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INTRODUCTION PILOT BIOGAS REACTORS AND APPLICATION TO DEFINE BIOGAS POTENTIAL OF BASIC SUBSTRAT, SWINE SLURRY

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Introduction pilot biogas reactors and application to define biogas potential of basic substrat, swine slurry

Cooperation between the 'Panvita Group' and the Biotechnical Faculty, University of Ljubljana, resulted in the construction of a pilot biogas reactor – a miniaturised version of the economical biogas reactor. The aim of construction was to support scientific research in the field of biogas generation, while, at the same time, optimising the processes conducted in economical reactors and testing the new substrates in the field of biogas generation. A 2500-litre reactor, containing a 500-litre gasholder, was built to this purpose. In the first operating period, biogas-generation potential of the raw and partially purified swine slurries was tested. The three repetitions allowed us to generate an average of 529 litres CH_4 per 1 kilogram of organic dry matter.

Key words: biogas reactor / pig slurry / biogas / methane / electric energy

Predstavitev pilotnega reaktorja in aplikativna določitev bioplinskega potenciala osnovnega substrata, prašičje gnojevke

Biotehniška fakulteta in Skupina Panvita smo v sodelovanju postavili preizkusni bioplinski reaktor, ki je pomanjšana različica gospodarskega bioplinskega reaktorja. Namen gradnje preizkusnega reaktorja je bil znanstveno raziskovalnem delo na področju pridobivanja bioplina in hkrati optimiziranje procesov v gospodarskih reaktorjih ter preizkušanja novih substratov v proizvodnji bioplina. Zgradili smo 2500 litrski reaktor, od celotnega volumna reaktorja je 500 litrov plinohrama. Kot cilj v prvem obratovalnem obdobju smo ovrednotili bioplinski potencial surove prašičje gnojevke in delno prečiščene prašičje gnojevke. Pravilno ovrednoten osnovni substrat je izhodišče za vse nadaljnje preizkuse, saj je to medij v katerem se bodo vrednotili vsi substrati ali mešanice substratov. S tremi ponovitvami smo dosegli v povprečju 524 litrov CH_4 na kilogram organske suhe snovi (OSS).

Ključne besede: bioplinski reaktor / prašičja gnojevka / bioplin / metan / električna energija

1 INTRODUCTION

The reduction of CO_2 values in the atmosphere is a world goal (UNFCCC, 1997). The EU member states have clear instructions to substitute the current fossil energy with renewable sources up to the value of 12% of the used gross energy by 2010. This means three times increasing the energy production from existent renewable sources in the EU.

In Slovenia there are already some existent biogas stations and some are being built. Biogas plants immensely help reducing greenhouse gas emissions and concurrently contribute a certain amount of renewable energy. The more biogas plants we have the bigger the effects of the test reactors will be, with which we can optimise the performance of biogas plants and test new substrates (Zver, 2005). Above all, the test reactors are intended for fast evaluation of a new organic mixture. This new organic mixture would be used in the actual reactor after the analysis of all the significant parameters for an economical and ecological performance of the reactor. The essential function of the test reactors is to enhance the economy of the real biogas plants.

Biogas is the mixture of gasses, which originate

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***Table 1:** Efficacy of biogas production from swine slurry*
***Preglednica 1:** Izpleni bioplina iz prašičje gnojevke po različnih avtorjih*

	Author	Extent of biogas production (l/kg organic substance)	Average biogas production (l/kg ODM)
Swine slurry	Beck, 1997	340–550	450
Swine slurry	Gaćeša, 1985		550
Swine slurry	Gobec, 2005	200–350	275
Swine slurry	Karpenstein-Machan, 2005	250–350	300

l/kg – litres of biogas per kilogram of organic substance; ODM organic dry matter

from anaerobic fermentation. Anaerobic fermentation is a biological process which is based on methanogenesis, where bacteria decompose organic material. The products of the process are mainly methane and carbon dioxide. The process can be simplified with the reaction: $2C + 2H_2O \rightarrow CH_4 + CO_2$ (Đulbić, 1986).

There are many factors to ensure optimal biogas production. They fall into three categories:

- Physical : imported heat in the reactor, mixing of the organic mixture in the reactor, density, structure of the organic mixture in the reactor, specific yield (1/kg DM)
- Chemical : C:N ratio, pH, content of macro and micro elements, toxins, heavy metals
- Biological: type of microorganisms, their quality and quantity

It is reasonable to search for and to optimise the mixture of different substrates in a test reactor. Thus we can ensure optimal exhaustion of substrates for biogas production and our findings can be applied in the economical devices.

