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Anaerobic recycling of organic waste and recovery of biogas

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The authors analyse the quantitative and qualitative findings of research on biogas. Biogas was recovered by anaerobic biodegrading of various substrates: sewage treatment sludge, hen manure, and pig manure. The volume of each substrate was 200 l, including 20% of dry mass. Once a day, the substrate temperature, pH, the content of biogas as well as of methane, hydrogen sulphide and oxygen in biogas were measured. Throughout the experiment, biogas output from sewage sludge totalled 0.0782 m^3, from hen manure 0.1066 m^3 and from pig manure to 0.1150 m^3 from 0.2 m^3 of the substrate. The largest biogas output was obtained from digesting pig manure in anaerobic conditions. The largest net amount of biogas (gas amount with regard to the content of methane therein) was produced in the course of anaerobic biodegradation of pig manure. The average amount of biogas was 0.0028 m^3 per day. The evolution of gas from sewage sludge was 58.2% and from hen manure 52.7% as compared with pig manure.

Key words: organic waste, anaerobic process, biogas

INTRODUCTION

The large amounts of organic waste formed in agriculture and food industry as well as sewage sludge are a problem of national significance in Lithuania (Savickas et al., 1997; Конаков и др., 1993; National Energy Strategy, 2000). For instance, about 60,000 tons of waste of animal origin accumulate at animal and poultry slaughterhouses and meat processing enterprises; 0.3–0.5 million tons of biodegradable household waste collect annually, which could be recycled at biogas power plants. This organic waste is transported to landfills. Thus, the space occupied by landfills is expanding, and additional drainage sites for sludge are being built. Applying liquid organic waste to fields results in excessive nutrients, part of which can permeate to groundwater (Paulauskas et al., 2006). Together with excessive nutrients, heavy metals can also escape to the environment (Mašauskas et al., 2006) with a negative effect on groundwater, soil as well as on the flora and thus the fauna. The discharge of organic waste into the environment is also responsible for odours.

Discharges of organic waste pollute the atmosphere, damage the landscape, contaminate the soil and groundwater. Moreover, landfilling of organic waste contradicts the European Union requirements.

When organic waste biodegrades, gas containing methane, carbon dioxide, hydrogen and hydrogen sulphide evolves (Savickas, 1999).

In reducing the amount of organic waste, bioreactors could be employed. Anaerobic recycling of organic waste therein would not only reduce the amounts of organic waste and minimize odours, but also generate alternative electric and heat energy along with high-quality fertilizers (Gunaseelan, 1997).

By recycling 30% of animal and poultry manure at biogas power plants, around 50 million cubic metres of biogas may be produced in Lithuania with an energy value of approximately 300 GWh. About 12 million m3 of biogas with an energy value of 70 GWh can be produced from waste of animal origin. From biodegradable household waste, 15–20 million m3 of biogas with an energy value amounting to 100 GWh can be produced per year (Lahmeyer..., 1994).

One of the key indicators of biogas output is the volume of formed gas. The larger the output of biogas at the same quantity of methane, the higher the benefits (more energy) obtained from anaerobic biodegradation of organic waste (Results..., 2004; Baltrėnas et al., 2004).

The output of biogas strongly depends on temperature. Temperature change directly influences the anaerobic emission of gas: an increase of temperature in the bioreactor increases the gas output over the same period of time (Baltrėnas et al., 2005). At a constant temperature in the bioreactor, the amount of gas is supposed to gradually decline after reaching the peak (Chanakya et al., 1998; Sharma et al., 1989). A very important indicator of gas output is its qualitative composition. Gas quality is best reflected by the content of methane (CH4) and other impurities such as hydrogen sulphide (H2S), oxygen (O2) and carbon dioxide (CO2), as well as humidity (Savickas et al., 1997). The content of methane in biogas depends on the population growth of anaerobic bacteria. When the temperatures are favourable and the quantity of nutrients sufficient, the bacterial population grows, yielding higher methane outputs (Kompala et al., 1986). In the course of fermentation fatty acids are formed, thus increasing the acidity of the substrate. However, methanogenic bacteria use fatty acids for biogas production and thus the acidity is immediately neutralized (Berber, 1996).

The experiment aimed at analysing the use of the anaerobic biodegradation process in reducing the amounts of organic waste and at determining the quantitative and qualitative composition of biogas resulting from organic waste biodegradation.

METHODS

The research was carried out in laboratory conditions. The qualitative and quantitative analysis of biogas involves the use of a substrate (organic waste) of different composition. To recover biogas, piggery and poultry-house manure as well as sewage treatment sludge were used for charging the bioreactor. These kinds of organic waste were chosen because their amounts in Lithuania are rather large.

