Predicting Preferable Substrate Blends for the Production of Biogas

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Abstract: – Laboratory equipment AMTS-II was used for anaerobic testing of the methane generating potential of different organic matter: raw sewage sludge from wastewater treatment plant, glycerol from biodiesel production, fish farming residues and their blends. Twenty days were sufficient to indicate proper substrate compositions. The tests performed in this study enable to avoid useless and time consuming stationary experiments and to select promising options. The results of the tests indicate, that the methane generation potentials for the studied matter were the following: 140…230 m^3/Mg (Mg – mega gram, ton) for raw sludge, 300…310 m^3/Mg for glycerol and 260 m^3/Mg for fish residues.

Key-Words: **-** Anaerobic testing, raw sewage sludge, glycerol, fish farming residue

1 Introduction

Nowadays the possibilities for biogas production as an alternative energy source are becoming more important [1], and from a practical viewpoint determining the capabilities of different organic materials to produce biogas are vital. Research in this area is quite time-consuming and frequently the research environment is not adequate for the expected outcomes. Therefore, the preliminary testing of different compositions in various organic components to determine more appropriate variants are time saving for the whole investigative process. For this purpose, the AMPTS –II (Automatic Methane Potential Test System) device is ideal. The device has 15 testing units and up to 400 ml or grams of degradable material (liquid or pulps) can be hermetically placed into each unit. The units can be thermostatically managed from 5 to 90 ^oC, with temperatures of 35–55 ^oC are ideal for the anaerobic tests. The device is equipped with a mixer, stirring the solution at programmed mixing intervals. Carbon dioxide is eliminated from the evolved biogas by alkaline solution and the quantity of pure methane is determined by the device itself.

2 Problem Formulations and Methods

In our practice, the following suspensions or pulps were used: a) pure inoculum, b) mixtures of inoculum and raw wastewater sewage sludge, c) blend of inoculum and glycerol from biodiesel production, d) blends of inoculum sewage sludge and glycerol, e) mixtures of inoculum and fish residues, f) mixtures of inoculum, raw sewage sludge and fish residues. The targets of the experiments are presented in the table 1. Among these variants, inoculum has three parallel units and other variants have 2 parallels. The data presented in tables 2–7 represent the averages of the parallels.

The inoculum was the sewage sludge received from Tallinn wastewater treatment plant, where it was anaerobically treated in mesophilic conditions (35–38 ^oC) over the course of 20 days. This sludge or inoculum was used in the tests processes at temperatures of 38 or 55 ^oC. It was possible to

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anaerobically treat the inoculum in a laboratory at a temperature of 55 ^{o}C over the course of 15 days. This was regarded as an adaptation for the thermophilic test conditions and was used once (see set no. 1). In other cases, the use of inoculum was direct, which meant that if the test temperature was 55 ^{o}C then the inoculum adaptation was absent. When the test temperature was 38 ^{o}C, the direct use of inoculum was regarded as an adapted process.

The raw sewage sludge was also received from Tallinn wastewater treatment plant. It was mixture of the preliminary sediment and the excess activated sludge, and the mixture was intended for treatment by mesophilic anaerobic process in the plant.

Glycerol was obtained from biodiesel production in Paldiski.

Fish residues were received from fish farming tanks in Saaremaa. These were sediments that were formed by fish excrements and settled fish fodder.

Table 1, Components under investigation: Inoculum (IN), Glycerol (GL), Sewage sludge (SS), Fish farming residue (F) and their blends

Tests set	Temperature in ^{o}C		Variants of the pulps
	In process	Inoculum prepared	
1	55	55	IN, GL, SS, IN+GL, IN+SS, IN+GL+SS
2	55	38	IN, GL, SS, IN+GL, IN+SS, IN+GL+SS
3	38	38	IN, GL, SS, IN+GL, IN+SS, IN+GL+SS
4	38	38	IN, IN+F, IN+SS+F

The serving of the test equipment took place every day and the capacity of the created methane was recorded. According to these data, the graphical presentation of the rate of methane production was possible, and process efficiency and its stabilisation became visible. It became evident that different degradable compositions behave differently and the duration of methane production is not equal. The tracking of tests lasted up to 42 days. At that time, gas production was finished everywhere and it became apparent that optimal time for some cases was shorter. We can see from figures 1–6, that the observing time of 20 days is sufficient, and longer monitoring periods are not necessary in future. This evidence is numerically outlined in table 2.

