BIOGAS POTENTIAL ASSESSMENT FROM BEER AND SUGAR PRODUCING FACTORIES WASTE

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Abstract. Sugar-beet sugar factories processing residue (molasses) and beer factory wastes (beer wort) were investigated for methane potential and degree of biodegradation. The experiment was conducted in 16 laboratory bioreactors (volume 0.075 l) in batch mode at a temperature of 38 ºC during a 43-day anaerobic fermentation period. The investigated biodegradation rate of dry organic matter of molasses and beer wort were 97.98 % and 92.37 %, respectively. Average specific biogas yield was 969 ± 50 $l \cdot kg^{-1}_{DOM}$ (534 ± 30 $l \cdot kg^{-1}_{DOM}$ methane) from molasses and 1255 ± 140 $l \cdot kg^{-1}_{DOM}$ biogas (726 ± 80 $l \cdot kg^{-1}_{DOM}$ methane) from beer wort. Average methane content in biogas obtained from molasses and beer wort was 55.21 ± 2.14 % and 57.91 ± 1.36 %, respectively. Biodegradation rates of organic matter of molasses and beer wort were 97.9 % and 92.4 % respectively during the anaerobic fermentation process. The study showed that significant amounts of methane can be obtained from molasses and beer wort in an anaerobic fermentation process.

Keywords: biogas, methane, biomass, anaerobic digestion, beer wort, molasses.

Introduction

In order to reach global climate goals, people must decarbonise their energy systems. The share of the EU renewable energy sources in the energy mix should reach at least 27 % by 2030 according to the European Council decisions from October 2014.

The European Landfill Directive 99/31/EC set mandatory targets for a three-step reduction of biodegradable waste going to landfill. Set against a 1995 baseline, it requires a reduction of 25 % by 2006, 50 % by 2009 and 65 % by 2016. It is necessary to reduce the amount of all types of waste going to landfill. Therefore, it is desirable for the EU Members to investigate also in novel technologies to reduce the waste and sub-products from the food industry and to utilize by-poducts for renewable energy production [1-3].

Biogas plants are considered as one of the best options to reduce the organic matter in food waste and to produce a renewable energy, which can be utilized as process energy in most cases [4].

An increased use of biogas as a fuel reduces dependence on oil, which has significant advantages both for the environment and for the security of energy supply in the long term. Furthermore, the biogas process plays a major role in the recycling of nutrients between urban and rural areas. With the help of the biogas process, the production and consumption of food and energy from all sectors of society can be included in a balanced re-circulation system.

Latvia is already running 56 biogas cogeneration plants [5], and maize silage is the most common biomass used as feedstock, as it gives a large quantity of biomass and good yield of biogas. Most of the biogas plants in Latvia are relatively big and need a lot of raw materials for round year running. Many of biogas cogeneration plant owners do not have land for cultivation of raw materials and are forced to transport raw materials even from a long distance, so the prices for biomass supply increase considerably. Competition on arable land areas grows. Therefore, using of organic wastes and unusable products from beer and sugar production factories for biogas production is the best solution. German researchers collected the information on brewery plants wastewater treatment, where up to 90 % of organic matter can be degraded in the 2-stage anaerobic fermentation process [6]. Biogas yield from molasses and beer wort anaerobic fermentation was not yet investigated in Latvia.

The aim of the study was to evaluate biogas and methane production from molasses and beer wort.

Materials and methods

To achieve high statistical confidence the heated incubator (Memmert Incubator) and 16 small bioreactors were used. Part of bioreactors was filled with pure inoculum (control) and another part was filled with substrate containing biomass (to be investigated) and inoculums, and placed in a heated chamber. The gas from each bioreactor was directed into a separate storage bag located outside the incubator. For calculation of the results widely applied methods were used [7].

