

Biogas production from sugar rich waste

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Abstract. 56 biogas plants are working today in Latvia. There is need to investigate the suitability of various biomasses for energy production. Sweets production factories by-products are organic waste and wastewater featuring a high sugar content. Wastewater have a high chemical oxygen demand (COD) level and requires special treatment that results in additional input of energy and financial resources.

This article shows the results of two studies evaluating sugar-containing biomass suitability for the production of biogas.

The anaerobic digestion process of damaged jam and sweets factory wastewater was investigated for biogas production in 0.75 L digesters, operated in batch mode at temperature 38 ± 0.1 °C. The average biogas yield per unit of organic dry matter (ODM) from digestion of damaged jam was $1.114 \text{ L g}^{-1}_{\text{ODM}}$ and methane yield was $0.716 \text{ L g}^{-1}_{\text{ODM}}$. Average biogas yield from digestion of sweets production factory wastewater was $1.058 \text{ L g}^{-1}_{\text{ODM}}$ and methane yield was $0.663 \text{ L g}^{-1}_{\text{ODM}}$. All investigated sugar rich wastes can be utilised for biogas production successfully thus providing an environmental solution for wastewater problem of sweets production factories.

Key words: anaerobic digestion, sugar rich wastes, biogas, methane.

INTRODUCTION

The research project aims to find out the potential for biogas production from sweets production plant by-products and from food industrial wastewater (SFW) as raw materials.

Organic biomass wastes utilization via anaerobic fermentation process can be regarded as environmental treatment technology, providing both biogas production for the energy as well as the organic fertilizer production for the plant nutrients recycling. Over the last decade considerable efforts have been invested in developing of biogas production technologies in many countries of the EU (Gomez, 2013). The first purpose for biogas plant is manure treatment for environment advantages, and the second purpose is to meet the growing energy demands in the situation, while prices on fuel and energy are increasing drastically. In recent years the biogas production is booming also in Latvia. 56 biogas plants are working today in Latvia. There is a need to use different raw materials in biogas plants (Dubrovskis et al., 2012). Advantages of biogas technology are as follows:

– the essential ecological advantage of biogas technology is that less greenhouse gases, e.g., methane, nitrogen oxide, carbon dioxide, are emitted. For example, greenhouse gases (GHG) emissions from usage of corn for biogas energy production are

by 28.8%, or 3.5 times less compare to GHG emissions from natural gas usage for heat energy production (Dubrovskis & Plume, 2009);

- the anaerobic treatment improves the quality of organic fertilizer obtained from anaerobic digestion of manure. Odours emission is reduced, as the substances with strong odour, such as volatile fatty acids or phenols are effectively decomposed. Both pumping ability and flow ability were improved, due to homogenization in the anaerobic fermentation process, so manure spreading as organic fertilizer in the field can be provided with high uniformity and quality (Dubrovskis et al., 2011a);

- finished digestate after anaerobic treatment still have substantial amount of organic matter (OM) that can be used as a source of plant nutrients. For example, maize biomass digestate contains up to 38% of initial OM after finishing of batch anaerobic fermentation process without mixing (Dubrovskis et al., 2010). Biogas technologies are an ideal solution for local conversion of waste, and for returning of organic by-products from towns and villages into the soil. Fermented organic waste is an efficient substitute of mineral fertilizers and reduces the risks of soil acidification and drinking water contamination from high doses mineral fertilizers application;

- biogas systems contributes to the climate protection goal, as the construction and operation of biogas plants can advance the sustainable development and to disseminate environmentally compatible technologies (Dubrovskis et al., 2011b).

Foreign researchers' results show that the biomass with high sugar content can get a large amount of biogas (Misi & Forster, 2001; Kaparaju et al., 2002; Neves et al., 2002; Mbohwa, 2003; Yasar et al., 2014). For example Lund University researchers studied the sugar beet co-fermentation (Parawira et al., 2004). Results from this study suggests that potato waste and sugar beet leaves are potential substrates for anaerobic digestion for the production of biogas and could provide additional benefits to farmers in southern Sweden. The general conclusion is that starch rich substrates may potentially be mixed with other biomass rich in nitrogen content and then co-digested.

