 25% and maintaining psychrophilic temperature mode, the highest biogas output (0.09 m^3) from 0.2 m^3 substrate in 32 days was recorded. When using the mixture of sewage sludge and fatty waste at 75% : 25% and maintaining psychrophilic temperature mode, the highest biogas output (0.10 m^3) from 0.2 m^3 substrate in 32 days was recorded. When using these mixtures, the concentration of methane was also the highest, and the average values reached 58.5% (with hen manure) and 61.7% (with sewage sludge). The evaluation of gas emissions and methane concentration in gas shows that the most efficient use of biogas could be obtained using biogas emitted from the mixture of hen manure and sewage sludge with fatty waste mixed at 75% : 25%. The concentration of sulphuretted hydrogen in biogas did not exceed 3%, the concentration of oxygen decreased from 4.9 % to 1.8%. pH indicator was decreasing when more fatty waste was added to the mixture. When using hen manure, the average value of pH changed from 6.4 to 6.3, when using sewage sludge – from 6.6 to 6.3.

Keywords: biogas, biomass, fatty waste, hen manure, sewage sludge, psychrophilic mode.

1. Introduction

Presently, the issue of alternative energy use receives increasing attention worldwide, and organic waste is more and more often used to generate alternative energy (Denafas 1997; Khandelwal 1990; Genutis *et al*. 2003; Karczmarczyk, Mosiej 2007).

In Lithuania one of the biggest environmental problems is large amounts of generating waste, including fair amounts of organic waste. According to the EU requirements, amounts of landfilled organic waste should be reduced (Savickas, Vrubliauskas 1997).

During biodegradation of organic waste, gas containing methane (CH_4), carbon monoxide (CO), hydrogen (H_2) and sulphuretted hydrogen (H_2S), is emitted. When inorganic substances contained in waste enter soil together with fertilisers they affect the soil structure and have a negative effect on its productivity, while pathogens pose danger to human and animal health. Apart from that, there is a big risk of surface and ground water contamination (Savickas 1996; Savickas, Vrubliauskas 1997).

Methane evolving during anaerobic process is gas causing the greenhouse effect. Attention should be paid to the fact that methane stimulates the greenhouse effect 21 times more intensely than carbon monoxide (Baltrėnas *et al*. 2005).

One of the most promising methods to convert organic waste into alternative energy and still obtain fertiliser is anaerobic degradation of waste in bioreactors where biogas is produced (Gunaseelan 1997; Mašauskas *et al.* 2006; Results... 2004).

All organic wastes generating in agriculture and cattle husbandry, some part of utility waste, sewage sludge from water treatment plants and technological waste from food processing companies (if not used for fodder or other purposes) are classified as organic waste suitable for anaerobic treatment (Savickas, Vrubliauskas 1997). When applying anaerobic organic waste treatment technologies, it becomes possible to reduce useful land areas used for storage sites of this waste, to reduce the hazardousness and a negative effect on the environment of this waste.

Waste water treatment plants and poultry farms generate nearly the largest amounts of organic waste. The generated manure, slurry and sewage sludge produce unpleasant odours (Zuokaitė, Ščupakas 2007). When applying slurry on soil, there emerges an excess of nutrients and part of sewage can penetrate into ground waters. Another big problem is large amounts of sludge generating in sewage treatment plants, which is transported to sludge accumulation and storage sites.

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The paper analyses quantitative and qualitative composition of biogas: the amount of gas emissions, concentrations of methane, sulphuretted hydrogen and oxygen in it, temperature and pH change during the experiment. The amount of gas emissions and methane concentration in gas are the most important parameters, which define the possibility of using biogas for energy generation. When gas contains more than 60% of methane it is considered valuable. (Savickas, Vrubliauskas 1997). Sulphuretted hydrogen is an undesirable component in biogas because it causes the corrosion of all the elements in the system. Sulphuretted hydrogen may be cleaned by mixing gas with a small amount of oxygen, using filters of iron compounds, absorbing it with water or solid sorbents (Savickas 1996). One of the most recent and promising sulphuretted hydrogen cleaning methods is biological treatment (Hirai *et al*. 2001). Temperature is a very important factor predetermining the composition of microorganisms populations and the intensity of their operation. The higher the temperature, the more intensive the operation of microorganisms (Nagel 2001). Microbiological activity in biogas reactors is the most favourable at the presence of a neutral or weakly alkaline medium ($6,5<pH<8,5$), therefore, it is important to observe and maintain the optimum medium for the growth and activities of microorganisms (Savickas 1996).

The paper analyses the performed experimental investigation of biogas production when using hen manure and sewage sludge with fatty waste (from margarine production). Using these organic substances, mixtures were prepared. The contents of proteins and carbohydrates in hen manure are similar, while sewage sludge contains the biggest amount of proteins and carbohydrates and less fat. As the amount of fat in biomass increases, the amount of emitted gas and methane concentration in gas also grows (Anand *et al*. 1990; Sharma *et al*. 1999).

It was determined which of the mixtures in question, during degradation of organic substances, had evolved the largest amount of biogas and which of them had the largest content of useful gas, i.e. methane.

The aim of the paper is to analyse the qualitative and quantitative composition of biogas using the mixture of hen manure and sewage sludge with fatty waste.

2. Investigation methods

When investigating the qualitative and quantitative composition of biogas, the biomass (organic waste) of different compositions, i.e. hen manure and sewage sludge with fatty waste (from margarine production) mixed at the ratios of 75:25, 50:50 and 25:75 in volume, was used.

Anaerobic degradation of mixtures of these organic wastes was performed in bioreactors united into a single system (Fig. 1).

Plastic closed tanks of 220 l capacity, each, were used in bioreactors, and anaerobic conditions were created in them. 200 l (91%) of the tanks were filled up, and the remaining part was left for gas accumulation.

Prior to the experiment, a substrate, containing 20% of dry substance of its total mass, was prepared.

Each bioreactor had a mixing system, a thermometer, a sampling place for determining pH and a gas meter.