Anaerobic decomposition of the mentioned organic waste was carried out in three bioreactors connected into a single system. For bioreactors, closed plastic containers with a volume of 220l, in which anaerobic conditions are created, were used. 200 l (90%) of the volume is filled, and the remaining space is reserved for gas to collect (Fig. 1).

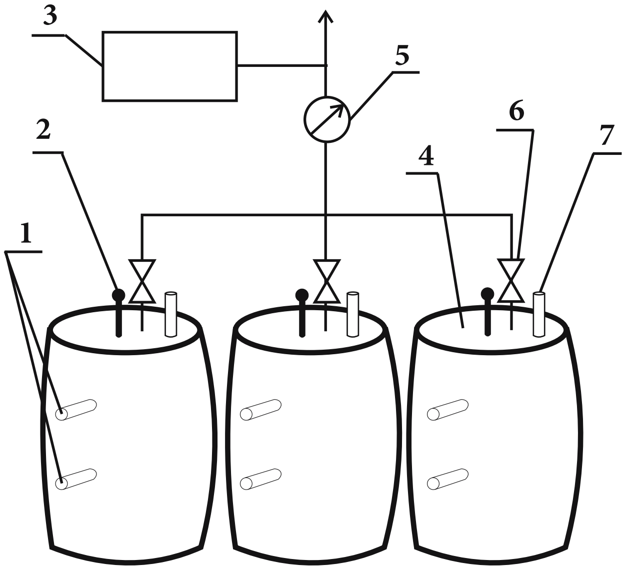

Fig. 1. Bioreactor system: *1* – thermometers; *2* – bioreactor mixer; *3* – gas analyser; *4* – bioreactor; *5* – gas meter; *6* – tap; *7* – hose for leachate sampling

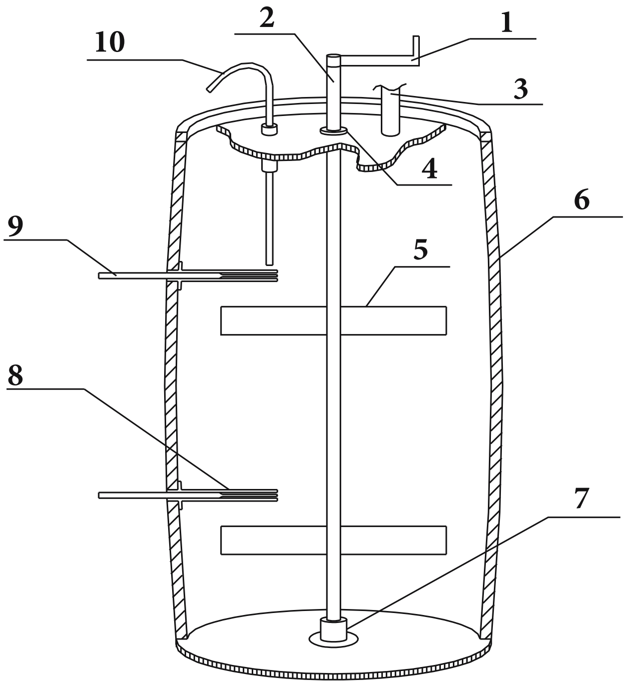

Fig. 2. Bioreactor: *1* – mixing handle; *2* – mixer axis; *3* – biogas output hole; *4* – seal; *5* – mixer paddle; *6* – bioreactor body; *7* – mixer fixation; *8* – thermometer holders; *9* – thermometers, *10* – hose for leachate sampling

Each bioreactor was equipped with a mixing system and had places for measuring temperature and pH (Fig. 2).

The bioreactor was charged using substrates of different compositions: 1 – sewage treatment sludge (Vilnius Sewage Treatment Facility), 2 – hen manure (AB Vilniaus Paukštynas), 3 – piggery slurry (UAB Cestos Maistas).

Once in two days the substrate temperature, pH, the amount of biogas and the content of methane, hydrogen sulphide and oxygen in the biogas were measured.

Prior to the experiment, the substrate had been prepared so that the portion of dry substance within it made 20% of the total mass.

Before the measurements, the substrate was mixed with a mixer to form a uniform phase throughout the whole volume. After mixing the substrate, the tap was turned on to allow the collected gas to flow through the hoses and pass through the gas flow meter and later through the gas analyser. The evolved amounts of biogas as well as those of methane, hydrogen sulphide and oxygen in the biogas entered the measurement report. When the biogas flow stopped (the gas flow meter stopped), the tap was turned off. The procedure was repeated in that way until the measurements of biogas quantity and quality are taken from all bioreactors. The temperatures in each bioreactor was measured and the leachate was taken to determine the pH level. The temperature was measured with two thermometers showing the biocharge temperature in the surface layer and closer to the bottom. The average temperature is entered into the report.