Raw biomass samples were analysed before fermentation. Dry matter content was determined by investigation of the initial sample weight and dry weight by using the moisture balances (Shimazu, model MOC-120H) processing biomass at 105 ºC temperature. Organic dry matter content was determined by ashing of the dried samples in the oven (Nabertherm) at 550 ºC using the standard processing cycle. All mixtures were prepared, carefully mixed, sealed in bioreactors and placed in the heated incubator for anaerobic fermentation digestion. Gases from every bioreactor were collected in a separate calibrated gas storage bag, and the gas volume was measured by help of the device Ritter. Gas composition (oxygen, carbon dioxide, methane and hydrogen sulphide) was measured with the gas analyser GA 2000. The substrate pH value was measured using the pH meter (PP-50) before and after finishing the anaerobic fermentation process. Scales (Kern KFB 16KO2) was used for weighting of the substrate before anaerobic processing and for weighting of digestate after finishing the fermentation process. Dry matter contents and ash contents were analysed for digestate from every bioreactor, to determine dry organic matter (DOM) content.

Each bioreactor with a volume of 0.750 l was filled in with a biomass sample 20 ± 0.005 g and with 500.0 ± 0.2 g inoculums (fermented cattle manure from 120 l bioreactor working in continuous mode). For calculation purposes, control bioreactors were filled with inoculums only. All data were recorded in the journal of experiments and into a computer. All bioreactors were placed into the incubator at operating temperature 38 ± 0.2°C, and every bioreactor has a flexible pipe connected to the gas storage bag positioned outside the heated incubator. Every gas bag was provided with a gas measurement port normally closed with a tap. Quantity and composition of gases were measured every day. Bioreactors were also gently shaken to mix the floating layer regularly. The fermentation process was provided with a single filling of each bioreactor and anaerobic fermentation in batch mode until biogas emission ceases or until the 43 day period elapses. Total biogas and methane production values were calculated for each bioreactor using the normal biogas volume and the quality parameters. For statistical accuracy, the representative data values were obtained as the average from every group of identical substrates positioned in the heated incubator.

Results and discussion

The results of raw material samples analysis for investigation of substrates with molasses and beer wort before anaerobic digestion are shown in Table 1.

Table 1

Results of analyses of raw material sample before anaerobic digestion

Bioreactor	Raw material	pH substrate	TS, %	TS, g	ASH, %	DOM, %	DOM, g	Weight, g
R1; R16	IN	7.41	2.81	14.05	27.2	72.8	10.23	500
-	M	-	81.77	8.18	14.9	85.1	6.96	10
R2-R8	M+IN	7.43	4.36	22.23	22.68	77.32	17.19	510
-	BW	-	43.27	6.4	21.28	78.22	5.11	15
R9-R15	BW+IN	7.38	3.97	20.45	24.99	75.01	15.34	515

Note: BW – beer wort; M – molasses; IN – inoculum; R1-R16 – bioreactors.

There was a large difference in the organic matter content between sugar-beet sugar factories processing residues and beer factory wastes. This difference was the reason, why the raw biomass sample (to be filled into each bioreactor) was selected 10 g for molasses and 15 g for beer wort (see Table 1. Results of analysis of substrates after finishing the anaerobic digestion process are shown in Table 2.

Average dry organic matter (DOM) of molasses after anaerobic fermentation was 9.62 g and the calculated total decomposition value of DOM of digestate (M+IN) in reactors R2-R8 was 7.57 g (digestate decomposes by 44.04 % on average). Also, dry organic matter (DOM) of inoculums still continues to degrade by 0.76 g (by 7.43 %) during the anaerobic fermentation process, see average results for control reactors (R1; R16) in Tables 1-2.