Prior to measuring, the substrate was mixed up with the mixer so as to obtain a uniform phase within its entire volume. After mixing up the substrate, the tap was opened to let the accumulated biogas flow via hoses passing the gas-flow meter and afterwards – the gas analyser. The amount of evolved biogas and the concentrations of methane (CH_4), sulphuretted hydrogen (H_2S) and oxygen (O_2) in the evolved gas were determined.

3. Investigation results

During biological degradation of *hen manure and waste from margarine production (the ratio of 75:25)* the measurement of parameters was started from the 5th day of the experiment, and the recorded amount of gas emissions

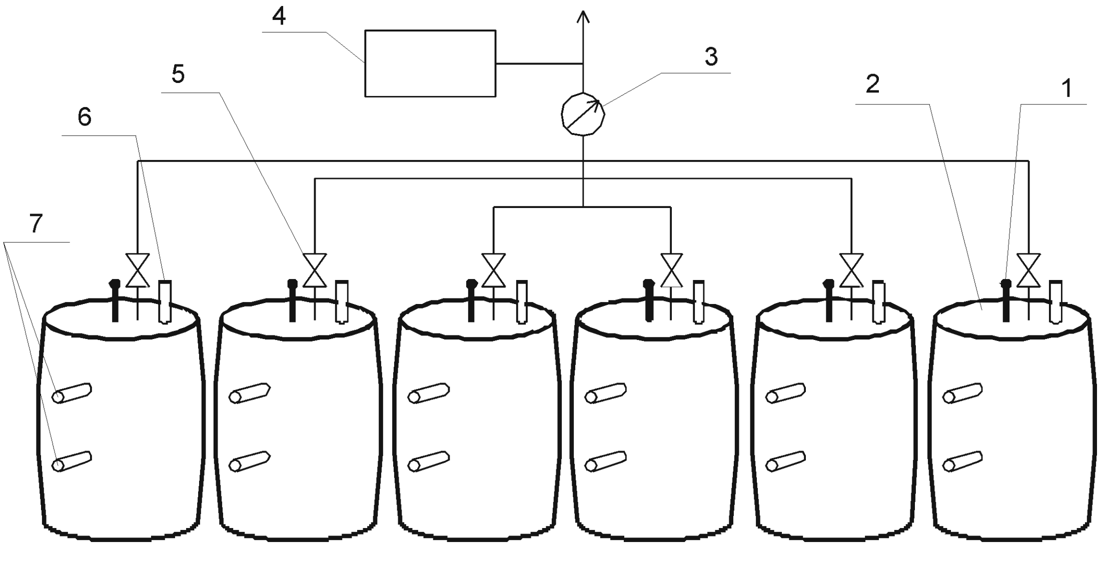

Fig. 1. The system of bioreactors: 1 – bioreactor’s mixer, 2 – bioreactor, 3 – gas meter, 4 – gas analyser, 5 – tap, 6 – sampling place to determine pH, 7 – thermometers

was 0.0043 m^3/d from 0.2 m^3 substrate, which rapidly grew until the 8th day of the experiment when gas output reached 0.0055 m^3/d from 0.2 m^3 substrate (Fig. 2). Until the 10th day of the experiment gas output was insignificantly decreasing up to 0.0053 m^3/d from 0.2 m^3 substrate and further decreased more rapidly – until the 23rd day of the experiment it fell to 0.0019 m^3/d from 0.2 m^3 substrate. Later the gas amount nearly steadied and fell insignificantly to 0.0014 m^3/d from 0.2 m^3 substrate at the end of the experiment. According to F. J. Nagel, the largest amount of evolving gas, depending on a temperature mode, is reached from the 6th to the 10th day. The higher the biomass temperature, the earlier the maximal gas amount evolves and until the 30th day of the experiment decreases nearly in half compared to the maximal value. The comparison of the obtained experimental results shows that the maximal biogas amount was achieved on the 8th day of the experiment but it decreased more than three times at the end of the experiment. Such a decrease in biomass amount could be predetermined by the decreased content of organic matter in biomass along with fatty waste in its content, the biological degradation of which was burdened by low temperature.

Sulphuretted hydrogen is an undesirable component in biogas (Savickas 1996), which forms at the presence of excess proteins in biomass. The content of sulphuretted hydrogen in biogas does not exceed 3% of biogas composition. During the first days the amount of sulphuretted hydrogen in gas rapidly fell and from 42 ppm at the beginning of the experiment dropped to 3 ppm on the 8th day of the experiment. Such a rapid decrease could be predetermined by fast activity of bacteria – in their activities they neutralised sulphuretted hydrogen. Later the amount sulphuretted hydrogen was insignificantly decreasing, and no sulphuretted hydrogen was found in biogas emissions in the period from the 14th day to the end of the experiment. It is obvious that the content of sulphuretted hydrogen is low and does not exceed 3% of biogas amount.

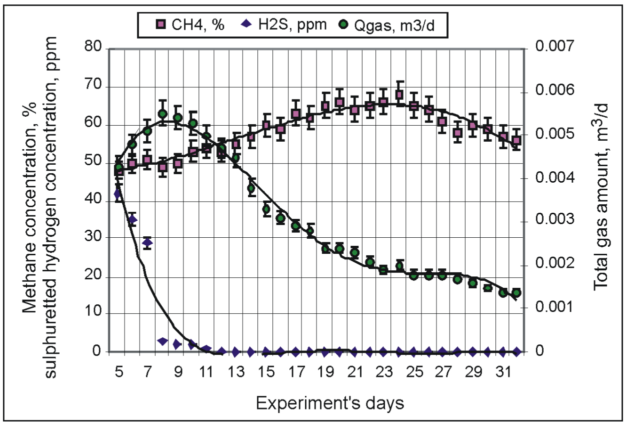

Fig. 2. Methane and sulphuretted hydrogen concentrations in gas and their amounts during biodegradation of hen manure and waste from margarine production (75% : 25%)