KG Rakičan EKOTEH d.o.o. is a member of the Panvita Group. They already operate a 1.3 MW biogas plant and they are also currently building a new smaller biogas plant. The following substrates are imported in the existent biogas plant:

13t of raw slurry, 8.5 t of by-products of animal origin (BPOAO2 and BPOAO3), 35.6t of maize silage, and 60t of slurry.

The article focuses on the biogas yield produced from swine slurry. Therefore, the results of preceding research will be presented as well. Different authors quote various biogas yields. We could practically say that the span of results is too big and unrealistic. Furthermore, the reason for the span is not given and this is the key factor for future assessment and planning of the device.

2 METHODS

2.1 INTRODUCTION OF THE TEST REACTOR

A pilot reactor was built in the immediate vicinity of the existent biogas plant (Fig. 1). Its purpose is optimising the functioning of economical biogas plants and testing new substrates. The volume of the pilot reactor is 2500 litres, from which the working volume is 2000 litres and the remaining 500 litres is intended for the gasholder. It is a miniature version of the economical biogas reactor. In it we can test substrates processed in the same manner as in the economical biogas reactor.

2.2 COMPONENTS OF THE REACTOR

- <u>The stirring device</u> is placed horizontally and driven by a 500W electro engine.
- <u>The heating appliance</u> is placed inside on the walls of the reactor; it is heated by water from an outer heating source.
- <u>The additional – auxiliary stirring device</u> is adjustable in the spill-over edge, which prevents clogging of the exit; it is driven by a 350W engine.
- <u>The swine slurry pump</u> is driven by an electrical engine and is used to pump the purified slurry into the reactor. It pumps 2 litres of slurry per minute, taking into account the losses in the pipeline. We can set the intervals of the pumping of the slurry and the amount of it.
- <u>The opening for adding additional substrates</u> is a funnel-shaped opening into which, at certain intervals, substrates are added. Due to stirring the opening is being gradually emptied and thus it ensures a continuous filling.
- <u>The biogas flow-metre</u> is a mechanical counter. It notes the biogas flow on the basis of the turns of the spades. In our case the spades are being driven by the biogas.
- <u>The analyser of the biogas quality</u> is portable. It

Figure 1: *Test reactor (on the left: view from the front, on the right: view from the back).*
Slika 1: *Preizkusni reaktor (levo: prednja stran, desno: zadnja stran).*

is used to analyse the biogas quality in certain intervals or when needed. We can measure % CH_4, % CO_2, % O_2, and ppm H_2S.

- The control box with a computer controls all the devices in the reactor except for the analyser of the biogas quality. The software enables the setting of the intervals for the stirring devices and the pump. It also provides a simultaneous register of the data during the intervals.
- Other equipment includes the laboratory with all the necessary equipment and other equipment for storage and handling of substrates.
- Sampling pints. The reactor has six exits with ball-bearing valves, which enable sampling for the analysis. Two of these are 80mm in diameter.
- The window is a glass door. We can observe the occurrence in the reactor from the top.

2.3 WORKING WITH THE REACTOR

The working volume of the reactor (2000 litres) is so big that the processes in it cannot be completely controlled and directed. Processes which are equal to those in the economical reactor are: complete stirring (usually a crust occurs on the substrates with a major proportion of dryness and fibres), emissions of biogas, comparable fluctuation of pH, structures of different microorganisms, etc.

The test reactor gives us more tangible results for a certain substrate in comparison to the results given in certain literatures, which usually contain average results gained in smaller reactor laboratories under optimal conditions. The results are then used directly in the economical reactor. Thus the fluctuation of the economical reactor is optimised. Concurrently, we can analyse the functioning of the test device.

2.4 INITIATION OF THE TEST REACTOR

The pilot reactor was filled with the mixture of bacteria from the anaerobic part of a purification device or an old biogas plant. The temperature was set to 37.5 °C with ±1.5 °C deviation. The stirring was adjusted to the economical devices. The swine slurry was gradually added.

