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Mini digester and biogas production from plant biomass

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ABSTRACT

Purpose: The aim of the paper is to present the construction of a mini digester for biogas production from different agriculture plant biomass and other organic wastes. The amount of biogas production (methane) is observed by the mini digester.
Design/methodology/approach: The mini digester consisting of twelve units was built and some measurements with agriculture plant biomass were performed according to DIN 38414 part 8. Four tests simultaneously with three repetitions can be performed.
Findings: With the mini digester the amount of biogas production is observed. The parameters such as biogas production and biogas composition from maize and sugar beet silage in certain ratio were measured and calculated. The highest biogas and methane yield was 493 NI kg VS^{-1} or 289 NI CH_4 kg VS^{-1}.
Research limitations/implications: The scope of substrates for the anaerobic digestion process is on the increase so the interest in the use of the biogas as a source of a renewable energy is very high. With mini digester it is possible to observe the amount of biogas (methane) production and so the most suitable plant giving the maximum methane yield, can be determined.
Practical implications: The aim of biogas as renewable source of energy is to replace fossil fuels with sustainable energy production systems and to fulfil the requirements of the Kyoto Protocol. On big farms the liquid manure and different energy crops can be used for biogas production. That can improve the economical efficiency of the farm and reduce the CO_2 emissions.
Originality/value: Mini digester for biogas production was built as special equipment. The quality of produced biogas is determined with a gas analyser GA 45.
Keywords: Technological devices and equipment; Mini digester; Biogas; Plant biomass

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1. Introduction

Increase in energy demand and the issues about current non-renewable energy sources led researchers to investigate alternative energy sources during the last two decades. Renewable energy sources draw attention all over the world because they are sustainable, improve the environmental quality and provide new job opportunities in rural areas [1].

Economic efficiency of anaerobic digestion depends on the investment costs, on the costs for operating the biogas plant and on the optimum methane production [2,3]. 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. Nearly two-thirds of renewable energy sources in the European Union stem from biomass, including wastes. The principle of a closed circuit is strengthened, because particularly the nitrogen is being hold stronger in the system [4,5].

The most important, methane emissions during manure storage are reduced and the fertiliser quality of the digestate is high. Suitable substrates for the digestion in agricultural biogas plants are different energy crops, organic wastes, and animal manures. Maize (Zea mays L.), herbage (Poacae), clover grass (Trifolium), Sudan grass (Sorghum sudanense), fodder beet (Beta vulgaris) and others may serve as energy crops. The predominant crop for biogas production is maize. Maize is considered to have the highest yield potential of field crops grown in Central Europe [6,7]. Biogas is a product of the metabolism of methane bacteria and is created when the bacteria decompose a mass of organic material. The methane bacteria can only work and reproduce if the substrate is sufficiently bloated with water (at least 50%). In contrast to aerobic bacteria, yeasts and fungi they cannot exist in solid phase.

Coal, natural gas and oil fired energy production plants are major contributors to CO_2 emissions in the atmosphere. The European Union has made a commitment to reduce its emissions by 8% in 2010 compared to 1990. Mitigating the current trend of increasing CO_2 emissions relies on taking measures to reduce final energy consumption, to encourage a more rational use of primary energy sources and to exploit renewable energy sources more intensively. Specific measures have been taken at the European level to encourage the production of electricity from renewable sources (‘‘green electricity’’). Several countries have implemented a ‘‘green certificates’’ market in order to support this production. In such a market, green certificates are issued by a regulating authority to the green electricity producers. The producers can then sell them to electricity distributors. As the latter need to acquire green certificates up to a certain percentage of the electricity sold to final customers, and as there are penalties for electricity distributors with insufficient green certificates, supply and demand in the green certificates market determine their price [8,9,10].

Biogas from sewage digesters usually contains from 55% to 65% methane, from 35% to 45% carbon dioxide and <1% nitrogen, biogas from organic waste digesters usually contains from 60% to 70% methane, from 30% to 40% carbon dioxide and <1% nitrogen while in landfills the methane content is usually from 45% to 55%, carbon dioxide from 30% to 40% and nitrogen from 5% to 15% Typically biogas also contains hydrogen sulphide and other sulphur compounds, compounds such as siloxanes and aromatic and halogenated compounds. Although amounts of trace compounds are low compared to methane, they can have environmental impacts such as stratospheric ozone depletion, the greenhouse effect and/or reduce the quality of local air [11, 12].