Methane is the main component of biogas, which predetermines the opportunities of its application. Only in case gas emissions contain more than 60% of methane, biogas is considered valuable (Savickas, Vrubliauskas 1997; Baltrėnas *et al*. 2004). The concentration of methane in biogas depends on the growth of an anaerobic bacterial population. At the presence of a favourable temperature mode and sufficient amount of nutrients the bacterial population is growing, and at the same time more methane is produced (Khandelwal 1990). The concentration of methane in biogas was gradually increasing from the 1st to the 24th day of the experiment despite small fluctuations which were predetermined due to variations in temperature and pH. At the beginning of the experiment biogas contained 48% of methane, while the biggest amount of methane reached 68%. Later methane concentration was decreasing to 56% until the end of the experiment. According to the results of experiments performed by many authors, methane content during organic waste degradation is increasing in the course of time. A consistent increase in methane amount up to the maximal allowable limit is achieved at the presence of conditions favourable to microorganism-degrading organic matter. The obtained experimental results show that the content of methane in biogas was gradually increasing until the 24th day, while its subsequent decrease could be predetermined by an insufficient amount of organic matter in biomass. Therefore, in order to obtain sufficient concentration of methane in gas emissions that will be further used, it is necessary to connect the reactors of periodical operation into a single system or use reactors with remote control. Such a knowledge is also given in literature (Savickas, Vrubliauskas 1997).

Temperature is a very important factor having influence on the composition of microorganisms population and intensity of their activities. The higher the temperature, the more intensive the activity of microorganisms (Nagel 2001). With the change of temperature mode, the composition of microorganisms degrading biomass changes. Therefore, it is important to maintain the temperature of biomass as stable as possible to prevent microorganisms from experiencing a temperature shock. During the experiment temperature varied from 22.0 °C to 25.0 °C, but the absence of tendency shows that temperature was stable until the 21st day of the experiment and slightly increased until the end of the experiment (Fig. 3). Throughout the experiment the average temperature in the bioreactor was around 23.5 °C, i.e. the psychrophilic mode was present. Even though temperature varied by 3 degrees but such a change is possible. At the presence of the psychrophilic medium the biggest change is 3 degrees per hour, consequently the required conditions of temperature stability were maintained during the experiment.

According to F. J. Nagel, during anaerobic degradation of organic matter, the amount of oxygen in biogas varies from 9–10% to 1–2%. A bigger amount of oxygen is dangerous to anaerobic microorganisms. Throughout the experiment the concentration of oxygen in biogas emissions was decreasing from 4.5% at the beginning to 1.9% at the end of the experiment.

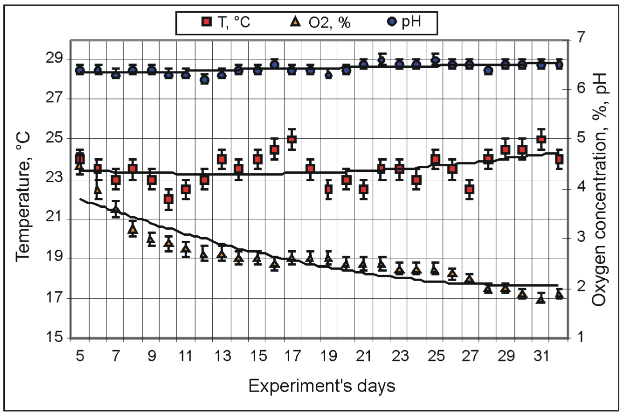

Fig. 3. Temperature, oxygen concentration and pH during biological degradation of hen manure and waste from margarine production (75% : 25%)

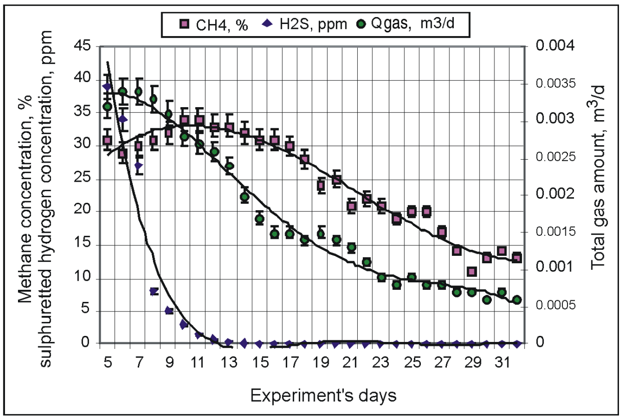

Fig. 4. Methane, sulphuretted hydrogen and gas amount during biological degradation of hen manure and margarine production waste (50% : 50%)

Microbiological activities in biogas reactors are the most favourable at the presence of neutral or weakly alkaline ($6.5<pH<8.5$) medium. Biogas generation is a complex process including simultaneous activities of several groups of microorganisms. This is the reason why the acidity of a substrate remains steady if the composition of raw materials is balanced. The process of fermentation produces fatty acids increasing the acidity of the substrate. But methanogenic bacteria use fatty acids for the production of biogas, and, therefore, the acidity is immediately neutralised (Savickas 1996). During anaerobic degradation of hen manure and margarine production waste (25:75) pH varied from 6.2 to 6.6, but throughout the experiment no clear tendency was noticed, and the average pH value was 6.4, i.e. of a very low acidity. Such a pH indicator could be predetermined by bigger amounts of fatty acids generating because of margarine waste added to the substrate. At the presence of the psychrophilic medium micro-organisms could not be active in degrading fatty waste.

During biological degradation of *hen manure and margarine production waste (the ratio of 50:50)* a decreasing tendency of gas emissions was observed, except for the start of the experiment (Fig. 4). The amount of biogas changes from 0.0032 m^3/d from 0,2 m^3 substrate at the beginning of the experiment to 0.0034 m^3/d from 0.2 m^3 substrate on the 6^{th} and 7^{th} days and falls to 0.0006 m^3/d from 0.2 m^3 substrate at the end of the experiment. Starting from the 6^{th} and 7^{th} days of the experiment, the maximal amount of biogas dropped more than five times until the end of the experiment. According to F. J. Nagel, the peak of biogas emissions is reached more rapidly, is bigger and decreases slower when the highest possible temperature is maintained in a bioreactor. If temperature is higher, organic matter is degraded more rapidly, and microorganisms use nutrients quicker. Despite the fact that only psychrophilic mode was maintained during the experiment, a significant decrease in biogas emissions could be influenced by the decreased content of organic substances in biomass as well as fatty waste in its content (50% of the total biomass).