After having established that the test reactor func-

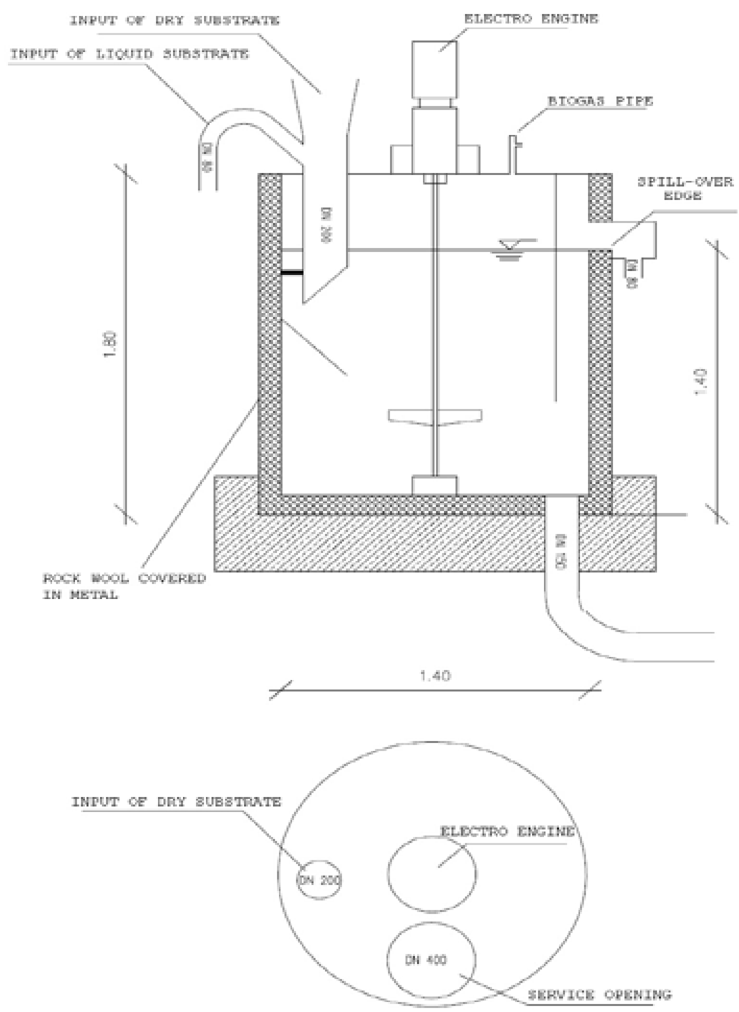

Figure 2: *Sketch of the test reactor (front view and ground plan).*
Slika 2: *Skica preizkusnega reaktorja (naris in tloris).*

tions perfectly, we started with the systematic research of the test reactor.

2.5 CHOOSING THE BASIC SUBSTRATE

During the first weeks of the operation we determined daily fluctuation of biogas production. We started researching the reasons for the unbalanced biogas production. The cause for this was the quality of the raw swine slurry and the changing dryness from 0.5% to 7%. The dryness of the swine slurry depended on the day of the week. During weekends the stables are not washed. During weekdays the stables are being washed, adding the water used for washing to the common reservoir of the slurry. From there the slurry is taken for the use in the experimental reactor. Another occurrence of unbalanced production was detected when the pipe for adding raw swine slurry was clogged by a ball of swine hair. The flow was lower than we expected. However, these are technical problems which can be solved by designing the device correctly. According to the above described technical problems we decided to use partially purified swine slurry with dryness between 1% and 1.5%. Thus we ensured that the input material is homogeneous and avoided technical stirring problems. The swine slurry under consideration has a very specific composition. On average it contains 41% of ash in dry matter.

2.6 EVALUATION OF SWINE SLURRY

The purified swine slurry will in future be the basic medium in the reactor. Thus we needed to assess its en-

***Table 2:** Basic statistics of biogas produced from partially purified swine slurry*
***Preglednica 2:** Osnovna statistika bioplina iz surove in delno prečiščene prašičje gnojevke*

	Biogas production in 10 days					
Substrate	Min.	Max.	Average	Median	Standard deviation	Produced biogas (l)
Slurry 1	70	510	240	200	141	2405
Slurry 2	280	420	379	398	53	3790
Partially purified slurry 3	250	320	284	298	28	2840
Partially purified slurry 4	225	320	267	265	33	2665

ergy potential at a certain residence time. We decided on a 30-day residence time. The purified swine slurry had 41% of ash in dry matter. After months of evaluation we gained the sought data for this swine slurry, biogas yield per kilogram of dry matter, and biogas yield per kilogram of organic dry matter. However, we did not seek for non-degradable organic dry matter.