2. Description of the approach, work methodology, materials for research, assumptions, experiments etc.

2.1. Construction of 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. Three tests with three repetitions simultaneously are possible, whereas three units serve for the control (inoculum). 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 [13,14,15].

The mini digester is used for laboratory tests. It 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. 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%. The exact composition is determined by the gas detector. Figure 1 shows the entire structure (mini digester) for biogas production for laboratory purposes.

Fig. 1. Mini digester for biogas production

The basic structure of the mini digester is 2500 mm long, 1000 mm high and 350 mm wide and is made of stainless steel (inox). 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 is placed beside the eudiometers and ensures constant temperature and water circulation. Thus, as uniform water temperature as possible is reached over the entire trough. The eudiometers are fixed to a metal beam above the structure, so that they can not overturn and that they can be removed and fixed as easily as possible for test purposes. 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 [16,17,18].

The gas composition (CH_4, CO_2 and O_2) is measured by gas detector Geotechnical Instruments GA 45. Figure 2 shows gas detector GA 45.

Fig. 2. Gas detector GA 45

2.2. Maize and sugar beet for anaerobic digestion

Maize and sugar beet was chopped after harvest and then mixed in certain ratios, prior to the ensiling process. Particle size was 2.0–4.0 mm. Whole maize and sugar beet crops in certain ratio were anaerobically digested and biogas yields and biogas quality were measured and compared. Table 1 shows three experiments with maize and sugar beet mixed in different ratios and their dry matter. Substrates were analysed prior to digestion for dry matter (DM), crude protein (XP), crude fibre (XF), crude fat (XL), ash (XA), gross energy (GE), carbon (C), nitrogen (N) and C/N ratio with standard analysing procedures.

Table 1.
Maize and sugar beet mixed in different ratios

Sample	Sample in certain ratio	Dry matter (%)
1	50% sugar beet + 50% maize	25.1
2	75% sugar beet + 25% maize	21.3
3	25% sugar beet + 75% maize	26.2

2.3. Measuring biogas production

Measurements were conducted according to DIN 38 414, part 8. Mini digester consists of twelve digesters. The biogas produced is collected in an equilibrium vessel and the biogas production is monitored every day. A water bath tempers the digesters. The substrates are mixed every day for 10 min. Biogas production is given in norm litre per kg of volatile solids (NI (kg VS) $^{-1}$), i.e. the volume of biogas production is based on norm conditions: 273 K, and 1013 mbar [19,20,21]. Biogas quality (CH_4, CO_2, O_2) was analysed 10 times in course of the 5- week digestion. Each variant was replicated three times and then the average biogas production was given. 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.

Substance and energy turnover during anaerobic digestion were measured in 0.5 l eudiometer batch digesters at constant temperature 35 +/- 1 degree C. Biogas yields and biogas composition from each treatment were measured in three replicates [22,23].

2.4. Inoculum

Actively digested pig manure slurry was collected from biogas plant that digests energy crops (maize, millet), filtered and used as inoculum to prepare substrate/inoculum ratios. 15 grams of substrate was digested together with 385 grams of inoculum. Biogas production from inoculum was measured as well. Figure 3 shows substrate/inoculum ratio in water bath.

Fig. 3. Substrate/inoculum ratio in water bath

2.5. 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 [19]. Biogas production is given in norm litre per kg of volatile solids (NI (kg VS) $^{-1}$), i.e. the volume of biogas production is based on norm conditions: 273 K, and 1013 mbar, because the temperature and pressure in room was variable.