Table 2

Results of finished digestate analysis

Bioreactor	Raw material	pH	TS, %	TS, g	ASH, %	DOM, %	DOM, g	Weight, g
R1I	IN	7.48	2.73	13.54	29.72	70.28	9.52	496.0
R16	IN	7.47	2.72	13.40	29.61	70.30	9.43	492.6
Average R1; R16		**7.48**	**2.73**	**13.47**	**29.67**	**70.29**	**9.47**	**494.30**
R2	M+IN	7.44	2.76	13.92	29.84	70.16	9.77	504.2
R3	M+IN	7.45	2.75	13.85	30.12	69.88	9.68	503.8
R4	M+IN	7.46	2.75	13.86	29.92	70.08	9.71	504.0
R5	M+IN	7.42	2.76	13.90	30.41	69.59	9.67	503.6
R6	M+IN	7.43	2.74	13.83	30.52	69.48	9.61	505.0
R7	M+IN	7.46	2.71	13.63	31.19	68.81	9.38	503.0
R8	M+IN	7.45	2.72	13.70	30.64	69.36	9.50	503.6
Average R2-R8		**7.44**	**2.74**	**13.81**	**30.38**	**69.62**	**9.62**	**503.89**
R9	BW+IN	7.39	2.75	13.89	29.25	70.75	9.83	505.2
R10	BW+IN	7.41	2.69	13.68	29.36	70.64	9.66	508.4
R11	BW+IN	7.44	2.73	13.89	29.90	70.10	9.74	508.8
R12	BW+IN	7.41	2.76	14.00	29.12	70.88	9.92	507.2
R13	BW+IN	7.42	2.77	14.09	29.50	70.50	9.93	508.6
R14	BW+IN	7.43	2.78	14.15	29.43	70.57	9.99	509.0
R15	BW+IN	7.40	2.78	14.15	29.32	70.68	10.00	508.9
Average R9- R15		**7.41**	**2.75**	**13.98**	**29.41**	**70.59**	**9.87**	**508.01**

Assuming, that this degradation rate is the same for inoculums in bioreactors R2-R8, the biodegradation rate of dry organic matter of molasses calculates as 97.98 %. The obtained degradation rate is higher compared to reported in literature, for example, investigated average rate of organic matter degradation for sugar beet pulp in the anaerobic fermentation process was 91.5 % [7].

Average dry organic matter (DOM) of beer wort after anaerobic fermentation was g (9.87 g) and the estimated total degradation value of DOM of digestate (BW+IN) in reactors R9-R15) was 5.47 g (digestate decomposes by 35.66 % in average). Assuming, that the biodegradation rate of inoculum (7.38 %) in control reactors is still the same also for inoculums in bioreactors with beer wort and inoculums (R9-R5), the degradation rate of dry organic matter of beer wort calculates as 92.37 %. The comparatively high biodegradation rates of both biomasses can be explained by the small particle size and low content of hardly biodegradable particles in substrates.

Production of biogas and methane from the molasses and beer wort, and pure inoculums in control reactors is presented in Table 3.

Table 3

Production of biogas and methane in bioreactors from molasses and beer wort

Bioreactor	Substrate	Biogas, l	Biogas, $l \cdot g^{-1}_{DOM}$	Methane, %	Methane, l	Methane, $l \cdot g^{-1}_{DOM}$
R1	IN	0.70	-	-	0.18	-
R16	IN	0.70	-	-	0.18	-
R2	M+IN	6.80	0.98	54.16	3.68	0.53
R3	M+IN	6.60	0.95	53.73	3.55	0.51
R4	M+IN	6.90	0.99	55.57	3.83	0.55
R5	M+IN	6.20	0.89	59.55	3.69	0.53
R6	M+IN	6.70	0.96	53.37	3.58	0.51
R7	M+IN	7.30	1.05	56	4.09	0.59
R8	M+IN	6.70	0.96	54.06	3.62	0.52
Average R2-R8 ± std.		**6.74 ± 0.33**	**0.969 ± 0.05**	**55.21 ± 2.14**	**3.72 ± 0.27**	**0.534 ± 0.03**

Table 3 (continued)

Bioreactor	Substrate	Biogas, l	Biogas, $L \cdot g^{-1}_{DOM}$	Methane, %	Methane, l	Methane, $L \cdot g^{-1}_{DOM}$
R9	BW+IN	5.30	1.04	59.6	3.16	0.62
R10	BW+IN	7.10	1.39	56.13	3.99	0.78
R11	BW+IN	6.90	1.35	57.97	4.00	0.78
R12	BW+IN	7.10	1.39	59.22	4.21	0.82
R13	BW+IN	6.60	1.29	58.23	3.84	0.75
R14	BW+IN	6.30	1.23	56.1	3.53	0.69
R15	BW+IN	5.60	1.10	58.14	3.26	0.64
Average R9- R15 ± std.		**6.41 ± 0.72**	**1.255 ± 0.14**	**57.91 ± 1.36**	**3.71 ± 0.40**	**0.726 ± 0.08**

Note: $l \cdot g^{-1}_{DOM}$ – litres per 1 g dry organic matter (DOM) added (added fresh biomass into inoculum).