Table 2, Average percentage ratio of methane (CH_4) production in time vs ultimate production

Tests sets	Duration of CH_4 generation	
	10 days	20 days
1	88.83	97.13
2	77.94	96.80
3	90.67	96.16
4	92.93	99.82

3 Problem Solution

3.1 Set no.1

These tests were carried out at a temperature of 55 ^{o}C and inoculum adaptation [2] was realised at the same temperature. The objective of the investigation was to examine glycerol and its blends with sewage sludge. A summary of the test and results are presented in table 3. The highest calculated yield of methane per total dry solids gives glycerol. This is followed by mixtures of glycerol and sewage sludge. It is known that glycerol in high concentrations inhibits anaerobic degradation [3, 4]. Therefore, a detailed investigation is needed to explain the proper concentrations and the relationships between sewage sludge and glycerol. When there is a lack of sewage sludge, the addition of glycerol can not only compensate but also even increase methane generation [5, 6].

The graph curves in Fig. 1 show that the methane production period is different for each component. However, after 20 days it is practically finished and the following generation of methane in some variants is negligible.

The lowest methane production has inoculum because it has previously been through an active anaerobic degradation process and has lost most of its degradable matter. The highest methane production of the pulps show sewage sludge but its dry matter concentration is 2.4–2.5 times higher than adequate concentrations of glycerol-sewage sludge mixtures.

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3.2 Set no. 2

The process is similar to the above described procedures except that inoculum adaptation for 55 ^{o}C was not used. A summary of the test is presented in table 4. The table shows that the same principal trends or inferences revealed in table 3 are valid here, but the numerical values of methane production per dry solids have a tendency to decline. Obviously, this is caused by the difference in temperature between inoculum preparation and the process undertaken. The inoculum formed in mesophilic conditions and it must work in thermophilic conditions. The picture of graph curves in Fig. 4 is very uneven with single peaks. The cause is obviously the same; mesophilic microflora has to be rearranged to thermophile conditions. Nevertheless, the process was stabilised and practically finished after 20 days.

3.3 Set no. 3

The structure of the tests set is the same as the two previous sets and the only difference is in temperature management. The data are presented in table 5.

The table shows the result when the process and inoculum preparation took place in mesophilic (38 ^{o}C) conditions. Largely, the trends and inferences are similar to the two previous test sets. The difference is that the numerical values of the results are mainly placed between them. They are less from the first batch because the process temperature was lower and they are higher from the second batch because the temperature conflict was absent in this. Graphs curves are not presented, as they did not have notable differences.

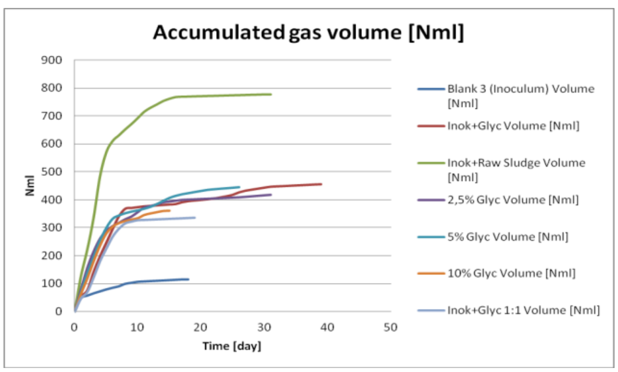

Fig.1, Cumulative methane generation (test set 1)

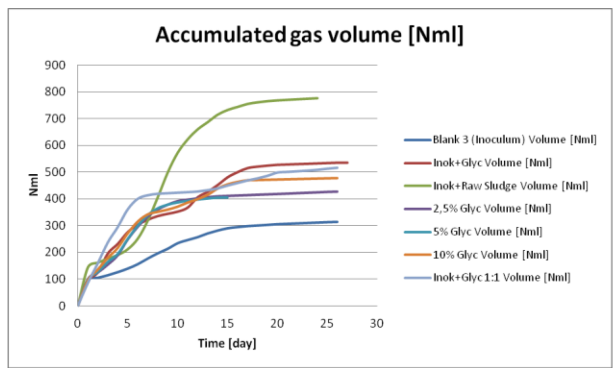

Fig. 3, Cumulative methane generation (test set 2)

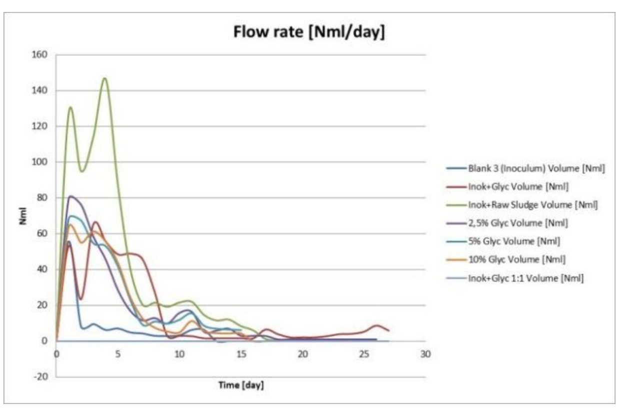

Fig.2, Daily methane generation intensity (test set 1)