Devices used: 220 l plastic containers; thermometers; pH meter; gas flow measurement meter; gas analyser GD/MTG – 7. Prior to each measurement, the gas analyser GD/MTG – 7 is calibrated.

RESULTS

Measuring the parameters of **sewage sludge** biodegradation began on the sixth day of the experiment (when, according to references, the biogas formation period starts). The amount of gas evolved was 0.0034 m^3, and it gradually increased until the 14th day of the experiment, when the gas output totalled 0.0054 m^3. Then the gas output rapidly declined, dropping to 0.0036 m^3 on day 18th, although later the decrease was not as fast. The amount of gas decreased gradually: changes in its amount became smaller and smaller with time.

The chart shows that the amount of gas evolved heavily depends on temperature. Temperature change directly affects the anaerobic evolution of gas: the higher the temperature the larger the amount of gas. At a constant temperature, the amount of gas on reaching the peak should gradually decrease (Chanakya et al., 1998), while the values of the curves representing changes in the amount of gas during the experiment change in proportion to temperature changes in bioreactors. In spite of the fact that the temperature in the bioreactor dropped by 6.5 °C from the start to the 14th day of the experiment, the gas output increased by 60% as a result of a surge in the number of anaerobic bacteria during the first several days of the experiment owing to advantageous conditions for reproduction – a sufficient amount of organic substances and a favourable temperature.

During the first several days, the amount of methane remained almost constant, and starting with day 14th it began to drop because of the drop in temperature. When it decreased from 29 to 22.5 °C, the temperature regime changed from mesophilic to psychrophilic. A simultaneous change was bound to occur in bacteria recycling the biomass – from mesophilic to psychrophilic bacteria. Then methane concentration kept increasing. Reaching 54% at the start of the experiment, it dropped to 22% with a change in the temperature regime, but later gradually climbed to reach 86.4% at the end of the experiment (on day 60).

Hydrogen sulphide is an undesirable component in biogas. The amount of hydrogen sulphide at the beginning of the experiment of anaerobic biodegradation of sewage sludge showed an intensive activity of methanogenic bacteria – the concentration of hydrogen sulphide on day 6 was 137 ppm. The concentration of hydrogen sulphide dropped sharply and on day 14 totalled a mere 11 ppm, then went down to 0 ppm on day 26 to stay at this level until the end of the experiment. The sudden decrease may be related to the emission of hydrogen sulphide to the environment together with biogas as well as to a slowdown in microorganism activity.

The amount of oxygen during the experiment showed a decreasing tendency, except for a couple of peaks 4% each, predetermined by a decrease in heat in the bioreactors by about 1 °C. In total, the amount of oxygen in biogas throughout the experiment stood at about 2.5%.

The pH changed from 6.6 to 7.1 in the course of sewage sludge biodegradation. In the course of fermentation fatty acids are formed and increase the acidity of the substrate. However, methanogenic bacteria use fatty acids for biogas production, and therefore the acidity is immediately neutralized. In the general case, pH balance was slightly acidic in the course of sewage sludge biodegradation (Figs. 3, 4).