Surprisingly good results for gases production were obtained in this investigation. Specific methane yield was $0.534 \pm 0.030\ l \cdot g^{-1}_{DOM}$ from molasses and $0.726 \pm 0.080\ l \cdot g^{-1}_{DOM}$ from beer wort. The high methane yield may be explained by the small particle size in the raw material, resulting in a good distribution favourable for anaerobic microorganisms, and/or by the chemical composition of the substrates (raw materials rich in sugar and juice).

Biogas and methane values for bioreactors R2-R15 with fresh source biomass were provided with already subtracted average biogas and methane values obtained from control reactors R1 and R16. Biogas and methane yield from molasses from each bioreactor is shown in Fig. 1.

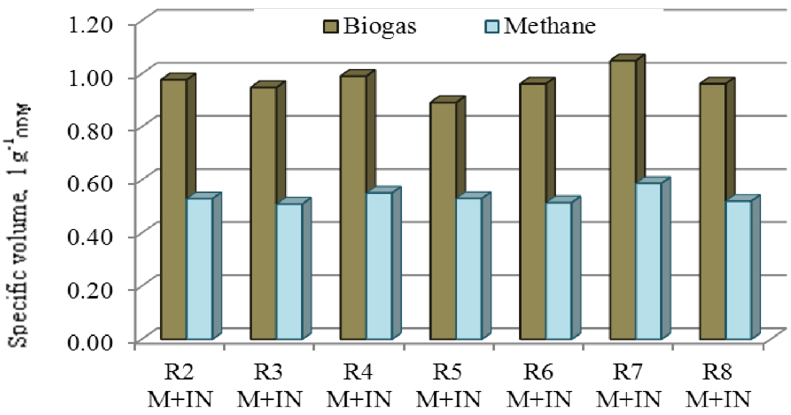

Fig. 1. **Specific biogas and methane yield from molasses**

Average methane content in biogas in each bioreactor with molasses can be seen in Fig. 2.

The relatively high methane yield from organic substances may also be explained by the fact that the inoculums still contain much acetic acid, from which bacteria produce methane.

Specific biogas and methane yields per 1 g dry organic matter of raw beer wort raw biomass are shown in Fig. 3. Average methane content in biogas in bioreactors with beer wort and inoculums is shown in Fig. 4.

The comparison of the average methane contents in biogas from molasses and beer wort shows that the methane content was higher in biogas produced from beer wort biomass (see Fig. 2 and Fig. 4). This could be explained by the fact that the coexistence of hydrolysis bacteria and methane bacteria was more harmonised in substrates with beer wort.

Specific methane yield obtained from sugar beet molasses is considerably higher, compared to the research data derived from literature, for example, the specific methane production obtained from spent sugar beet pulp was $0.430\ l \cdot g^{-1}_{DOM}$ [8] and $0.336\ l \cdot g^{-1}_{DOM}$ [9].