Biogas production from sugarcane waste has large potential for energy generation, however, to enable the optimization of the anaerobic digestion (AD) process each substrate characteristic should be carefully evaluated. Biochemical methane potential assays were performed to evaluate the energy potential of the substrates according to different types of sugarcane plants. Methane yields obtainable from fresh matter (FM) varied considerably (5–181 Nm³ ton FM⁻¹), mainly due to the different substrate characteristics and sugar and/or ethanol production processes (Janke et al., 2015).

The previous study (Dubrovskis & Adamovics, 2012) showed that the damaged food products with high sugar content can be successfully utilised in the production of biogas. The raw materials can be by-products, residues or products not more usable for food production.

The research project aims to find out the potential for biogas production from damaged jam and sweets production factory wastewater. Positive results will give confidence on advantages of utilization of food industrial wastewater (FIW) for biogas production instead of entering SFW in the biological treatment plant.

MATERIALS AND METHODS

The volume of biogas production was studied using laboratory equipment consisting of 16 bioreactors. Fermentation temperature was maintained 38 ± 0.1 °C inside containers during batch mode process. Mixture for investigation consists of 500 g inoculum (fermented cow manure) and added biomass sample 20 g damaged jam (Study 1) or 500 g inoculum and 40 g sweet factory wastewater (Study 2) placed into 0.75 L bioreactors for anaerobic fermentation. Dry matter, ash and organic dry matter content was determined for every sample mixture before filling into bioreactor. All bioreactors within each study were placed into large, single-compartment thermostat at constant temperature 38°C for anaerobic fermentation processing during 21-day period. Measuring accuracies were following: ± 0.2 g for inoculum and substrate weight (scales Kern FKB 16KO2), ± 0.001 g for biomass samples for dry matter, organic matter and ashes weight analyses, ± 0.02 pH for pH measurements (accessory PP-50), ± 0.05 L for gas volume, and ± 0.1 °C for temperature inside the bioreactor. Gas volumes were measured help by special gas bags in volume of 2 litres positioned outside of reactor and connected with reactors by plastic pipes. Gases volume measurements and gases analysing were provided during fermentation period regularly.

Biogas composition, e.g. methane, carbon dioxide, oxygen and hydrogen sulphide volume, was measured with the gas analyser GA 2000. Dry matter was determined using specialized unit Shimazy at temperature 105 °C, and ashing was performed in oven Nabertherm at temperature 550 °C using the standard heating program. Standard error was calculated using standardized data processing tools for each group of bioreactors.

RESULTS AND DISCUSSION

In **Study 1** was provided anaerobic fermentation of damaged jam for biogas and methane production using 8 bioreactors for inoculum (IN) and damaged jam production wastes (DJ) mixture and 2 bioreactors for control (IN). Biogas and methane data from all 10 bioreactors were used to calculate the average biogas and methane volume for each group of similar bioreactors filled in with the same sample replications. The results were summarized in Tables 1, 2, and in Fig. 1, below.

Results of analyses of damaged jam (DJ) are determined separately and also together with inoculum in reactors R2-R9, see Table 1. The initial pH value for damaged jam is rather low, probably, due to long storage period and/or storage at elevated temperatures.

Table 1. The results of the analyses of raw materials in Study 1

Bioreactor numbers	Raw material	Substrate pH	TS, %	TS, g	Ashes, %	ODM, %	ODM, g	Weight, g
R1, R16	IN 500	7.25	3.42	17.1	28.71	71.29	12.19	500
	DJ20	4.2	41.3	8.26	13.1	86.9	71.18	20
R2-R9	IN500+DJ20	7.15	4.88	25.36	23.62	76.38	19.37	520

Abbreviations: TS – total solids; ODM – organic dry matter; IN – inoculum. DJ – damaged jam.

Biogas and methane yields from damaged jam are shown in Table 2. Average volume of biogas (1.5 L) or methane (0.276 L) released in control bioreactors R1, R16 is already subtracted from biogas volume obtained from every bioreactor filled in with inoculum and jam biomass mixtures, see in Table 2.