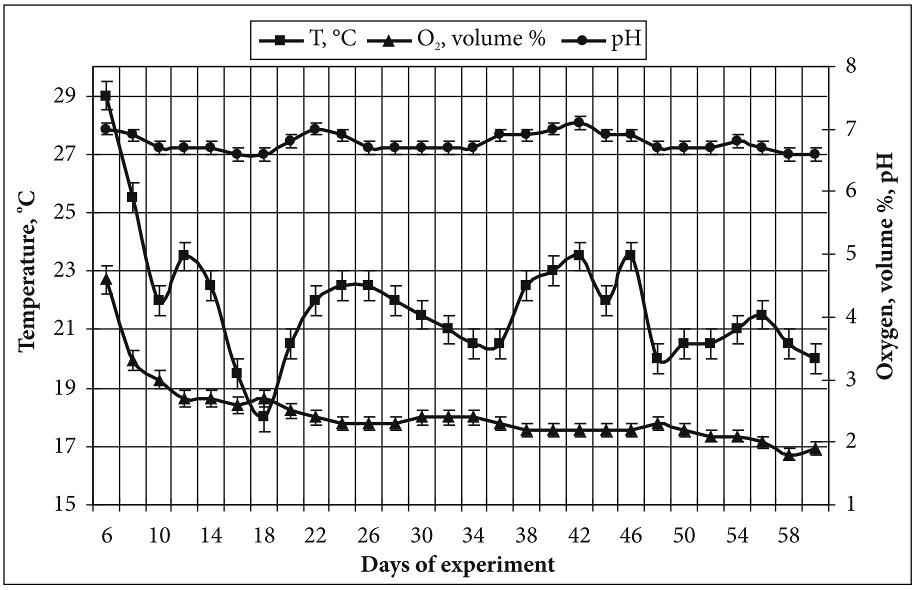

Fig. 3. Temperature, volume part of oxygen and pH in anaerobic biodegradation of sewage sludge

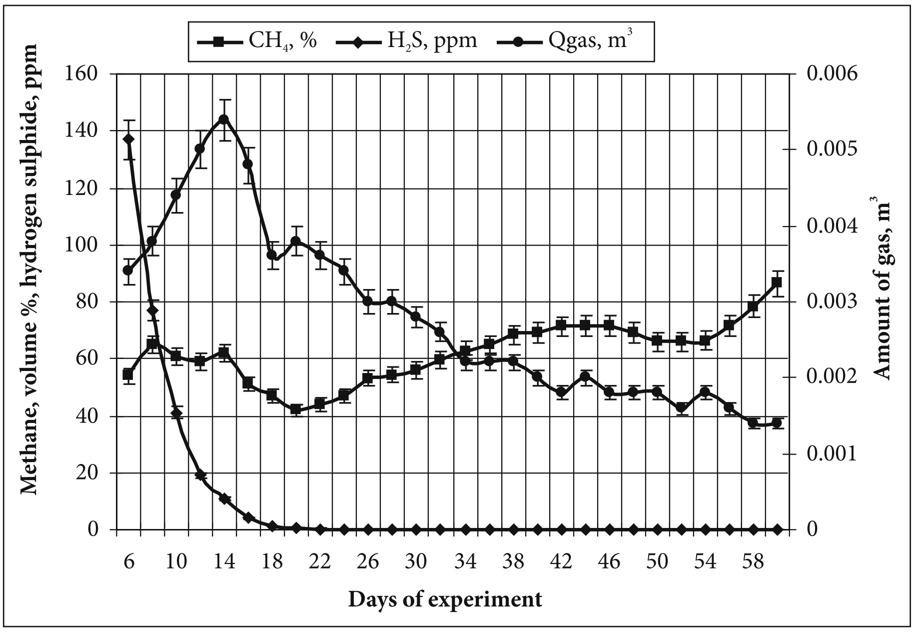

Fig. 4. Amounts of methane, hydrogen sulphide and gas in anaerobic biodegradation of sewage sludge

At the start of the experiment of biodegrading **hen manure,** the amount of gas evolved was 0.0042 m^3. It gradually increased until day 12 when the gas output reached 0.0056 m^3. Then the gas output was decreasing until day 20 at the same pace as at the start of the experiment. By day 20 the biogas output declined to the initial level of 0.0042 m^3, and later the decrease was insignificant. The amount of gas was decreasing gradually: the change in the amount became smaller and smaller with time. The average amount of biogas totalled 0.0034 m^3 and dropped to 0.0026 m^3 towards the end of the experiment.

As noted above, biogas output is directly and clearly affected by temperature in the bioreactor. During the anaerobic process of hen manure degradation, the temperature remained rather constant, ranging from 18 °C on day 18 to 28 °C at the beginning of the experiment. The average temperature in the course of the whole experiment was 22 °C.

When the temperatures were favourable and the amount of organic substances sufficient, the population of anaerobic bacteria grew immediately and the temperature increase from the beginning of the experiment to its 18th day did not have a major impact on the biogas output. When the temperature dropped by 6 °C, the gas output still grew by 30%.

The amount of methane in biogas, dependent on the growth of the anaerobic bacteria population, remained almost constant in the course of hen manure degradation throughout the experiment. The amount of methane ranged from 43.4% on day 8 to 29.6% at the end of the experiment. A more conspicuous decrease in the concentration of methane (to 31.1%) was noted on day 18 when the temperature regime shifted from mesophilic to psychrophilic.

The amount of hydrogen sulphide in the course of anaerobic biodegradation of hen manure at the beginning of the experiment shows an intensive activity of methanogenic bacteria because hydrogen concentration on the 6th day of the experiment was 137.5 ppm. The concentration of hydrogen sulphide dropped suddenly and on day 24 stood at only 0.6 ppm to remain such until the end of the experiment. A sudden decrease could be related to a temperature drop within the bioreactor as well as to a slower bacterial activity.