3 RESULTS AND DISCUSSION

During the first three months of production, we were evaluating biogas potential of the raw swine slurry and partially purified swine slurry. Figure 3 and Table 2 show biogas productions in time periods 1, 2, 3 and 4. In the time periods 1 and 2 we used raw swine slurry. However, due to its physical characteristics it was not suitable to include it in further experiments. The main problem was the unbalanced amount of dry matter. In the time periods 3 and 4 we evaluated partially purified swine slurry. This is shown in Figure 3. Curve 1 shows that raw swine slurry is not suitable as the basic substrate because of dryness volatility. Curve 2 shows operation with raw slurry. However, in this case the slurry was left in a container for the thick part to sediment. We only used the cleaner upper part of the slurry, but the volatility of the dryness was still too high. Thus it is not suitable to be used as the basic substrate.

Table 2 shows data about the biogas yield from slurry tested during certain time periods. The standard deviation with raw slurry is immense. Thus it is not suitable to be used as the basic substrate in further experiments.

3.1 BIOGAS POTENTIAL OF PARTIALLY PURIFIED SWINE SLURRY

Due to technical problems and homogeneity of the basic substrate we decided to use partially purified swine slurry. In Table 3 we see the average biogas yield for a

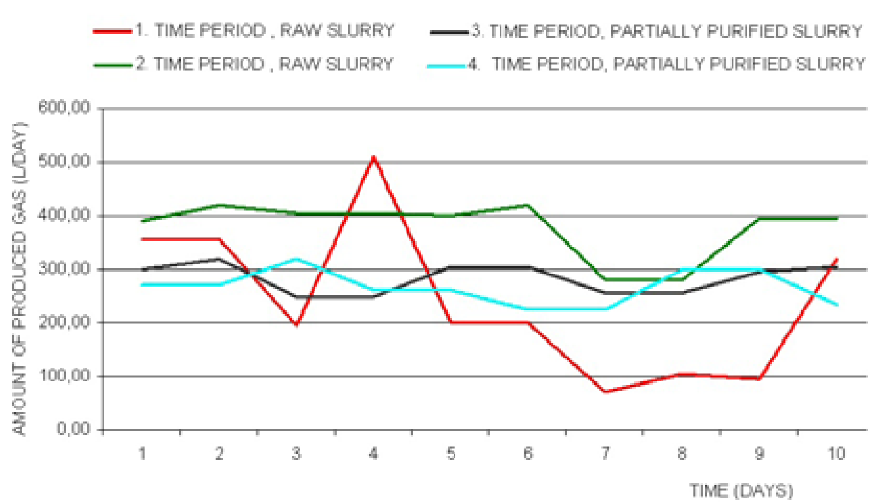

***Figure 3:** Biogas production per day during the evaluation of biogas potential of raw swine slurry (1 and 2) and partially purified swine slurry (3 and 4).*
***Slika 3:** Produkcija bioplina po dnevih pri vrednotenju bioplinskega potenciala surove gnojevke (1 in 2) in delno prečiščene prašičje gnojevke (3 in 4).*

Table 3: *Chemical characteristics of partially purified swine slurry and biogas yield*
Preglednica 3: *Kemične lastnosti delno prečiščene prašičje gnojevke in izplen bioplina*

	Substrate
	Partially purified swine slurry
% DM	1.0–1.5
% CA* in DM	44
C : N	36
Biogas / litre of slurry (l)	5.29
Biogas / kg DM (l)	423
Biogas / kg ODM (l)	756
CH_4 / litre of slurry (l)	3.71
CH_4 / kg DM (l)	296
CH_4 / kg ODM (l)	529

*CA = crude ashes, BG; We gained comparable results with previous researchers on the test biogas reactor.

20-day period. We used a total of 1040 litres of slurry and produced 5505 litres of biogas or 3854 litres of methane. We reached the average biogas yield of 275 litres per day, or 756 litres of biogas per kilogram of organic dry matter, or 423 litres per dry matter. The average biogas composition is: CH_4 70%, CO_2 30%, O_2 0% in 1500 ppm H_2S.

4 CONCLUSION

We evaluated the biogas potential of specific swine slurry. Partially purified swine slurry has specific characteristics in comparison with other slurries mentioned by other authors. It was reasonable to use partially purified slurry. It gave us valuable information concerning its biogas potential.

In future, partially purified swine slurry will be used as the basic medium for testing and determining the biogas potential of different substrates. One of the examples is the mixture of partially purified slurry and silage. From the gross produced biogas, gained from this mixture, we mathematically subtract the produce of partially purified swine slurry. Thus we gain the net biogas yield from certain substrate. Partially purified slurry will also hold the function of a means of transportation into the biogas reactor for different substrates. Thus, with the help of the fluid partially purified slurry, for which the energy potential is already known, we can import into the reactor organic material with bigger content of dry matter. This enables us to define the common or partial energy potential, or we can anticipate the energy utility of a certain organic material.

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