The experiment showed a clear decreasing tendency of sulphuretted hydrogen concentration during the first days, i.e. from 39 ppm at the beginning to 0 ppm on the 15^{th} day of the experiment. No sulphuretted hydrogen was found in gas emissions during other days of the experiment. According to Savickas, sulphuretted hydrogen concentration in biogas does not exceed 3%. The comparison of the obtained experimental results shows that the concentration of sulphuretted hydrogen does not exceed the mentioned value. Biogas contained a low concentration of sulphuretted hydrogen because microorganisms managed to use sulphur in their activities and its excess did not generate.

The concentration of the most important biogas component methane in biogas from the beginning of the experiment (29%) reached the maximum (34%) until the 11^{th}, 12^{th} days, and later was gradually decreasing. At the end of the experiment the concentration of methane was 13%. Such a decrease was influenced by the fact that the major part of hen manure was biologically degraded, but margarine production waste was poorly degrading in the psychrophilic medium. Even though the amount of organic matter should have been sufficient for the activities of microorganisms but psychrophilic microorganisms are very slow to degrade fatty organic waste, which preconditions the accumulation of fatty acids having a negative effect on general activities of (Sharma *et al*. 1999). This is the reason why methane concentration decreased in gas emissions.

As it was mentioned above, the psychrophilic temperature was maintained during the experiment. It varied in the range of 22.0 °C and 24.5 °C, but throughout the experiment the average temperature in a bioreactor was 23.1 °C (Fig. 5). In this case the average temperature in a bioreactor was slightly lower (0.4 °C) compared to the previous case. The maximal possible temperature change during the psychrophilic process (3 °C per hour) was maintained throughout the experiment. Consequently, a lower average temperature in a bioreactor could have only an insignificant effect on the experimental results.

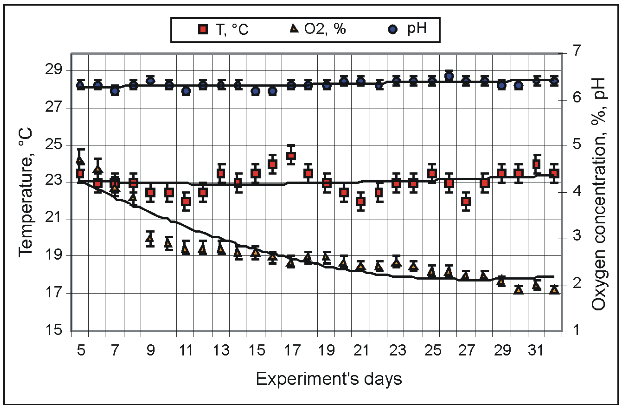

Fig. 5. Temperature, oxygen concentration and pH during biological degradation of hen manure and margarine production waste (50%:50%)

Throughout the experiment oxygen concentration in biogas emissions was falling from 4.7% at the beginning to 1.9% at the end of the experiment. The oxygen concentration determined during this experiment is similar to that of the previous experiment. Upon comparing to data given in literature (F. J. Nagel), the probable oxygen concentration was established.

The indicator of pH changed from 6.2 to 6.5, the experiment did not produce any clear tendency and the average pH value throughout the experiment was 6.3, i.e. weakly acid.

As maintained by Sharma, the most favourable medium for microorganisms is the neutral or weakly alkaline one. In the process of fermentation methanogenic bacteria use fatty acids for the production of biogas, therefore, the acidity is immediately neutralised. But such pH indicator could be predetermined by larger amounts of fatty acids generating because of adding margarine production waste to substrate as well as insufficient temperature in a bioreactor.

During biological degradation of *hen manure* and *margarine production waste (the ratio of 25:75)* the increasing tendency of gas emissions until the 10th day and the decreasing tendency until the very end of the experiment were recorded (Fig. 6). At the beginning of the experiment, the amount of emitted gas was 0.0016 m^3/d from 0.2 m^3 substrate, later it increased to 0.0020 m^3/d and fell to 0.0003 m^3/d from 0.2 m^3 substrate at the end of the experiment. It was noticed that much less of gas had been emitted compared to the previously described cases because margarine production waste badly degrades in the psychrophilic medium. Even though the obtained biogas amount was smaller due to fatty waste (75% of the total biomass) compared to the previous cases, the general tendencies have remained.

Like in the previously described cases, a tendency of rapid decrease in sulphuretted hydrogen concentration during the first days, from 27 ppm at the beginning to 0 ppm on the 17th day of the experiment, was observed. No sulphuretted hydrogen was found in gas emission during the other days of the experiment. In their activities bacteria neutralised sulphuretted hydrogen. It is obvious

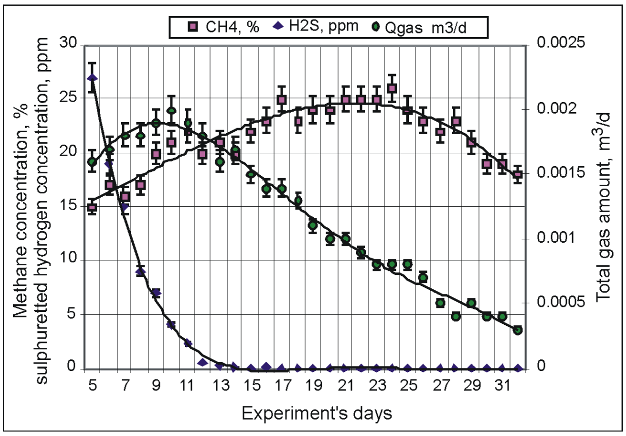

Fig. 6. Methane, sulphuretted hydrogen concentration in gas and its amount during biological degradation of hen manure and margarine production waste (25%:75%)

that the concentration of sulphuretted hydrogen is low and does not exceed 3% (Savickas 1996) of the biomass amount.

