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Construction of Device for Laboratory Production of Biogas

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Preliminary note

The aim of the paper is building of the mini digester for biogas production from energy plants. The basic structure is of welded construction from stainless steel. The mini digester consists of twelve units so that four tests simultaneously with three repetitions can be performed. Each unit consists of an eudiometer, fermenter containing the substrate and a levelling bottle for surplus closing liquid. Other components ensuring correct functioning of the mini digester are the pump and heater with thermostat, the thermometer, barometer, eudiometer clamps. Finally, some measurements with energy plants according DIN 38414 were made.

Konstrukcija laboratorijske opreme za proizvodnju bioplina

Prethodno priopćenje

Osnovna namjera istraživanja bila je izgradnja mini digestora za proizvodnju bioplina od energetskih biljaka. Osnovna struktura digestora zavarena je od nehrđajućeg čelika. Mini digestor sastavljen je od dvanaest jedinica, tako da se ujedno mogu izvoditi četiri pokusa sa tri ponavljanja. Svaka jedinica sastavljena je od eudiometra, fermentora, koji sadrži supstrat i nivojne posude za spremanje suvišne tekućine. Drugi sastavni dijelovi koji omogućavaju pravilno funkcioniranje mini digestora su pumpa sa grijaćem i termostatom, termometar, barometar te stezaljke eudiometra. Na kraju smo izveli mjerenja proizvodnje bioplina od energetskih biljaka po standardu DIN 38414.

1. Introduction

The mini digester serves for the tests of biogas production from energy plants in laboratory. The biogas production from agricultural biomass is of growing importance as it offers considerable environmental benefits and is an additional source of income for farmers. Economic efficiency of anaerobic digestion depends on the investment costs, on the costs for operating the biogas plant and on the optimum methane production. The biogas is a renewable source of energy and reduces CO_2 emissions [1].

Energy production from anaerobic digestion of sewerage sludge has been in use worldwide for over 30 years. Its viability and cost effectiveness depends not only on the biogas quantities produced, the available technology and operation efficiency of the wastewater treatment unit but also on external parameters, such as the cost of locally produced energy and available energy resources. Apart from the economic advantages, biogas recycling has environmental benefits because primary material can be saved, and pollution loads from conventionally produced energy can be minimized [2].

Anaerobic digestion is becoming more and more attractive for the treatment of high strength organic wastes such as swine manure, since it produces renewable energy, methane, and valuable digested residues, liquid fertilizer and soil conditioner [3]. Different organic substances are used as fermentation substrates in agricultural biogas plants. The planning of these plants in particular requires precise knowledge of the achievable methane yields of the existing substrates. For this purpose, generally discontinuous fermentation experiments are carried out in the laboratory in order to determine the maximum biogas yield potential. The standard technique according to DIN 38414, part 8, has been designed for thin substrates [4].

Agricultural residues, including manure and energy crops, represent an important source of biomass that can serve as a substrate in anaerobic digestion, resulting in the production o f renewable energy. Within the EU, these types of biomasses could amount to 1545 million tonnes per year, if 760 tonnes of energy crops were produced each year [5]. Sustainable biogas production from energy crops must not be based on maximum yields from single crops, but on maximum methane yield from sustainable and environmentally friendly crop rotations [6].

Symbols/Oznake

CO_2	- carbon dioxide ugljični dioksid
O_2	- oxygen - kisik
H_2	- hydrogen - vodik
H_2S	- hydrogen sulfide - vodikov sulfid
N_2	- nitrogen - dušik
NH_4	- ammonia - amonijak
CH_4	- methane - metan
NI	- norm litre, l - normirana litra
VS	- volatile solids - organička suha tvar
kg	- kilogram, kg - kilogram
V_0	- norm volume, ml - mormirani volumen
V	- volume of formation of biogas, ml - volumen proizvedenog bioplina
P_1	- air pressure, mbar - zračni pritisak
P_w	- steam pressure of water, mbar - parni tlak vode
T_0	- norm temperature, K - normirana temperatura
P_0	- norm pressure, mbar - normirani tlak
T	- room temperature, ml - sobna temperatura
V_{is}	- volume of formation of biogas from inoculum, ml - volumen proizvdenog bioplina od gnojnice
ΣV_{is}	- sum of formation of biogas from inoculum in experiment, ml - svota proizvedenog bioplina od gnojnice u pokusu
m_{is}	- mass of inoculum used in mixture, g - masa gnojnice upotrijebljena u mješavini
m_M	- mass of inoculum used in check sample, g - masa gnojnice upotrijebljene u kontrolnom uzorku
V_s	- specific bigas production, NI (kg VS)$^{-1}$ - specifična proizvodnja bioplina
ΣV_n	- net gas volume of biogas, ml - neto volumen biplina
m	- mass of our test, g - masa našeg pokusa
W_t	- dry matter of the substrate, % - suha tvar supstrata
W_v	- ignition of the dry solids, % - gubitci organske suhe tvari

Traditionally it is primarily manure that is digested in farm-scale digesters. However, in Germany, where substantial subsidies are provided for electricity produced from biogas which is produced on a farm scale, energy crops are used as co-substrates in more than 90 % of the digesters to increase the gas yield [7].

