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TESTING WASTE MATERIALS AS STAND-ALONE BIOGAS SUBSTRATES: METHANE YIELD OF DAIRY BY-PRODUCTS AND KITCHEN WASTE IN LABORATORY CONDITIONS

ABSTRACT

Numerous types of biomass can be utilized as substrates for biogas generation: energy crops, agricultural by-products, wastewater sludge, organic industrial waste or municipal solid waste. One of the most valuable substrate ingredients is animal slurry. Kitchen waste and dairy by-products were tested as sole biogas substrates with municipal wastewater sludge as inoculant. Experiments were carried out under mezophilic conditions, using WTW Oxitop measurement system, comprising of a glass fermenter of 1 liter volume and a piezoelectric measuring head. Anaerobic digestion results in biogas production, therefore the sealed fermenter experiences a pressure change inside, which can be measured relative to atmospheric pressure with a differential pressure sensor. Carbon dioxide was absorbed by sodium hydroxide and biomethane kinetics curves were derived from extracting the relative pressure change results with NaOH from the original pressure change results without NaOH. The total solid (TS) and the organic content (TOS) were determined. The inoculum were taken from biogas fermentor working with sewage sludge, output from plant. The changes of the pressure were registered with Oxitop measurehead. The biogas were calculated as were written by Pentulla, A. [15]

INTRODUCTION AND AIM

Although growing energy demand due to overpopulation seems to be one of the unresolved challenges of our century, renewable energy sources still face various obstacles like the lack of environmental awareness and available support and subsidy system. Furthermore, fossil fuels still count as a relatively low-cost energy source. [1] Instead of depletable fossil fuels, sustainable, green approaches need to be embraced to prevent the harmful environmental, ecological and health consequences of using fossil fuels.

Biogas generation qualifies as a renewable energy source, especially when produced from different types of waste and other by-products. [2] Utilizing these materials as biogas substrates has several different benefits. On one hand, we can transform useless products into a valuable energy carrier. [3] Biogas typically consists of 50-70% of combustible methane, 28-48% of carbon dioxide and 1-2% of other gases. Therefore, the total combustible volume can be approximately 50-70%. If carbon dioxide is removed from biogas, this ratio can reach even 100%. [4] The average energy content of biogas is 21-25 MJ/m^3. [5]

Biogas management is not only a renewable method of energy production, it also prevents methane, a potent greenhouse gas produced during the decomposition of organic materials from entering the atmosphere by its energetic utilization. [6] Biomethane can be used the same way fossil natural gas is used. [3]

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Hungary possesses a significant biogas production potential. It is expected to reach 47.1% of the annual natural gas consumption of the country. [7] The agricultural sector holds a fair share of the biogas production potential, up to 30-77 PJ/year. Agricultural byproducts attribute to 8-14 PJ/year of the total calculated energy volume. [8]

Literature review

Numerous types of biomass can be utilized as substrates for biogas generation: energy crops, agricultural by-products, wastewater sludge, organic industrial waste or municipal solid waste. One of the most valuable substrate ingredients is animal slurry. Despite its relatively low gas production potential (30-70 m^3/t), the methane content of the resulting biogas can reach 60-70%, making it a valuable substrate. Plant-based products (e.g. sugar beet, maize biomass) produce a higher gas yield (170-200 m3/t), however the methane content only reaches about 55%. High gas production (250-300 m3/t) can be achieved from spelt coming from the food industry and from fatty by-products of slaughterhouses. The methane content of the biogas produced from these substrates is remarkable (up to 75%). [9] In general, raw materials with high sugar, starch and/or fat content can be considered adequate substrates for biogas production. Protein as a raw material is not a particularly valuable substrate.

In Hungary, biogas production is mainly based on energy crops (like silage maize or grasses) and food waste. 78% of the biogas potential of the country is attributed to the former two sources of substrates. The remaining 22% is derived from communal waste, sewage sludge, animal manure and other waste materials. [10]

In the future, a considerable increase in the number of biogas producing plants is expected. Anaerobic digestion and biogas production have proven to be promising alternative methods for waste management. [11]

Biogas production methods can be categorized according to the dry matter content of the input raw material. Wet, dry and semi-dry processes are distinguished. [9] The input raw material of the semi-dry process has a dry matter content of 20-30%, while the water content of the biomass used in wet digestion can reach 92-93%.

During biogas production, acidifying and methanogenic bacteria participate in the decomposition of organic matter. The process has 4 distinctive biochemical phases: hydrolysis, acid formation, acetic acid formation and methane formation.

The efficiency of biogas production depends on several aspects, including dry matter content, organic matter content, C/N ratio, NH_4-N and the presence of certain trace elements [12].

Microorganisms play an essential role as catalysts in biogas formation. The significance of these microbes has been studied extensively. During hydrolysis, the acetogenic period and the methanogenic phase, biogas formation is realized as a result of the joint operation of a consortium of 80 decisive species. Different kinetics can be observed during digestion depending on the composition of biogas substrates. Some microbes, like hydrogen-producing microorganisms have a crucial function in degradation. Adding these hydrogen-producing micro-organisms to the original microflora results in a higher methane yield. [3]

Aside from primary and secondary substrates that can be applied in biogas plants, the energetic exploitation of different waste and by-products is gaining importance.