Methane concentration in biogas is also low due to inactive work of methanogenic bacteria.

At the beginning of the experiment methane concentration in biogas was 15% and gradually rose to 26% until the 24th day of the experiment irrespective of low variations caused by temperature and pH fluctuations. Later decrease in methane concentration was recorded – at the end of the experiment gas emissions contained 18% of methane. Biogas is considered valuable only when methane concentration is higher than 60% (Nagel 2001). The experiment's findings show that this biogas with low methane concentration would not be suitable for use because of a low calorific power.

During the experiment temperature varied in the range of 22.5 °C and 24.5 °C, but the average temperature in a bioreactor throughout the experiment was psychrophilic and reached 23.4 °C (Fig. 7). The composition of microorganisms' population and intensity of activities depend on a temperature mode. The higher the temperature, the more intense the activities of micro-organisms (Sharma *et al*. 1999).

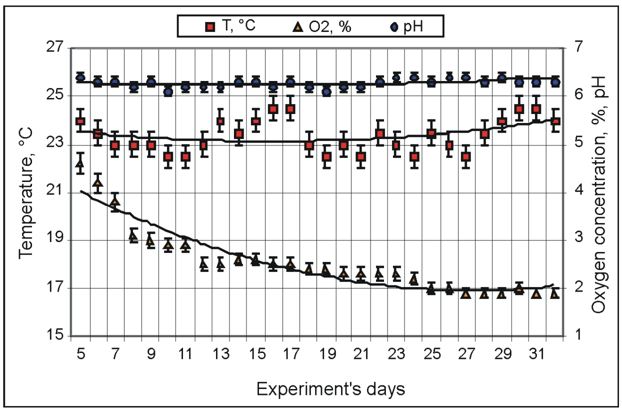

Fig. 7. Temperature, oxygen concentration and pH during biological degradation of hen manure and margarine production waste (25% : 75%)

Like in the previous cases, throughout the experiment oxygen concentration in evolved biogas was gradually decreasing from 4.6% at the beginning to 1.9% at the end of the experiment. The direction and strength was the tendency did not differ from the previously analysed experimental cases.

The indicator of pH changed from 6.1 to 6.4. Throughout the experiment, the average value of pH was 6.3, i.e. weakly acid. Such a pH indicator could have been predetermined by a larger amount of fatty acids generating because of adding margarine production waste to the substrate. It was also noticed that the bigger the part of fatty waste in the substrate, the lower the pH indicator at the presence of psychrophilic medium in a bioreactor. The reason for this is that psychrophilic micro-organisms are very slow to degrade fatty organic waste. In the case of a slow growth in microorganisms' population and non-intensive activities, microorganisms are too slow in neutralising generated fatty acids and, therefore, the pH indicator is lower than the neutral one.

During biological degradation of *sewage sludge and margarine production waste (the ratio of 75:25),* the tendency of decreasing gas emissions throughout the experiment was noticed except for the first days of the experiment (until the 9th day). At the beginning of the experiment gas emissions amounted to 0.0056 m^3/d from 0.2 m^3 substrate, later increased to 0.0061 m^3/d but fell to 0.0017 m^3/d from 0.2 m^3 substrate at the end of the experiment (Fig. 8). The general tendency of gas emission is very similar to the previously described cases. At the beginning of the experiment when there is a sufficient amount of nutrients, the population of microorganisms degrading organic waste is rapidly growing, at the same time more gas is generated (Nagel 2001).

During the experiment a tendency of rapid decrease in sulphuretted hydrogen concentration during the first days from 89 ppm to 0 ppm on the 17th day of the experiment was noticed. No sulphuretted hydrogen was found in gas emissions during the other days of the experiment. Like in the previous cases, during this experiment the concentration of sulphuretted hydrogen did not exceed the concentration of 3% mentioned in literature (Savickas 1996).

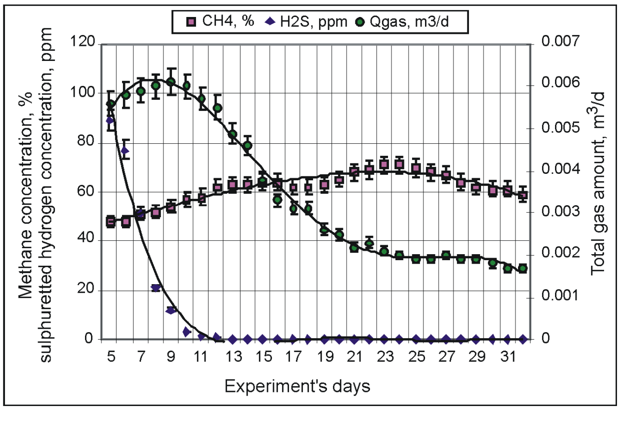

Fig. 8. Methane, sulphuretted hydrogen concentration in gas and gas amount during biological degradation of sewage sludge and margarine production waste (75% : 25%)

An increase in methane concentration was recorded until the 24th day of the experiment. Later, the methane concentration decreasing tendency was noticed. At the beginning of the experiment methane content in biogas was 48% reaching the maximum of 71%, but at the end of the experiment it fell to 59%. The concentration of this essential component of biogas emissions (Savickas 1996) is sufficient to use biogas for energy generation. In order to regularly maintain the concentration of methane in gas higher than 60% several reactors of periodic operation connected into a single system or reactors with remote control should be used.

During the experiment temperature varied in the range of 22.0 ºC and 24.5 ºC (Fig. 9), but the average temperature in a bioreactor throughout the experiment was around 23.0 ºC. Like in the previous cases temperature in a bioreactor was psychrophilic and its average value was nearly the same as in the previously described cases. The requirement not to have bigger temperature variations than 3 ºC per hour was maintained throughout the experiment.