2. Mini digester for biogas production

The mini digester consists of twelve units and serves to produce the biogas from various energy crops and other organic waste material [8-9]. The basic structure is made of stainless steel (inox) and is 2500 mm long, 1000 mm high and 350 mm wide [10-11, 13]. At the top a shelf is provided on which there are the levelling vessels for surplus confining liquid. At the bottom, a trough 2500 x 200 x 200 mm lined with insulating material is provided to prevent excessive heat losses and to enable the fermenters to be in the dark. Heating pump ensures constant temperature and water circulation. The eudiometers are fixed to a metal beam above the structure. A thermometer and a barometer measuring, through a sensor, the water temperature in the trough and separately the adjacent air temperature are fixed on the left side of the steel structure. The barometer serves for measuring air pressure. Figure 1 shows the entire fermenter (mini digester) for measuring biogas production.

Three tests with three repetitions simultaneously are possible, whereas three units serve for the control (inoculum) [14-15]. During the test the biogas production must be read daily. The volume produced is let out in case of each reading each day at the beginning of test, later on every two or three days, when the gas formation diminishes [16-17].

The mini digester comprises twelve gas cells. Each cell consists of a reaction vessel (500 ml fermenter) and a well closed gas pipe. The gas pipe - eudiometer is of 350 ml size and contains the confining liquid. It is connected to the levelling vessel with solution. The biogas produced in fermenters supplants the confining liquid in the gas pipe into the outside levelling vessel of 750 ml volume. The gas produced is read on the gas pipe. The fermenters are connected with the glass gas pipe and submerged into water with constant temperature 35+/-1 degrees *C* (mesophilic anaerobic digestion).

The biogas produced contains 50 - 75 % of methane, 10 - 40 % of carbon dioxide and other matters (O_2, H_2, H_2S, N_2, NH_4 ...). Oxygen is an indicator of anaerobic fermentation and the level of oxygen must be under 1 %.

Figure 1. Entire fermenter for measuring biogas production

Slika 1. Digestor za proizvodnju bioplina

3. Measurements

Measurements were conducted according to DIN 38 414, part 8. The biogas produced is collected in an equilibrium vessel and the biogas production is monitored every day. The substrates are mixed every day for 10 min. Biogas production is given in norm litre per kg of volatile solids ($Nl\ (kg\cdot VS)^{-1}$), i.e. the volume of biogas production is based on norm conditions: 273 K, and 1013 mbar (DIN38414, 1985). Biogas quality (CH_4, CO_2, O_2) was analysed with gas detector Geotechnical Instruments GA 45 (Figure 2), 10 times in course of the 5-week digestion. Each variant was replicated three times and then the average biogas production was given.

Actively digested pig manure slurry was collected from a biogas plant that digests energy crops (maize, millet), filtered and used as inoculum to prepare substrate/inoculum ratios. Biogas production from inoculum alone was measured as well and subtracted from the biogas production that was measured in the digesters that contained inoculum and biomass (Figure 3).

Figure 2. Gas detector Geotechnical Instruments GA 45

Slika 2. Analizator plinova Geotechnical Instruments GA 45

Figure 3. 500 ml fermenter with inoculum and biomass

Slika 3. 500 ml fermentor sa gnojnicom i biomasom

4. Data processing

During the experiment the date, hour, room temperature, room pressure and volume of formation of biogas were measured. Measurements were conducted according to DIN 38 414.

Firstly, it is necessary to lead out the norm volume of produced biogas (V_0) due to the equation:

$$V_0 = V \cdot \frac{(P_1 - P_w)\cdot T_0}{P_0 \cdot T}. \tag{1}$$

For each experiment with substrate and inoculum the test protocol was made. Also the norm volume from inoculum was measured and the quota of produced biogas from inoculum was calculated due the equation:

$$V_{\text{is}} = \frac{\sum V_{\text{is}} \cdot m_{\text{is}}}{m_{\text{M}}}. \qquad (2)$$

The mass of inoculum used in mixture was 385 grams, meanwhile the mass of inoculum used in check sample was 400 grams. The sum of norm volume of the experiment minus volume of formation of biogas from inoculum represents the net gas volume of biogas.