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

$$Vo = V \cdot \frac{(Pl - Pw) \cdot To}{Po \cdot T} \qquad (1)$$

V_o – norm volume of biogas; in ml
V - volume of formation of biogas; in ml
P_l – air pressure; in mbar
P_w – steam pressure of water in dependence upon room temperature; in mb
T_o – norm temperature; T_o= 273 K
P_o – norm pressure; P_o=1013 mbar
T - room temperature; in K

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:

$$V_{is} = \frac{\sum V_{is} \cdot m_{is}}{m_M} \quad (2)$$

V_{IS} – volume of formation of biogas from inoculum; in ml
ΣV_{IS} – the sum of formation of biogas from inoculum in experiment; in ml
m_{IS} – the mass of inoculum used in mixture; g
m_M – the mass of inoculum used in check sample; in g

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 (V_S) in norm litre per kg of volatile solids (NI (kg VS) $^{-1}$) was calculated due the Equation:

$$Vs = \frac{\sum Vn * 10^4}{m * Wt * Wv} \quad (3)$$

V_s - the specific biogas production (V_S) in norm litre per kg of volatile solids (NI (kg VS) $^{-1}$)
ΣV_n - the net gas volume of biogas; in ml
m - the mass of our test; in g
W_t - dry matter of the substrate; in %
W_v - the ignition of the drfy solids at 550 degree C; in %

The mass of our test is the mass of used substrate (silage) in the experiment. For each experiment the15 grams of silage was used.

On the basis of data some graphs were describes.

3. Description of achieved results of own researches

3.1. Composition of substrates and specific biogas and methane yield

Table 2 gives the nutrient composition of the samples: dry matter (DM), crude protein (XP), crude fibre (XF), crude fat (XL), ash (XA), gross energy (GE), carbon (C), nitrogen (N) and C/N ratio. Biogas and methane yield per norm litre of volatile solids are listed as well. [17] digested maize silage and found methane yield 289 Nl CH_4 VS^{-1}.

3.2. Biogas production

Biogas production was measured during 5 – week digestion. Average biogas and methane yield in norm litre per kg of volatile solids (NI (kg VS) $^{-1}$) with standard deviation from three replicates per treatment during 5 – week digestion is shown in Figure 4.

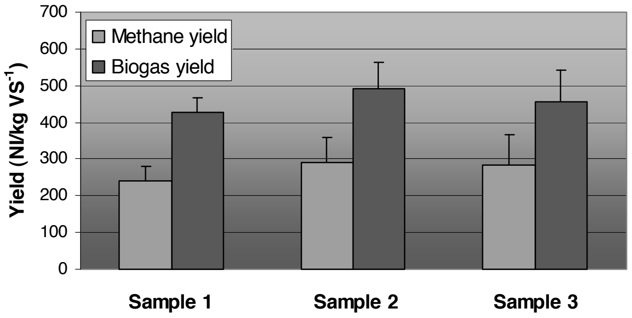

Fig. 4. Average production of methane and biogas in NI/kg VS^{-1} during 5 – week digestion

The lowest biogas yield was in case of sample 1 (50% sugar beet + 50% maize), 428 NI kg VS^{-1} or 242 NI CH_4 kg VS^{-1} (standard deviation of three replicates +38.8 NI biogas VS^{-1}). The highest biogas and methane yield was achieved in case of sample 2 (75% sugar beet + 25% maize). The highest biogas yield was 493 NI kg VS^{-1} or 289 NI CH_4 kg VS^{-1} (standard deviation of three replicates +70.2 NI biogas VS^{-1}). Sample 3 (25% sugar beet + 75% maize) has a biogas production of 455 NI kg VS^{-1} or 282 NI CH_4 kg VS^{-1} (standard deviation of three replicates +85.7 NI biogas VS^{-1}).

Biogas production of sample 1 (50% sugar beet + 50% maize) in norm litre per kg of volatile solids (NI (kg VS)$^{-1}$) during 5-week digestion is shown in Figure 5.