The amount of oxygen during the experiment showed a decreasing tendency, with an exception of a couple of peaks 3% each, predetermined by a decline in the heat inside the bioreactors by about 1.5 °C. Throughout the experiment, the content of oxygen in biogas remained at about 2.7%.

The pH ranged from 6.6 to 6.9% in the course of anaerobic biodegradation of hen manure. In the course of fermentation, fatty acids are formed and increase the acidity of the substrate. However, methanogenic bacteria use fatty acids for biogas production, and therefore the acidity is immediately neutralized. In the general case, pH balance was slightly acidic in the course of sewage sludge biodegradation (Figs. 5, 6).

The amount of gas in the course of biodegradation of **pig manure** at the beginning of the experiment was 0.0044 m^3. It increased gradually until the 14th day of the experiment when the gas output reached 0.0066 m^3. Subsequently, the gas output dropped sharply until day 18. By day 20, the gas output decreased to the initial 0.0046 m^3 and later continued with small increases on separate days. The average amount of biogas stood at 0.0041 m^3 and declined to 0.0026 m^3 at the end of the experiment.

The mentioned biogas output differences were directly influenced by the temperature within the bioreactors. Having grown suddenly in the first several days of the experiment, the quantity of anaerobic bacteria compensated for a decrease in temperature from 26 to 23 °C (3 °C) and the amount of gas evolved was on the rise, however, on days 16 and 18 when the temperature dropped to, respectively, 18 °C and 17 °C, the amount of gas decreased by 0.0020 m^3 and was 1.4 times below the maximum. Later, the temperature in the bioreactor remained rather constant, averaging 21 °C. On separate days of the experiment, the recorded changes in temperature were insignificant (from 19.5 to 23.5 °C) as influenced by the ambient temperature.

During the first several days, methane concentration remained almost constant (64%). Starting with day 14 it began to drop and decreased to 46.3% on day 18. This resulted in a drop of temperature from 22 to 17 °C. Subsequently, methane concentration increased in a linear direction until day 36 and reached 83.9%. By day 48, methane concentration in biogas had settled and averaged 85.7%. The maximum methane concentration, 87.8%, was recorded on day 42. During the last several days of the experiment, methane concentration in the course of anaerobic biodegradation of pig manure increased by nearly 10% from the maximum and dropped to 77.9%.

The amount of hydrogen sulphide in the course of anaerobic biodegradation of sewage sludge at the beginning of the experiment shows an intensive activity of methanogenic bacteria to have occurred, as hydrogen concentration on day 6 was 137.7 ppm. The concentration of hydrogen sulphide dropped suddenly and on day 20 stood at only 13.6 ppm. Until day 36, the hydrogen sulphide concentration in gas was growing insignificantly to reach 17.3 ppm, then dropped to 3.5 ppm by day 42 and stayed around 3.2 ppm until the end of the experiment. The sudden decrease could be related to a slowdown in the methanogenic bacterial activity resulting from a temperature drop.

The amount of oxygen during the experiment showed a decreasing tendency, except peaks on days 28 and 36. At the beginning of the experiment, the content of oxygen in gas was 4.1% and by day 26 dropped to 2.6%, to increase to 2.7% on day 28. A slight increase (to 2.7%) in oxygen was also recorded on the 36th day of the experiment. Throughout the experiment, the average content of oxygen in biogas was 2.6%.

The pH ranged from 6.9 to 7.3% in the course of anaerobic biodegradation of sewage sludge. In the course of fermentation, fatty acids are formed and increase the acidity of the substrate. However, methanogenic bacteria use fatty acids for biogas production, and therefore the acidity is immediately neutralized. In the general case, pH balance was alkaline in the course of sewage sludge biodegradation, and pH totalled 7.1 (Figs. 7, 8).

Analysis of gas output with different substrates has shown that the largest amount of biogas evolves in the course of anaerobic degradation of pig manure, while the smallest was generated by anaerobic degradation of hen manure. Throughout the experiment, biogas output from sewage sludge amounted to 0.0782 m^3, that from hen manure reached 0.1066 m^3 and from pig manure totalled 0.1150 m^3.