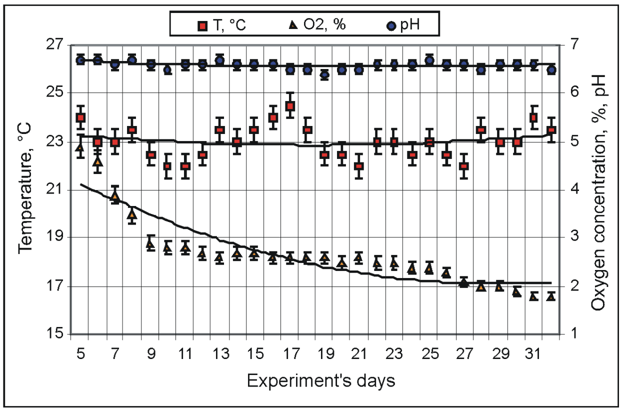

Fig. 9. Temperature, oxygen concentration and pH during biological degradation of sewage sludge and margarine production waste (75% : 25%)

Like in the previous cases, throughout the experiment oxygen concentration was gradually falling and decreased from 4.9% at the beginning to 1.8% at the end of the experiment. Numeric values and changing tendency of oxygen concentration, in fact, did not differ from the previously described experimental findings.

The acidity of biomass is important to microbiological activities. Neutral and weakly alkaline media are the most favourable ones to the activities of microorganisms. (Savickas 1996). During this experiment, pH indicator varied from 6.4 to 6.7. Throughout the experiment the average pH value was 6.6, i.e. weakly alkaline. Such a pH indicator was predetermined by sufficiently good conditions for the development of bacterial population, while a small portion of fatty waste (25% of the total biomass) did not have a significant effect on the activities of microorganisms like in the previously described case (hen manure and margarine production waste at the ratio of 25:75). This could be influenced by the fact that at the beginning of the experiment a bigger population of microorganisms generated than in the analogous case with hen manure. This statement can also be confirmed by bigger gas emissions and a higher concentration of methane in gas.

During biological degradation of *sewage sludge and margarine production waste (at the ratio of 50:50),* like in the previous cases, at the beginning gas emissions increased but afterwards decreased. Even though only psychrophilic mode was maintained during the experiment, a significant decrease in the biogas amount could have been predetermined by a decreased content of organic substances in biogas as well as fatty waste (50% of the total biomass) in its content. The biogas emissions of 0.0028 m^3/d from 0.2 m^3 substrate at the beginning increased to 0.0041 m^3/d on the 11th day of the experiment but fell to 0.0017 m^3/d from 0.2 m^3 substrate at the end of the experiment (Fig. 10). The peak of biogas emissions was achieved at the presence of sufficient nutrients necessary for the growth of microorganisms population (Savickas 1996). Later, when the amount of nutrients decreased, i.e. part of organic waste was degraded, biogas emissions decrease.

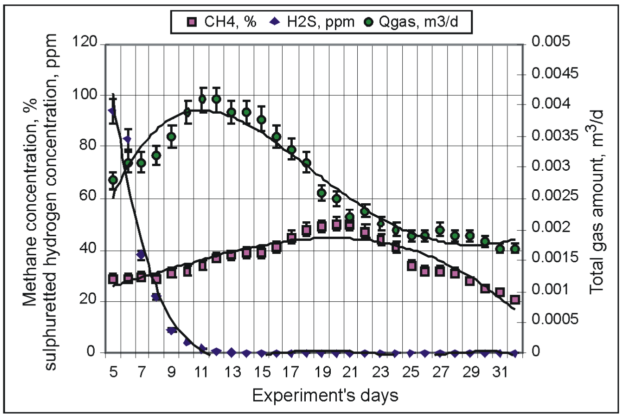

Fig. 10. Methane, sulphuretted hydrogen concentration in gas and gas amount during biological degradation of sewage sludge and margarine production waste (50% : 50%)

During the experiment a tendency of rapid decrease in sulphuretted hydrogen concentration during the first days from 94 ppm to 0 ppm on the 16th day of the experiment was noticed. No sulphuretted hydrogen was found in gas emissions during the other days of the experiment. Like in the previous cases, during this experiment the concentration of sulphuretted hydrogen did not exceed the concentration of 3% mentioned in literature (Savickas 1996) 3. Taking into consideration the fact that the concentration of this contaminant in gas emissions is low, biogas would be suitable for use in this respect.

Both the increase and decrease of methane concentration in biogas were recorded during nearly a half of the experiment time. During the first days methane concentration was 29% and rose to 50% until the 20th day but fell to 21% until the end of the experiment. The concentration of methane is not sufficient to use biogas for energy generation. According to data given in literature (Savickas, Vrubliauskas 1997), biogas is considered valuable when methane in its content accounts for at least 60%. A decrease in methane concentration could have been predetermined by the fact that fatty waste remaining after biological degradation of sewage sludge are difficult to degrade due to a low temperature in a bioreactor.

Like in the previous cases, during the experiment temperature was not completely steady – it varied from 22.0 ºC to 24.0 ºC, while throughout the experiment the average temperature in a bioreactor was around 23.0 ºC, i.e. the psychrophilic medium was maintained (Fig. 11). The required temperature change not bigger than 3 ºC per hour was maintained throughout the experiment.

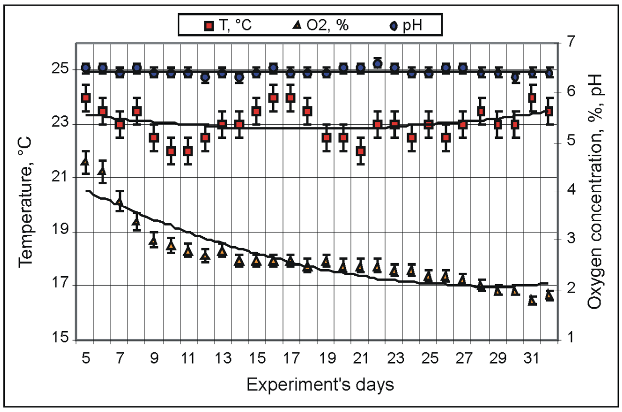

Fig. 11. Temperature, oxygen concentration and pH during biological degradation of sewage sludge and margarine production waste (50% : 50%)

Throughout the experiment oxygen concentration in biogas emissions was gradually decreasing from 4.6% at the beginning to 1.9% to the end of the experiment, including small fluctuations. Oxygen change and the intensity of this change did not differ from the previously described cases.