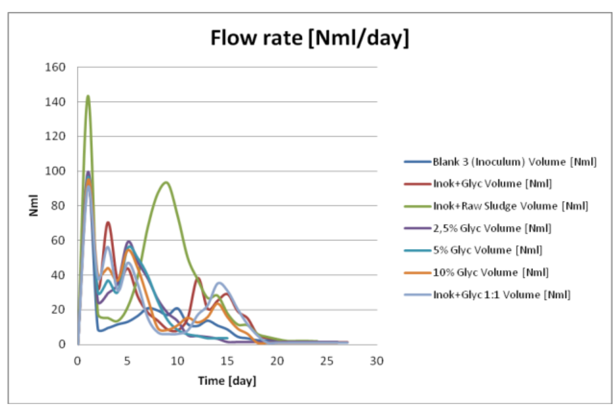

Fig. 4, Daily methane generation intensity (test set 2)

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Table 3, Characteristics and outcomes from tests set no. 1 (process and IN preparing by 55 °C)

Tests	Dry components in pulps kg/m^3					Production of methane			
	Inoculum	Glycerol	Sewage sludge	Total solids (TS)	Volatile solids (VS)	For pulps m^3/m^3		Per dry solids m^3/Mg	
						Blend	Substrate	Blend	Substrate
IN	22.50			22.50	12.05	0.273		12.13	
IN+GL	22.40	2.64		25.10	14.43	1.101	0.829	43.86	314.30
IN+RL	18.84		6.92	25.80	15.14	1.851	1.622	71.70	234.40
IN+GL+SS	21.48	1.02	1.89	24.40	13.81	0.972	0.711	39.82	232.50
IN+GL+SS	21.38	1.48	1.34	24.60	13.98	1.052	0.788	42.76	279.60
IN+GL+SS	22.02	1.92	0.82	24.80	14.15	0.979	0.712	39.50	259.50

Table 4, Characteristics and outcomes from tests set no. 2 (process 55 and IN preparing by 38 °C)

Tests	Dry components in pulps kg/m^3					Production of methane			
	Inoculum	Glycerol	Sewage sludge	Total solids (TS)	Volatile solids (VS)	For pulps m^3/m^3		Per dry solids m^3/Mg	
						Blend	Substrate	Blend	Substrate
IN	23.60			23.60	13.60	0.767		32.50	
IN+GL	23.50	3.02		26.52	16.31	1.311	0.547	49.44	181.050
IN+RL	19.39		9.01	28.40	16.78	1.893	1.270	66.65	140.954
IN+GL+SS	22.38	1.15	2.54	26.07	15.53	1.062	0.342	40.74	92.683
IN+GL+SS	22.73	1.67	1.79	26.19	15.73	0.962	0.227	36.70	65.607
IN+GL+SS	23.03	2.05	1.09	26.17	15.90	1.124	0.376	42.95	119.745

3.4 Set no. 4

It was previously was known that different fish farming wastes can be anaerobically treated [7, 8]. These tests were carried out in conditions similar to the set 3, but the objective of the investigation was to determine the potential of methane productivity of fish farming residues and their mixtures with raw sewage sludge. The data are presented in table 6.

The data shows that the potential of methane production from fish farming residues is placed between glycerol and raw sewage. Comparing with glycerol, their possible or presumable process inhibition is less or is absent entirely, and further tests are needed to explain this fully. The test graphs of the set are striking by their very smooth curves; the single post peaks are absent entirely.

[Nml - normal milliliter (normal operating conditions, ie the Standard may be called chemistry experimental conditions in which the temperature is 20 ° C (273.16 K) and pressure of 1 atm or 101325 Pa)].

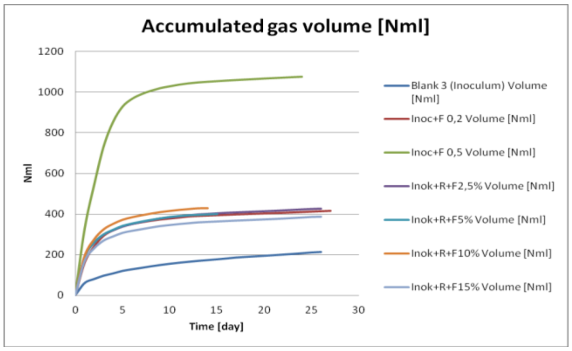

Fig. 5, Cumulative methane generation (test set 4)

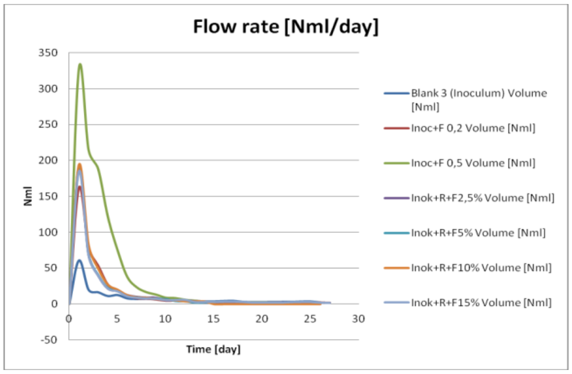

Fig. 6, Daily methane generation intensity (test set 4)