In the course of pig and hen manure biodegradation, the amount of biogas stabilized from day 28 to day 30 of the experiment and was further decreasing insignificantly. In the course of

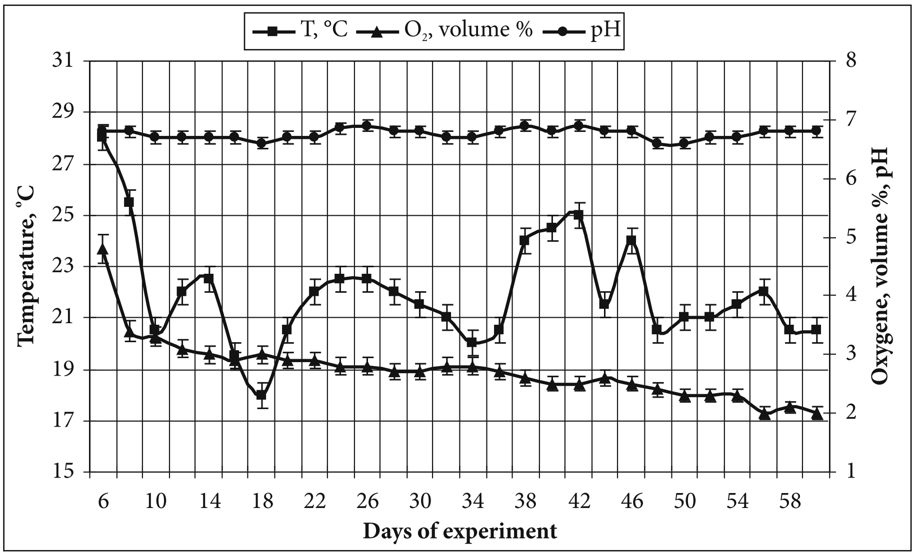

Fig. 5. Temperature, volume part of oxygen and pH in anaerobic biodegradation of hen manure

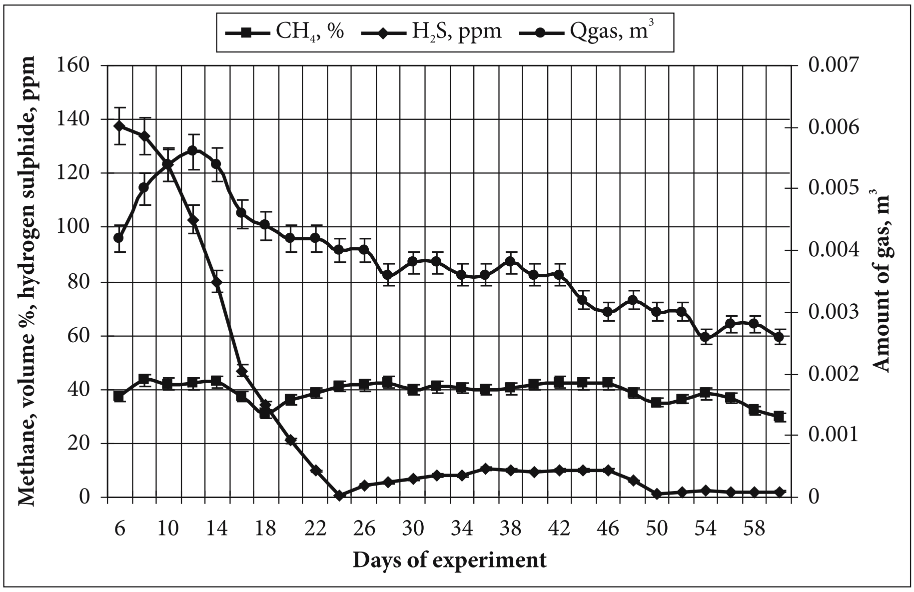

Fig. 6. Amounts of methane, hydrogen sulphide and gas in anaerobic biodegradation of hen manure