The specific biogas production (*VS*) in norm litre per kg of volatile solids (*NI* (*kg·VS*)$^{-1}$) was calculated due the equation:

$$V_{\text{s}} = \frac{\sum V_{\text{n}} \cdot 10^4}{m \cdot W_{\text{t}} \cdot W_{\text{v}}}. \qquad (3)$$

The mass of our test is the mass of used substrate (silage) in the experiment. For each experiment the 15 grams of silage was used.

On the basis of data some graphs were describes.

5. Analysis of results

In Figure 4 the quantities of the produced biogas in comparison with the methane yield are graphically shown. During the tests of various alternative crops it was estimated that the sunflower has the highest energy potential and results in the highest methane production and concentration.

In case of sunflower the methane concentration reached about 62.85 %; it means that out of 451 *Nl*/*kg·VS* the methane quantity was 283 *Nl*/*kg·VS* which was useful for utilization of the fuel. Two universally useful crops are maize and sorghum which are predominant animal feed as mixture or singly. The maize and sorghum are also suitable for the biogas production because they contain much proteins and carbohydrates, which is a high energy potential.

The amount of the biogas produced from sorghum is about 350 *Nl*/*kg·VS*, the methane content concentration is 50 - 60 %, i.e., about 180 - 205 *Nl*/*kg·VS*.

Other alternative crops such as Jerusalem artichoke and amaranth, which also have a high protein supply but cannot compete with predominant crops such as maize, produced considerably less gas and methane. The methane concentration in the amaranth sample was not excessively low, since it amounted to about 50 % on an average.

The biogas and methane yield was in strong contrast with the value of the dry matter and moisture percentage in the sample, since it varied round 180 - 280 *Nl*/*kg·VS* of biogas and 120 *Nl*/*kg·VS* of methane.

The average methane concentration percentages in the substrate, shown in Figure 5, represent the percentages of the methane amount present in the crop, which is of key importance for the biogas yield.

The effects on the methane production in the biogas depend on preparation of the substrate which must not contain undesirable anorganic matters that would hinder the fermentation process.

The key factors for the fermentation process are the pressure in the fermentor and the percentage of moisture in it. In this way the biogas yield and the methane concentration percentage can be considerably larger.

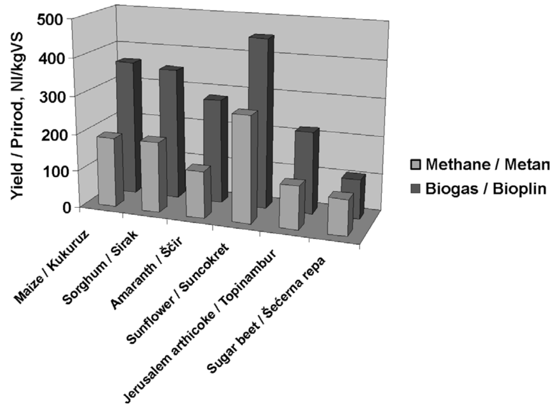

Figure 4. Comparison of results of production between methane and biogas

Slika 4. Usporedba rezultata proizvodnje metana i bioplina

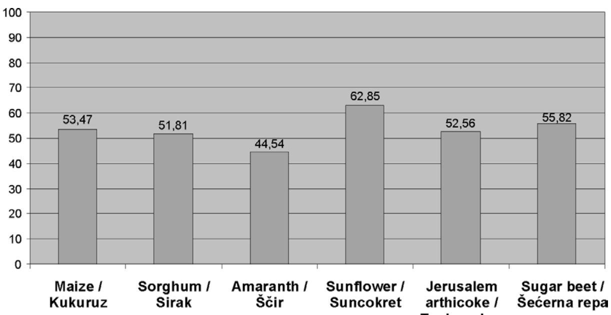

Figure 5. Average methane concentration (%) in substrate

Slika 5. Prosječan sadržaj metana (%) u supstratu

6. Conclusion

Firstly, the digester was built. The digester serves to produce the biogas from various energy plants and other organic waste materials. Measurements were conducted according to DIN 38 414, part 8. Four tests simultaneously with three repetitions can be performed.

Energy plants were anaerobically digested in mesophilic conditions and biogas yields and biogas composition were measured and compared.

Biogas quality (CH_4, CO_2, O_2) was measured by gas detector Geotechnical Instruments GA 45 eleven times during 5 - week digestion. Biogas production from inoculum alone was measured as well.

The paper presents the construction for anaerobic digestion and measuring biogas production with fermenters. Anaerobic digestion is a system that harnesses natural process to treat waste, produce biogas that can be converted to heat and electricity and anaerobic digestate, a soil improving material. The experiment is made according to DIN 38 414, part 8. The quality and amount of biogas production (methane) is observed. The basic structure is made of stainless steel, on which other components are fixed. Some experiments with different energy plants are made.

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