The indicator of pH varied from 6.3 to 6.6. Throughout the experiment the average pH value was 6.4, i.e. weakly acid. This indicator is lower and the most favourable for the optimum activities of microorganisms because, due to fatty waste in biomass (50% of the total biomass), an additional excess of fatty acids, that microorganisms had no time to neutralise, could generate.

During biological degradation of *sewage sludge and margarine production waste (the ratio of 25:75)* the amount of gas emissions was the lowest of all the mixtures of sewage sludge and fatty waste showing a decreasing tendency of gas emissions throughout the experiment. A small amount of gas was emitted due to a big content of fats in a biomass mixture as well as the insufficient psychrophilic medium for fat decomposition in a bioreactor. At the beginning of the experiment evolved biogas amounted to 0.0014 m^3/d , and at the end – 0.003 m^3/d from 0.2 m^3 substrate (Fig. 12).

During the experiment a tendency of rapid decrease in sulphuretted hydrogen concentration during the first days from 68 ppm to 0 ppm on the 15th day of the experiment was noticed. Such a rapid decrease could have been predetermined by rapid activities of bacteria which neutralised sulphuretted hydrogen. No sulphuretted hydrogen was found in gas emissions during the other days of the experiment. An undesirable component in biogas is sulphuretted hydrogen (Savickas 1996) which forms at the presence of an excess of proteins in biomass. The content of sulphuretted hydrogen in biogas does not exceed 3% of biogas composition (Savickas 1996).

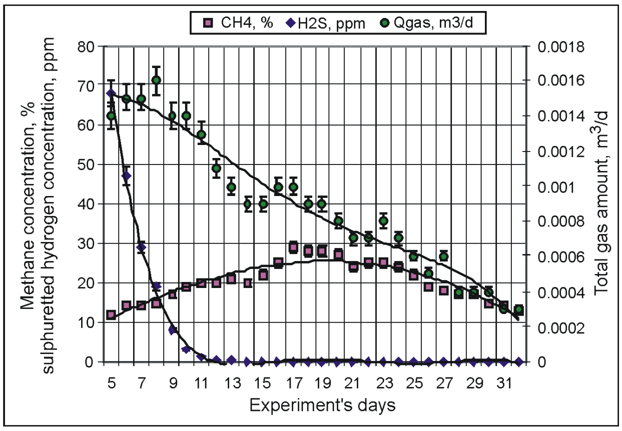

Fig. 12. Methane, sulphuretted hydrogen concentration in gas and gas amount during biological degradation of sewage sludge and margarine production waste (25% : 75%)

Both the increase and decrease of methane concentration in biogas were recorded during nearly a half of the experiment's time, like in the previously described case. During the first days methane concentration was 12% and increased to 29% until the 17th day of the experiment and fell to 13% at the end of the experiment. It can be stated that the concentration of the most important component of biogas (methane), compared to the previous experimental findings, was lower throughout the experiment. Such a result was for the most part influenced by the maintenance of the psychrophilic medium in a bioreactor, which greatly burdened the degradation of fatty waste accounting for 75% of the biomass mixture.

Like in the previous cases, during the experiment temperature was not completely steady – it varied in the range of 22.0 ºC and 25.0 ºC, while the average temperature in a bioreactor throughout the experiment was around 23.5 ºC (Fig. 13). Temperature is the most important factor predetermining the size of microorganisms population and the intensity of their activities, which has a direct influence on the amount of emitted biogas and methane concentration in it.

Throughout the experiment the oxygen concentration in biogas emissions was gradually decreasing from 4.6% at the beginning to 1.8% at the end of the experiment, including small fluctuations. According to F. J. Nagel, during anaerobic degradation of organic matter oxygen content in biogas changes from 9–10% to 1–2%. A bigger content of oxygen is dangerous to anaerobic microorganisms.

The indicator of pH ranged from 6.2 to 6.4. The average pH value throughout the experiment was 6.3, i.e. weakly acid. Microbiological activities in biogas reactors is the most favourable at the presence of neutral or weakly alkaline medium. The indicator of pH could have been influenced by the excess of fatty acids forming in the process of fermentation. Microorganisms did no manage to degrade fatty organic waste because very intensive growth and activities of microorganisms population do not occur at the presence of the psychrophilic temperature mode.

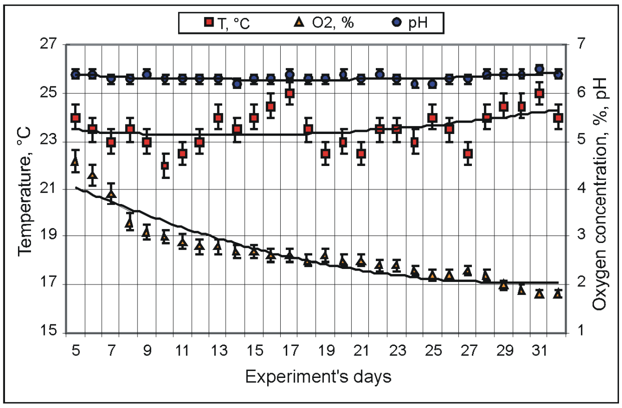

Fig. 13. Temperature, oxygen concentration and pH during biological degradation of sewage sludge and margarine production waste (25% : 75%)