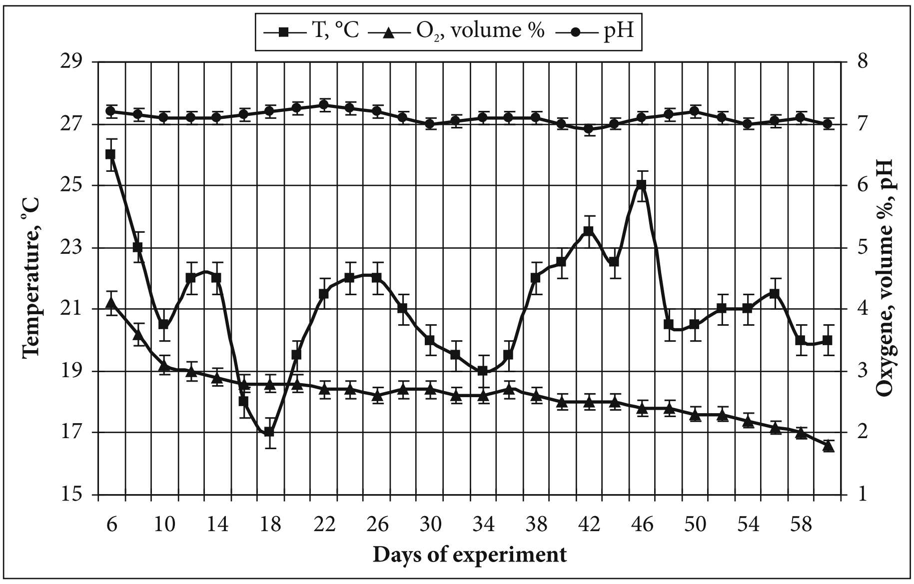

Fig. 7. Temperature, volume part of oxygen and pH in anaerobic biodegradation of pig manure

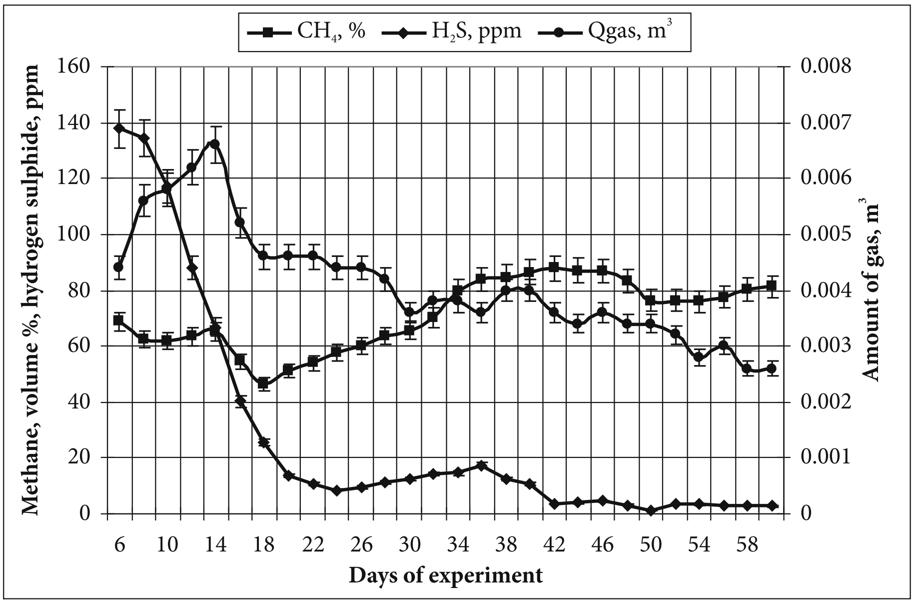

Fig. 8. Amounts of methane, hydrogen sulphide and gas in anaerobic biodegradation of pig manure

sewage sludge biodegradation, the amount of gas evolved after days 34–36 had noticeably declined and was almost stable, the increase being insignificant.

However, important is not only the amount of evolved gas, but also methane concentration in it. Therefore, the net amount of biogas obtained with respect to the total amount of gas evolved and the methane concentration in it is presented.

The largest amount of biogas was produced by the biodegradation of pig manure. The average biogas amount was 0.0028 m^3 from 0.2 m^3 of substrate. The degradation of sewage sludge and hen manure averaged, respectively, 0.0017 m^3 and 0.0015 m^3 of biogas from 0.2 m^3 of substrate.

Comparing the average values of biogas output from different substrates and accepting that the largest amount of biogas resulting from pig manure biodegradation is 100%, the respective yield of biogas from sewage sludge is 58.2% and that from hen manure 52.7%.

Analysing the maximum obtained values of biogas output and accepting that the largest amount of biogas resulting from pig manure biodegradation is 100%, the respective yield of biogas from sewage sludge is 77.8% and that from hen manure 54.9%.

In psychrophilic ambience, keeping substrates in bioreactors for a long time did not prove useful. After keeping substrates under anaerobic conditions in bioreactors for approximately 18 days, the amount of biogas increased very insignificantly, except for biogas evolved as a result of anaerobic biodegradation of pig manure. In that case, the net amount of biogas was growing from day 18 to day 40 of the experiment. This increase was a result of a significant rise in methane concentration in the gas.

Evaluation of just the first 20 days of the experiment indicates that in the course of anaerobic biodegradation of sewage sludge 0.019 m^3 of biogas evolved, accounting for 41% of the total amount of biogas evolved during the experiment. The respective figure for the biodegradation of hen manure was 0.015 m^3 (36.5%) and that for pig manure totalled 0.026 m^3 (32.2%).