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Table 5, Characteristics and outcomes from tests set no. 3 (process and IN preparing by 38 ^{o}C)

Tests	Dry components in pulps kg/m^3					Production of methane			
	Inoculum	Glycerol	Sewage sludge	Total solids (TS)	Volatile solids (VS)	For pulps m^3/m^3		Per dry solids m^3/Mg	
						Blend	Substrate	Blend	Substrate
IN	23.50			23.5	14.13	0.556		23.64	
IN+GL	23.42	3.11		26.53	16.87	1.505	0.951	56.86	305.70
IN+SS	18.21		7.85	26.06	16.43	1.577	1.147	56.88	140.10
IN+GL+SS	22.06	1.37	2.09	25.52	15.83	1.238	0.717	48.50	207.20
IN+GL+SS	22.50	1.90	1.41	25.81	16.05	1.390	0.857	53.84	259.00
IN+GL+SS	22.88	2.35	0.83	26.06	16.24	1.337	0.795	51.81	250.10

Table 6, Characteristics and outcomes from tests set no. 4 (process and IN preparing by 38 ^{o}C)

Tests	Dry components in pulps kg/m^3					Production of methane			
	Inoculum	Sewage sludge	Fish	Total solids (TS)	Volatile solids (VS)	For pulps m^3/m^3		Per dry solids m^3/Mg	
						Blend	Subs-trate	Blend	Subs-trate
IN	24.40			24.40	12.92	0.487		19.96	
IN+F 0.2	21.99		3.23	25.22	13.98	1.272	0.833	50.44	257.895
IN+F 0.5	19.16		7.03	26.19	15.22	2.242	1.860	85.62	264.552
IN+SS+F35%	21.88	2.255	1.18	25.32	13.90	1.012	0.575	39.97	167.312
IN+SS+F50%	21.91	1.716	1.67	25.29	13.92	1.123	0.685	44.40	202.304
IN+SS+F75%	21.95	0.843	2.46	25.25	13.95	0.861	0.423	34.10	128.005
IN+SS+F90%	21.98	0.334	2.93	25.23	13.97	1.174	0.735	46.53	225.536

3.5 Single substrate influence

The nature of pulps or slurries single components are presented in table 7, whereby the essential data are juxtaposed against methane productivity, which is calculated from an adequate test sets and revealed as yield per dry (water free) solids.

The conspicuous connections between dry matter and some other component content and methane production were not revealed. Therefore, the determining factors are temperature, a proper inoculum forming temperature, the nature of substrate and concentrations, and the relations of components in the mixture.

Table 7, Tests components (CO) and their ability to produce methane

Tests set	CO	TS %	VS %	COD* g/L	P_{total} g/L	N_{-NH4} g/L	CH_4 m^3/Mg
1	IN	2.25	1.2	22.7	0.78	1.37	12.13
2	IN	2.36	1.4	21.7	0.76	0.76	32.50
3	IN	2.35	1.4	21.0	0.67	0.66	23.64
4	IN	2.44	1.3	29.2	0.77	0.87	19.96
1	RS	4.26	3.1	53.7	0.81	0.38	234.4
2	RS	5.06	3.2	53.4	0.82	0.14	141.0
3	RS	3.49	2.4	30.6	0.61	0.18	140.1
4	RS	3.36	2.2	36.2	0.63	0.42	
1	GL	89.4	91	1284	2.5	0.19	314.30
2	GL	89.5	91	1284	2.5	-	181.05
3	GL	89.5	91	1284	2.5		305.70
4	F	89.5	91	1284	2.5		261.20

*COD - chemical oxygen demand

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4 Conclusions

1. AMTS II is possible when indicating a suitable composition for anaerobic stationary processes.
2. The sufficient testing period is 20 days.
3. The test results are significantly influenced by a difference between inoculum preparation and process temperatures. Generally, this influence deteriorates methane generation. It is important that the temperatures would be equal.
4. In the lack of raw sewage sludge, as a main substrate for the anaerobic reactors by wastewater treatment plants, additional substrates (waste glycerol, fish farming residues) can be used.
5. Methane productivity is significantly influenced by the nature of substrate concentrations and their compositional relations.
6. The approximate calculation of potential methane production per total dry solids (m^3/Mg) for single components can be revealed as: a) glycerol 300-310 m^3/Mg, b) raw sewage sludge of wastewater treatment plants 140 – 230 m^3/Mg, c) residues from fish farming pools 260 m^3/Mg.

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