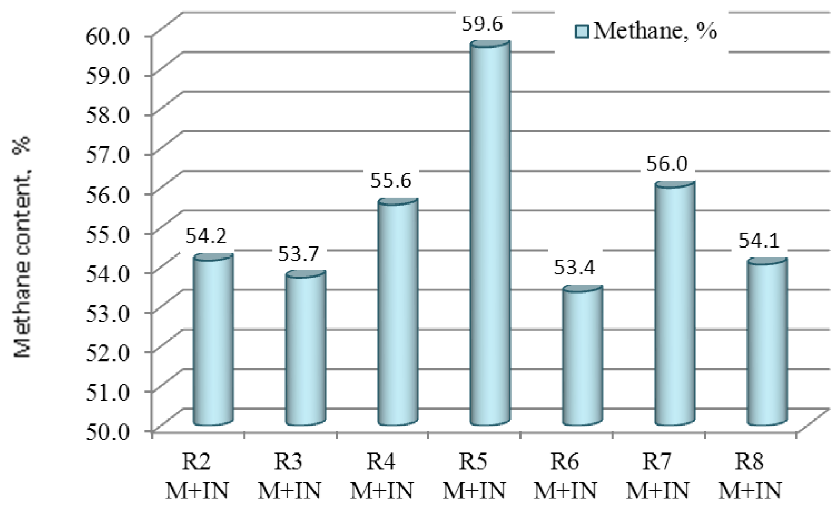

Fig. 2. **Average methane content in biogas in bioreactors with molasses**

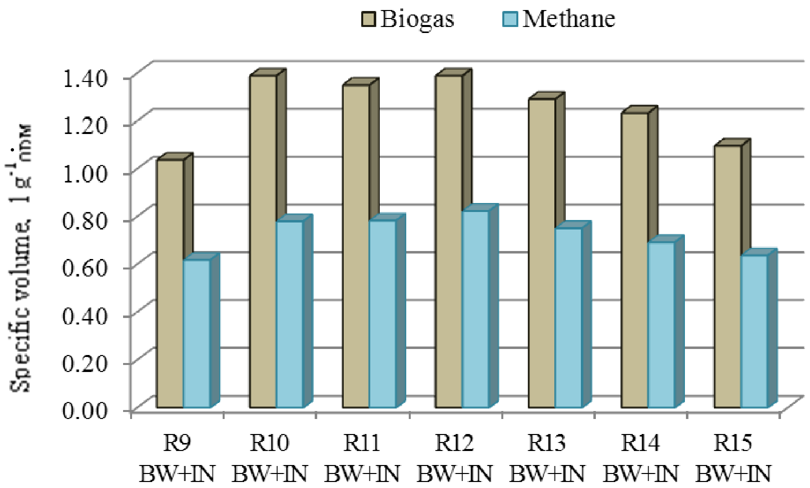

Fig. 3. **Specific biogas and methane yield from beer wort**

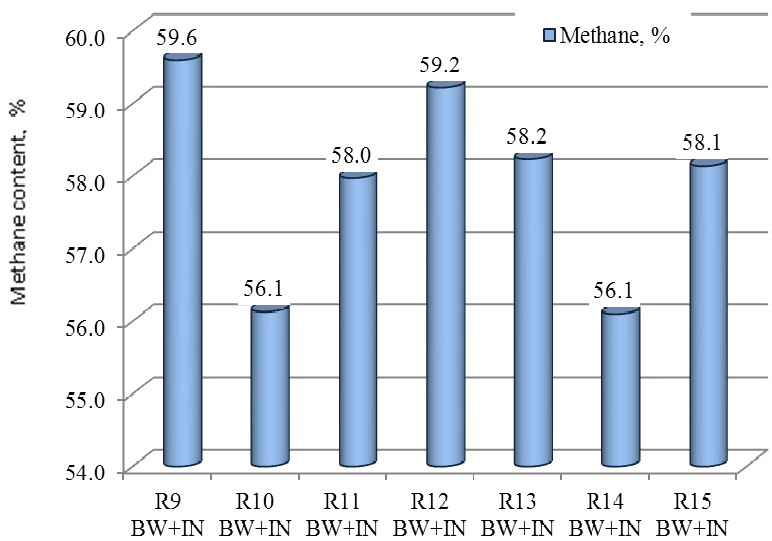

Fig. 4. **Average methane content in biogas from bioreactors with beer wort**

Conclusions

1. Biodegradation rates of dry organic matter of molasses or beer wort were 97.98 % or 92.37 % respectively during the anaerobic fermentation process.
2. Average specific methane production from molasses was 0.534 ± 0.038 $l \cdot g^{-1}{}_{DOM}$ calculated per 1 g of dry organic matter of raw molasses biomass before anaerobic fermentation.
3. High average specific methane yield 0.726 ± 0.080 $l \cdot g^{-1}{}_{DOM}$ was obtained from beer wort.
4. Average methane content in biogas from molasses or beer wort was 55.21 ± 2.1 % or 57.91 ± 1.36 %, respectively.
5. The results of the investigation show that both molasses and beer wort are excellent raw materials for biogas and methane production.
6. The investigation shows that inoculums (finished digestate) in control bioreactors still degrade by 7.38 %, so the return of finished digestate into bioreactor for re-fermentation can be considered as useful.

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