Comparing the average values of biogas output from different substrates over 20 days of the experiment and accepting that the largest amount of biogas resulting from pig manure biodegradation constitutes 100%, the respective yield of biogas from sewage sludge was 74.2% and from hen manure 59.7%.

Analysing the maximum values of biogas output over 20 days of the experiment and accepting that the largest amount of biogas resulting from pig manure biodegradation constitutes 100%, the respective yield of biogas from sewage sludge was 77.8% and from hen manure 54.9%.

Graphic results are presented after evaluating confidence intervals. The confidence interval includes gas analyser GD/MTG–7 measuring error (±5% for methane, oxygen, hydrogen sulphide), thermometer measuring error (±1 °C), pH meter error (±0.1) and gas meter measuring error (±7%).

CONCLUSIONS

1. Throughout the experiment, biogas output from sewage sludge totalled 0.0782 m^3, from hen manure 0.1066 m^3 and from pig manure 0.1150 m^3 from 0.2 m^3 of substrate.

2. The largest net amount of biogas (gas amount with regard to the amount of methane therein) evolved in the course of anaerobic biodegradation of pig manure. The average amount of biogas was 0.0028 m^3 per day. The evolution of gas from sewage sludge was 58.2% and from hen manure 52.7% as compared with pig manure.

3. The average amount of the evolved undesirable component, hydrogen sulphide, throughout the experimental period was the largest for the biodegradation of hen manure (28.6 ppm), while the respective figures for the biodegradation of pig manure and sewage sludge were 27.7 ppm and 10.4 ppm.

4. For the larger part of the experiment (until day 46), the amount of methane in the gas evolved in the course of biodegradation of the substrates was growing. In the course of biodegradation of sewage sludge, the amount of methane in the gas initially was 54% and then reached 71.5%, while in the course of biodegradation of hen and pig manure it was, respectively, 37.5% and 68.7% at the beginning and 42.2% and 86.9% on day 46 of the experiment.

5. The content of oxygen in the gas showed a decreasing tendency. Only when the temperature dropped (1–1.5 °C), a slight increase in oxygen content was observed in the bioreactors: 4% for biodegradation of sewage sludge and 3% for biodegradation of hen and pig manure.

6. The main factor in the changes of the pH indicator was temperature fluctuations in the bioreactors. As the temperature grows, the microorganism activity intensifies, therefore fatty acids formed during fermentation are used by methanogenic bacteria for biogas production and the acidity is neutralized. With an average rise in temperature by 2 °C (sewage sludge) the pH rose by 0.4; with a rise in temperature by 4 °C (hen manure) the pH went up by 0.3, and when the temperature rose by 2 °C (pig manure), the pH edged up by 0.2.

7. The findings confirm the theoretical knowledge that the optimum period of keeping a substrate in the bioreactor under the psychrophilic temperature regime is about 20 days.

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ANAEROBINĖ ORGANINIŲ ATLIEKŲ UTILIZACIJA IR BIODUJŲ IŠGAVIMAS

S a n t r a u k a

Analizuojami ir pateikiami biodujų kiekybiniai ir kokybiniai tyrimų rezultatai. Biodujos buvo išgaunamos anaerobiškai biodegraduojant skirtingiems substratams: nuotekų valymo dumbliui, vištų mėšlui ir kiaulių mėšlui. Kiekvieno substrato buvo po 200 l, o tai sudarė 20% sausos masės. Vieną kartą per parą matuojama substrato temperatūra, pH, biodujų kiekis ir metano, sieros vandenilio bei deguonies kiekis jose. Biodujų išeiga iš nuotekų dumblo per visą eksperimento laikotarpį siekė 0,0782 m^3, vištų mėšlo – 0,1066 m^3 ir kiaulių mėšlo – 0,1150 m^3 iš 0,2 m^3 substrato. Iš šių kompleksinių tyrimų matyti, kad geriausi biodujų išeigos rezultatai gauti biologiškai skaidant kiaulių mėšlą, o kiek mažesni anaerobiškai skaidant vištų mėšlą bei nuotekų valymo dumblą. Daugiausia grynųjų biodujų (dujų kiekis įvertinus metano kiekį jose) išsiskyrė anaerobiškai biodegraduojant kiaulių mėšlui – 0,0028 m^3 per parą. Biodujų iš nuotekų dumblo išsiskyrė 58,2%, iš vištų mėšlo – 52,7%, lyginant su kiaulių mėšlu.

Raktažodžiai: organinės atliekos, anaerobinis procesas, biodujos