Table 2. Biogas and methane extraction in Study 1

Bio-reactor	Raw material	Biogas, L	Biogas, L g ⁻¹ _{ODM}	Methane average %	Methane, L	Methane, L g ⁻¹ _{ODM}
R1	IN500	1.40	0.115	18.32	0.256	0.021
R16	IN500	1.60	0.131	18.52	0.296	0.024
Average, R1, R16		1.50	0.123	18.42	0.276	0.023
R2	IN500+DJ20	8.00	1.115	64.00	5.168	0.720
R3	IN500+DJ20	7.90	1.100	65.05	5.139	0.716
R4	IN500+DJ20	8.10	1.128	64.16	5.197	0.724
R5	IN500+DJ20	7.90	1.100	64.51	5.096	0.710
R6	IN500+DJ20	8.20	1.142	63.55	5.211	0.726
R7	IN500+DJ20	7.90	1.100	64.05	5.060	0.705
R8	IN500+DJ20	7.80	1.087	65.24	5.089	0.709
R9	IN500+DJ20	8.20	1.142	63.11	5.175	0.721
Average, R2-R9		8.00 ± 0.2	1.114 ± 0.028	64.21 ± 0.96	5.142 ± 0.076	0.716 ± 0.011

Abbreviations: L g_{ODM}⁻¹ – litres per 1 gram organic dry matter of the original raw material.

Biogas and methane production from damaged jam is shown in Fig. 1

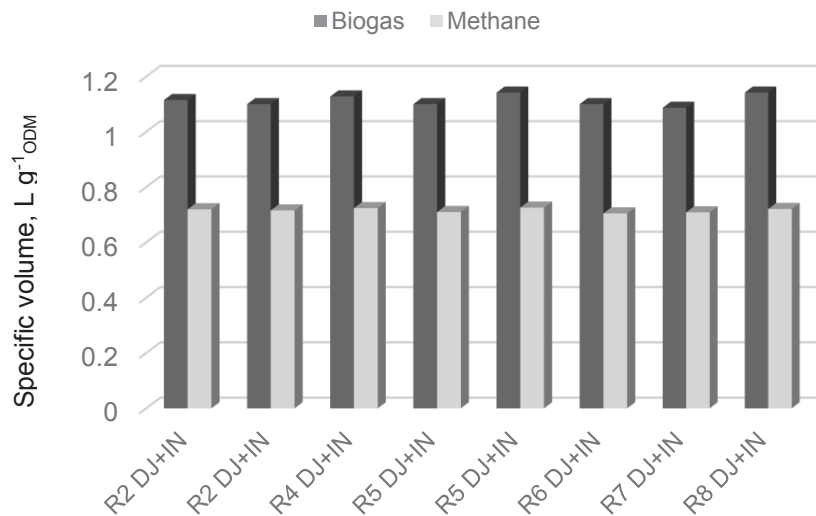


Figure 1. Specific biogas and methane volumes from bioreactors with damaged jam and inoculum.

An investigated average methane yield from damaged jam was 0.716 ± 0.011 L g_{ODM}⁻¹ and study shows that jam not usable for food still can be successfully utilised for biogas production.

In **Study 2** wastewater from sweet production factory was investigated. The methodology for biogas and methane potential estimation was the same as in Study 1, only difference was number of bioreactors – 12 bioreactors were used in this investigation. Raw material analysis results are shown in Table 3.

Table 3. The results of the analyses of raw materials in Study 2

Bioreactor number	Raw material	Substrate pH	TS, %	TS, g	Ash, %	ODM, %	ODM, g	Weight, g
R1 and R16	IN	7.29	3.05	15.25	21.9	78.1	11.910	500
	SFW	5.95	3.41	2.225	0.60	99.4	2.212	40
R2-R11	IN + SFW	7.22	3.24	17.475	19.19	80.81	14.122	540

Raw sweets factory wastewater (SFW) had low total solid and organic dry matter content (see Table 3). However, SFW is well suited for the production of biogas, as it contains a lot of sugars and juice. This is confirmed by results of finished digestate analyses and calculation of biogas parameters (Table 4).