Table 2.
Composition of samples and specific biogas and methane yield

Sample	DM[a]	XP[b]	XF[b]	XL[b]	XA[b]	GE [MJ]	C	N	C/N	Biogas NI[c]	Methane NI[c]
1	251.8	68.7	178.1	87.0	106.2	5.46	48.39	429.4	8.9	428	242
2	213.2	75.3	85.1	81.6	171.4	5.19	49.67	470.6	9.5	493	289
3	262.3	74.3	161.4	79.9	110.2	5.44	49.89	464.4	9.3	455	282

DM = dry matter; XP = crude protein; XF = crude fibre; XL crude fat; XA = crude ash; GE = gross energy; C = carbon; N = nitrogen; C/N = carbon/nitrogen ratio
[a] [g (kg FM)$^{-1}$]
[b] [g (kg DM)$^{-1}$]
[c] Nl = norm litre [(kg VS^{-1})], (273 K, 1.013 bar)

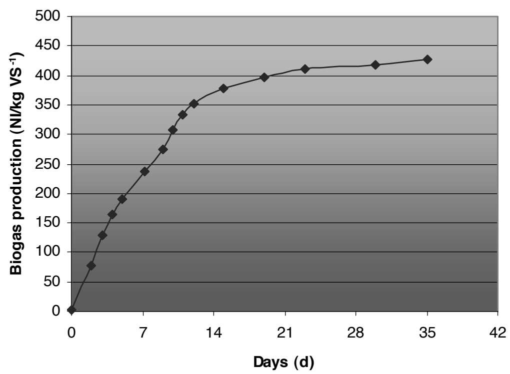

Fig. 5. Biogas production of sample 1 during 5 – week digestion

Most of the biogas is produced in the first week of the experiment, after twenty days the anaerobic digestion is mostly finished. After 35 days the amount of biogas is very low.

Biogas production of sample 2 (75% sugar beet + 25% maize) in norm litre per kg of volatile solids (Nl $(kg\ VS)^{-1}$) during 5-week digestion is shown in Figure 6.

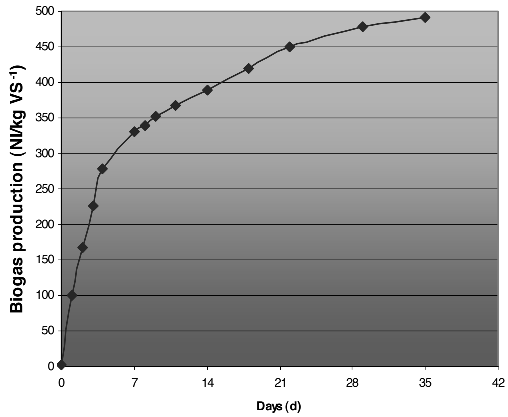

Fig. 6. Biogas production of sample 2 during 5 – week digestion

Biogas production of sample 3 (25% sugar beet + 75% maize) in norm litre per kg of volatile solids (Nl $(kg\ VS)^{-1}$) during 5-week digestion is shown in Figure 7.

3.3. Biogas quality

Biogas quality (CH_4, CO_2 and O_2) was analysed 10 times in course of the 5 - week digestion.

Figure 8 shows the biogas quality of sample 1 (50% sugar beet + 50% maize) where the methane content ranged from 26.5 to 80.5% (mean: 56.4%, n = 30). The average content of CO_2 was 35.5% during 5 – week digestion. The maximal level of CO_2 was on the second day of the experiment, 65%, and then decreases to 19% and stays stable. Oxygen content in the biogas was under 1%. That means that the digestion was anaerobic. The biggest differences in biogas quality occur in the first week of the digestion and then the gas content is more or less stable.

Figure 9 shows the biogas quality of sample 2 (75% sugar beet + 25% maize) where the methane content ranged from 33.5 to 73.8% (mean: 59.1%, n = 30). The average content of CO_2 was 26.6% during 5 – week digestion. The maximal level of CO_2 was on the second day of the experiment, 47.5%, and then decreases to 14.7% and stays stable. Oxygen content in the biogas was under 1%. That means that the digestion was anaerobic. The biggest differences in biogas quality occur in the first week of the digestion and then the gas content is more or less stable.

Figure 10 shows the biogas quality of sample 3 (25% sugar beet + 75% maize) where the methane content ranged from 52.2 to 69.2% (mean: 62.1%, n = 30). The average content of CO_2 was 32.3% during 5 – week digestion. The maximal level of CO_2 was on the second day of the experiment, 46%, and then decreases to 27.2% and stays stable. Oxygen content in the biogas was under 1%. That means that the digestion was anaerobic. After the first week of the digestion the gas content is more or less stable.