4. Conclusions

1. Throughout the experiment (32 days) the highest biogas emission (0.09 m^3) from 0.2 m^3 substrate was achieved using a mixture of hen manure and fatty waste at the ratio of 75:25.
2. Throughout the experiment (32 days) the highest biogas emission (0.10 m^3) from 0,2 m^3 substrate was achieved using a mixture of sewage sludge and fatty waste at the ratio of 75:25.
3. When using mixtures of hen manure and sewage sludge with fatty waste at the ratio of 75:25, methane concentration was also the highest, and the average value reached 58.5% (in the case of hen manure) and 61.7% (with sewage sludge).
4. Analysis of emitted gas content and methane concentration in gas shows that the biogas, evolved from hen manure and sewage sludge with fatty waste mixed at the ratio of 75:25, is the most efficient for use.
5. At the presence of the psychrophilic medium in bioreactors, the more fatty waste was added to biomass mixtures, the lower the biogas amount and methane concentration in gas.
6. Biogas emissions and methane production are impeded by increased acidity of biomass because microorganisms are not capable of neutralising fatty acids at the presence of the psychrophilic medium.
7. The concentration of sulphuretted hydrogen in biogas did not exceed 3% in any of the cases investigated.
8. Oxygen concentration in gas emissions fell from 4.9% to 1.8%.
9. The indicator of pH was decreasing when more fatty waste was added to the mixture of biomass. When using hen manure, the average pH value changed from 6.4 to 6.3, when using sewage sludge – from 6.6 to 6.3.

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BIODUJŲ GAMYBOS EKSPERIMENTINIAI TYRIMAI PANAUDOJANT RIEBALINES ATLIEKAS

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Santrauka

Pateikiami eksperimentinių biodujų gamybos tyrimų, naudojant vištų mėšlą ir nuotekų valymo dumblą su riebalinėmis (margarino gamybos) atliekomis, rezultatai. Iš šių organinių atliekų buvo paruošti mišiniai: vištų mėšlas bei nuotekų valymo dumblas buvo maišomas su riebalinėmis atliekomis 75 % : 25 %, 50 % : 50 % ir 25 % : 75 %. Darbe nagrinėjama biodujų kiekybinė ir kokybinė sudėtis: išsiskyrusių dujų kiekis, metano, sieros vandenilio ir deguonies koncentracija jose, temperatūros bei pH pokytis eksperimento metu. Eksperimentų metu bioreaktoriuose buvo palaikomas psichrofilinis temperatūrinis režimas. Nustatyta, kad didžiausias biodujų kiekis (0,09 m^3) išsiskiria vištų mėšlą maišant su riebalinėmis atliekomis santykiu 75 % : 25 %. Naudojant nuotekų valymo dumblo ir riebalinių atliekų mišinį (75 % : 25 %), taip pat gauta didžiausia biodujų išeiga per visą eksperimento laikotarpį – 0,10 m^3. Metano koncentracija naudojant šiuos mišinius taip pat buvo didžiausia. Vidutinė reikšmė siekė 58,5 % (su vištų mėšlu) bei 61,7 % (su nuotekų dumblu). Įvertinus išsiskyrusių dujų kiekį ir metano koncentraciją jose, nustatyta, kad efektyviausiai būtų galima naudoti biodujas, išsiskyrusias iš vištų mėšlo ir nuotekų valymo dumblo su riebalinėmis atliekomis, kurių santykis 75 % : 25 %. Sieros vandenilio koncentracija biodujose neviršijo 3 %, deguonies koncentracija mažėjo nuo 4,9 % iki 1,8 %. pH rodiklis mažėjo į biomasės mišinį įdedant daugiau riebalinių atliekų. Naudojant vištų mėšlą vidutinė pH reikšmė kito nuo 6,4 iki 6,3, naudojant nuotekų valymo dumblą – nuo 6,6 iki 6,3.

Reikšminiai žodžiai: biodujos, biomasė, riebalinės atliekos, vištų mėšlas, nuotekų valymo dumblas, psichrofilinis režimas.

ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ПРОИЗВОДСТВА БИОГАЗА С ИСПОЛЬЗОВАНИЕМ ЖИРОВЫХ ОТХОДОВ

П. Балтренас, М. Квасаускас

Резюме

Представлены результаты экспериментальных исследований по производству биогаза с использованием куриного помета и ила сточных вод с жировыми отходами (от производства маргарина). Были исследованы следующие смеси из органических отходов: куриный помет и ил сточных вод были смешаны с жировыми отходами в объеме 75% : 25%, 50% : 50% и 25% : 75%. Проанализирован количественный и качественный состав биогаза: газовое содержание эмиссии, концентрации метана, сероводорода и кислорода, а также изменение температуры и фактора pH в течение эксперимента. Во время эксперимента в биореакторе поддерживался психрофильный температурный режим. Было установлено, что при смешивании куриного помета с жировыми отходами в соотношении 75% : 25% и поддерживании психрофильного температурного режима наибольший выпуск биогаза (от 0,09 $м^3$ до 0,2 $м^3$ субстрата) обнаружен спустя 32 дня. При использовании смеси из ила сточных вод и жировых отходов в соотношении 75% : 25% и поддерживании психрофильного температурного режима был установлен наибольший выпуск биогаза (от 0,10 $м^3$ до 0,2 $м^3$ субстрата) спустя 32 дня. При использовании этих смесей концентрация метана также была самая большая, ее средние значения составляли 58,5% (с куриным пометом) и 61,7% (с илом сточных вод). В результате оценки газовой эмиссии и концентрации метана в эмиссии установлено, что наиболее эффективным будет использование биогаза, получаемого от смеси куриного помета и ила сточных вод с жировыми отходами в соотношении 75% : 25%. Концентрация сероводорода в биогазе не превышала 3%, концентрация кислорода уменьшилась от 4,9% до 1,8%. Индикатор фактора pH уменьшался, когда к смеси добавлялось больше жировых отходов. При использовании только куриного помета среднее значение фактора pH менялось от 6,4 до 6,3, при использовании ила сточных вод – от 6,6 до 6,3.

Ключевые слова: биогаз, биомасса, жировые отходы, куриный помет, ил сточных вод, психрофильный режим.

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