Table 4. The results of the analyses of digestate

Bioreactor	Raw material	Substrate pH	TS, %	TS, g	Ash, %	ODM, %	ODM, g	Weight, g
R1	IN	7.21	2.90	14.21	23.53	76.47	10.87	490.2
R16	IN	7.16	3.01	14.90	21.40	78.60	11.71	495.2
R2	SFW + IN	7.08	2.69	14.21	23.96	76.04	10.81	528.4
R3	SFW + IN	7.19	2.51	13.29	28.92	71.08	9.45	529.4
R4	SFW + IN	7.10	2.55	13.46	24.93	75.07	10.11	528.0
R5	SFW + IN	7.06	2.46	13.04	30.02	69.98	9.12	530.0
R6	SFW + IN	7.05	2.74	14.26	30.04	69.96	9.98	520.6
R7	SFW + IN	7.08	2.89	15.25	25.82	74.18	11.31	527.6
R8	SFW + IN	7.02	2.69	13.88	27.63	72.37	10.04	515.8
R9	SFW + IN	7.17	2.31	12.11	34.06	66.94	8.12	524.4
R10	SFW + IN	7.11	2.81	14.86	25.65	74.35	11.05	528.8
R11	SFW + IN	7.12	2.45	12.86	26.75	73.25	9.42	525.0

The content of remaining organic dry matter in finished digestate shows, that organic matter was biodegraded in average by 4.181 g (29.6%) or 0.62 g (5.2%) in mixture (SFW + IN) or in inoculum (IN) respectively. Assuming, that organic matter from sweet factory wastewater (2.212 g) is degraded almost completely, the only logical explanation of excessive biodegraded organic matter in mixture (SFW + IN) is that mixing of wastewater with inoculum causes additional biodegradation of inoculum (IN) by 1.249 g (11.3%) in average, compared to biodegradation of pure inoculum. Surprisingly good results of methane production in reactors R2-R11 can be explained by uniform distribution of raw biomass (favourable for anaerobic fermentation microorganisms) and the chemical composition of raw SFW substance (a lot of sugar and juice) as well as with the above mentioned co-digestion effect of inoculum.

Specific biogas and methane production per 1 g organic dry matter of raw material, average results and standard error were calculated using standard statistical methods. Biogas and methane volumes for bioreactors R2-R11 are shown with already subtracted an average biogas and methane volumes obtained from control reactors (R1, R16) in Table 5.

Table 5. Biogas and methane extraction in study 2

Reactor	Material	Biogas, L	Biogas, L g ⁻¹ _{ODM}	Methane aver. %	Methane, L	Methane, L g ⁻¹ _{ODM}
R1	IN 500 g	0.90	0.076	26.11	0.235	0.02
R16	IN 500 g	1.10	0.092	28.82	0.317	0.027
R2	SFW 40 g + IN 500 g	1.70	0.769	54.24	0.922	0.417
R3	SFW 40 g + IN 500 g	2.30	1.040	63.78	1.467	0.663
R4	SFW 40 g + IN 500 g	2.30	1.040	63.48	1.460	0.660
R5	SFW 40 g + IN 500 g	3.30	1.492	60.82	2.007	0.907
R6	SFW 40 g + IN 500 g	2.40	1.085	61.42	1.474	0.666
R7	SFW 40 g + IN 500 g	1.80	0.814	70.83	1.329	0.601
R8	SFW 40 g + IN 500 g	3.10	1.401	58.65	1.818	0.822
R9	SFW 40 g + IN 500 g	2.30	1.040	59.22	1.362	0.616
R10	SFW 40 g + IN 500 g	2.00	0.904	69.70	1.394	0.630
R11	SFW 40 g + IN 500 g	2.20	0.995	65.45	1.440	0.651
Average (R2-15)		2.34	1.058	62.76	1.467	0.663
		± 0.51	± 0.23	± 5.05	± 0.29	± 0.13

Biogas and methane specific volumes per 1 g organic dry matter from sweets factory wastewater (SFW) from each bioreactor is shown in Fig. 2.