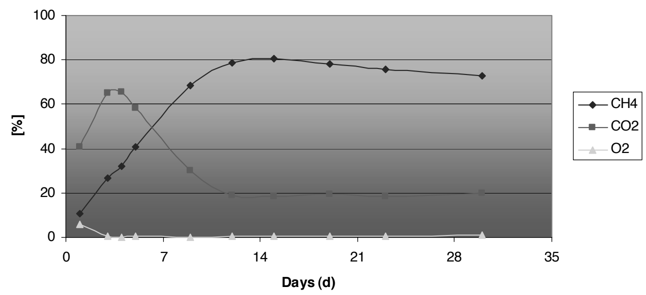

Fig. 8. Biogas quality of sample 1

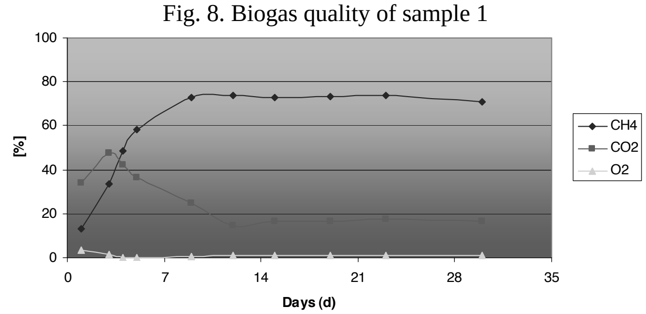

Fig. 9. Biogas quality of sample 2

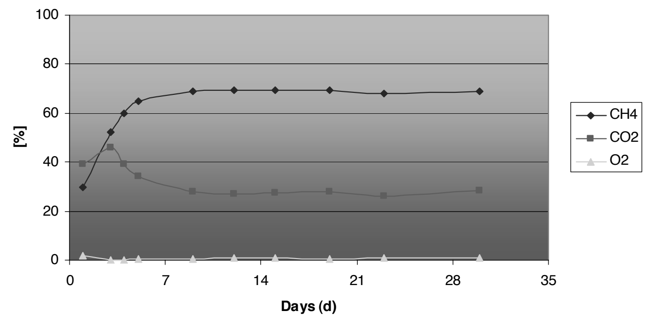

Fig. 10. Biogas quality of sample 3

4. Conclusions

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.

Plant biomass was treated anaerobically for 35 days, in order to generate biogas.

Firstly, the mini digester used for laboratory tests was built. The mini digester serves to produce the biogas from various energy plants and other organic waste materials. Measurements were conducted according to DIN 38 414. Four tests simultaneously with three repetitions can be performed. Whole maize and sugar beet crops in certain ratio were anaerobically digested 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.

The lowest biogas yield was in case of sample 1, 428 NI kg VS^{-1} or 242 NI CH4 kg VS^{-1} (standard deviation of three replicates +38.8 NI biogas VS^{-1}). The highest biogas and methane yield was 493 NI kg VS^{-1} or 289 NI CH4 kg VS^{-1} (standard deviation of three replicates +70.2 NI biogas VS^{-1}) in case of sample 2. Sample 3 has a biogas production of 455 NI kg VS-^{1} or 282 NI CH4 kg VS^{-1} (standard deviation of three replicates +85.7 NI biogas VS^{-1}).

Biogas quality (CH_4, CO_2, O_2) was analysed 10 times in course of the 5- week digestion. Biogas quality was on average 56.4% of CH_4, 35.5% of CO_2, O_2 content in the biogas was under 1% in case of sample 1. In case of sample 2 the biogas quality was on average 59.1% of CH_4, 26.6% of CO_2, O_2 content was under 1%. In case of sample 3 the biogas quality was on average 62.1% of CH_4, 32.3% of CO_2, O_2 content in the biogas was under 1%. Oxygen is an indicator of anaerobic fermentation and the level of oxygen must be under 1%.

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