Previously, in cooperation with the Waste Management Center of Pécs-Kökény, we examined the biodegradation and biogas formation potential of fractions with high organic matter content derived from the mechanical waste treatment of communal municipal waste [13]. Results showed that biodegradation started on its own, with the presence of only the microflora of the high organic matter fraction of waste, however, in laboratory experiments

with municipal sludge as inoculant, the degradation of the cellulosic components and the start of biogas production was observed significantly earlier.
Besides kitchen waste, the anaerobic digestion of two types of wastewater from the dairy industry were also examined in laboratory conditions. One of dairy byproducts contained a noteworthy amount of whey and the other one was rich in milk fat. Whey consists of lactose (4.5-5%), proteins, lipids and mineral salts. The lactose content of whey is easily digestible for acetogenic microorganisms, resulting in an acidic environment in fermenters that reduces biogas productivity and methane yield. Whey has high biological and chemical oxygen demand; therefore, it poses a significant environmental risk. Attempts have already been taken to find an alternative waste treatment solution for wastewater containing whey.[14]

MATERIALS AND METHODS

The basis for all the calculations in the thesis is the ideal gas law [15]:

Ideal Gas Law:

$$n = p \times V / R \times T \qquad \textbf{1}$$

n = number of moles of gases formed (mol)
p = gas pressure in Pascal (N/m^2)
V = gas volume (m^3)
R = gas constant (8,314 J/(mol*K))
T = incubation temperature (K)

Carbon (methane) content of the gaseous phase can be calculated with the following formula [15]:

$$n = ((p \times Vg)/(R \times T)) * 10^{-4} \qquad \textbf{2}$$

n = number of moles of gas formed, CH_4 (mol)
Dp = the difference of the gas pressure in the sample bottle at the end of the experiment (plateau)
minus the pressure in the beginning of the experiment minus the difference of the blank values
(hPa)
Vg = gas volume of the headspace (ml)
10^{-4} = conversion factor Pa in hPa and m^3 into ml

RESULTS AND DISCUSSION

We used the results of the following tables (Table 1-3) to calculate the biomethane potential of the examined subtrates. Table 4 contains the calculated biomethane potential.

Table 1

Dry matter content of all substrates

Sample			Dry matter content (g/kg)			
Notation	Content	Date	1.	2.	3.	Mean
P1	Milk fat	2018.09.13	32,51	40,62	45,75	39,63
P2	Milk whey	2018.09.13	34,51	36,78	35,36	35,55
Inoculum	Inoculum	2018.09.13	23,71	29,01	31,72	28,15
K.W.	Kitchen waste	2018.10.11	45,31	46,42	46,12	45,95

Table 2

Organic content of the whole sample

Sample			Organic content of the whole sample (g/kg)			
Notation	Content	Date	1.	2.	3.	Mean
P1	Milk fat	2018.09.13	18,85	22,72	25,39	22,32
P2	Milk whey	2018.09.13	29,47	32,33	31,36	31,05
Inoculum	Inoculum	2018.09.13	19,89	17,31	18,87	18,69
K.W.	Kitchen waste	2018.10.11	35,51	36,27	36,64	36,14

Table 3

Organic matter content of the dry content

Sample			Organic matter content of the dry content (g/kg)			
Notation	Content	Date	1.	2.	3.	Mean
P1	Milk fat	2018.09.13	568,27	559,36	554,96	560,86
P2	Milk whey	2018.09.13	867,73	878,83	886,88	877,81
Inoculum	Inoculum	2018.09.13	838,94	596,92	594,79	676,88
K.W.	Kitchen waste	2018.10.11	783,59	781,28	794,45	786,44

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Table 4

Biomethan recovery in lab experiments

Measurement number	Ratio of the substrate	Duration of the measurement	(hPA)	Amount of gas (mol)	dm^3/kg TOS
18101201	100 ml KW + 100 ml inoculum	3 day			
18101203	100 ml KW + 100 ml inoculum	3 day	247	0,0096	
18101204	100 ml KW + 100 ml inoculum	3 day			12
91801	100 ml P2 + 100 ml inoculum	3 day	98	0,0038	
91802	100 ml P2 + 100 ml inoculum	3 day			5
91803	100 ml P1 + 100 ml inoculum	3 day			
91804	100 ml P1 + 100 ml inoculum	3 day	37	0,0014	
92501	100 ml P1 + 100 ml inoculum	3 day			2

CONCLUSION

Actual biomethane yield in laboratory experiment were 12 dm^3/ kg TOS in the case of kitchen wastes, 5,0 dm^3/kg TOS is the case of milk fat substrate and 2,0 dm^3/ kg TOS in milk whey substrate. The kitchen waste were the best substrate for cofermentation with sewage sludge. Because of the high organic content and C/N ratio, will be the ideal substrate for biogas plant.

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