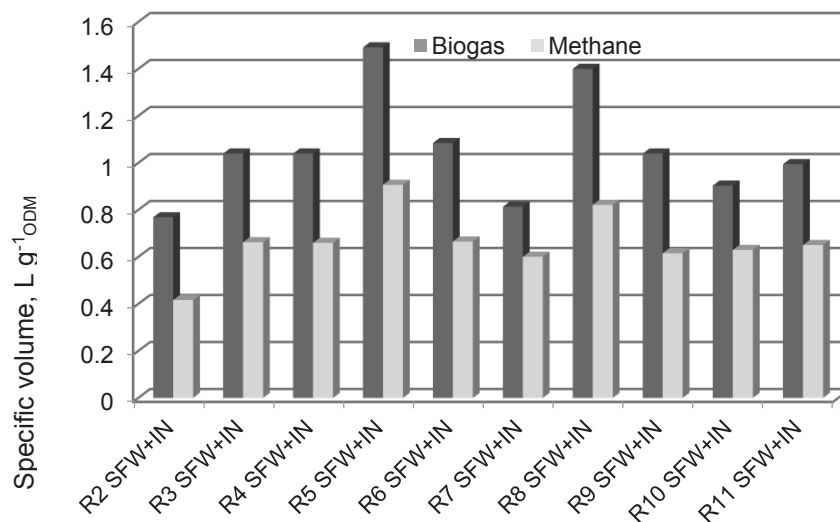


Figure 2. Specific biogas and methane volumes from sweets factory wastewater.

The average methane content of biogas from each bioreactor with wastewater is shown in Fig. 3. High methane content can be explained by the fact that sweets production factory wastewater have a large quantity of organic acids, including acetic acid (acetic acid is consumed foremost by the bacteria in methane production process).

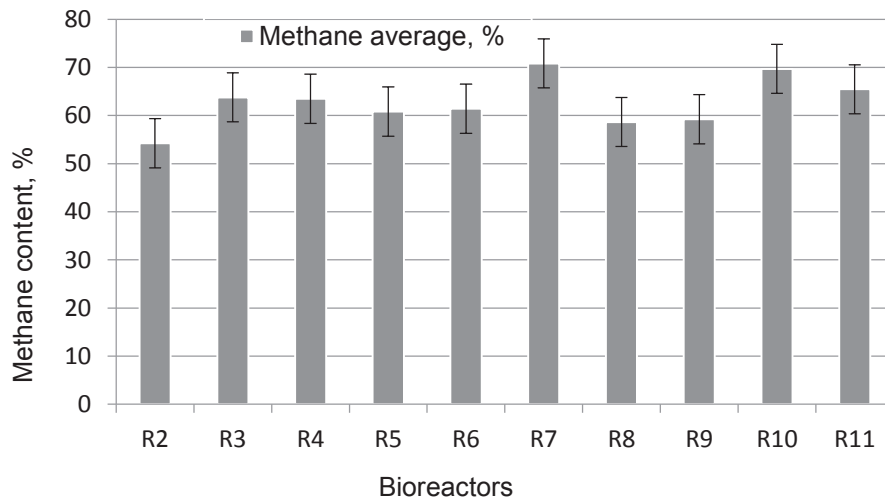


Figure 3. Average methane content in biogas from sweets factory wastewater mixtures with inoculum.

There can be estimated from Table 5 that one kg sweets factory wastewater mixtures with inoculum (weight of mixture before treatment) produces 36.75 L methane (58.5 L biogas) or 1 t produces 36.75 m³ methane (58.5 m³ biogas). Approximately 2 kWh of electricity and 3 kWh of heat can be produced from 1 m³ of biogas (with methane content 63%).

CONCLUSIONS

The average biogas yield per unit of organic dry matter added (ODM) from digestion of damaged jam was 1.114 L g⁻¹_{ODM} and methane yield was 0.716 L g⁻¹_{ODM}.

Lots of methane (0.663 ± 0.245 L g⁻¹_{ODM}) is possible to obtain from sweets producing factory waste.

The research results show that the damaged, not usable for food jam is a good raw material for the production of methane.

The addition of raw materials with high sugar and protein content to the inoculum (finished digestate) causes additional methane extraction from digestate, and therefore re-fermentation of digestate by prolongation of fermentation period or by returning of digestate back to the bioreactor can be regarded as useful.

Sweets factory liquid wastes decompose very rapidly and produce a lot of methane in anaerobic fermentation process. Therefore, more methane can be actually obtained from such a liquids compared to mixtures with high concentrations of organic dry matter.

Anaerobic fermentation of sweets factory wastewater can be regarded as most optimal solution, as storing of untreated wastewater results in sharp decline of its pH

value. If acidification was ongoing, it is recommended to raise pH value in mixture for anaerobic treatment help by additives to create more favourable conditions for microorganisms.

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