BIOGAS POTENTIAL FROM DAMAGED BREAD

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Abstract. Latvian bakeries for various reasons result in production of waste and non-standard bread, which cannot be used for food. Damaged bread accumulates and stores mold. The bread utilization is problematic for manufacturers and traders. Environmental solution of this problem can be the usage of damaged bread for biogas production. This article shows the results of investigated biogas potential from five different damaged breads. Sixteen 0.75 liter bioreactors were filled with inoculums or with inoculums mixed together with different bread mass. Anaerobic digestion was provided in a batch mode at temperature 38 ºC. The following specific biogas volumes (methane percentage in biogas) were obtained after 30 days anaerobic digestion (AD) process: French bread 0.723 $l \cdot g^{-1}_{DOM}$ (50.6 %); Rye flour bread 0.634 $l \cdot g^{-1}_{DOM}$ (49.9 %); Wheat flour (coarse) bread 0.731 $l \cdot g^{-1}_{DOM}$ (50.9 %); Toaster bread 0.694 $l\ g^{-1}_{DOM}$ (44.9 %); White bread (with the addition of egg and milk additives) 0.943 $l \cdot g^{-1}_{DOM}$ (45.4 %). The results show that damaged bread can be used for biogas production sucessfully.

Key words: biogas, anaerobic digestion, damaged bread.

Introduction

Modern civilization is based on high energy consumption. On average, each citizen living on the Earth consumes 2 t of C (carbon) in a year for energy needs [3]. Consumption of carbon is varying in different countries, it is 6 $t \cdot ha^{-1}$ C in Europe or 40 times more compared to Bangladesh [3]. More than 15 billion tonnes of CO_2 is released into the atmosphere due to the human activities every year. Now, the main source of energy is the fossil resources. In order to reduce CO_2 emissions and prevent global warming the renewable energy sources should be used, including biomass serving as almost CO_2 neutral resource [4]. Economically justified local energy use and energy supply security are among the main conditions having influence on economic independence of the country. The development of the national energy policy is an essential measure to reduce the dependency on energy imports and to create the conditions for sustainable energy production in Latvia in future. The balanced usage of local resources in electricity, heat and transport sectors should be assessed to provide the highest benefit from each specific resource utilisation. Price increase due to increase of renewable energy usage should not compromise competitiveness of the Latvian economy and products in the world market. One of the most economically viable renewable energy sources is biogas. The use of biogas for electricity production deals with some problems concerning agricultural production, processing and recycling of biodegradable products and derived product management, reduction of soil, water and air pollution, and minimisation of the potential danger to human health [5].

The cheapest raw biomass and the most stable anaerobic fermentation technologies should be provided to reduce the expenses on production of biogas, heat and electricity and increase its competitiveness with fossil fuels. The variety of food industry processing organic waste, by-products and defective products can be utilised as the cheap raw material [6].

The reliable feedstock supply is critical for profitability of the anaerobic digestion (AD) facility, especially if the raw biomass is bought from the third party, therefore, such supply should be secured with a long-term contract based on acceptable terms. The yield of biogas from a different feedstock will vary according to the following criteria: quality of the feedstock, dry matter content, energy content in the feedstock (it may be biodegraded during long-term storage), hydraulic retention time, type of the AD plant and conditions in the digester [7].

If the 'wet' AD system (TS < 15 %) will be used for treatment of waste biomass, the food waste needs to be collected separately at source or co-digested with the wet biomass, e.g., sludge. The food waste co-digestion with sludge in large sludge treatment plants has the potential to be an efficient way for energy producing from waste, considering that wastewater treatment plants are located nearby urban centres usually [8].

The key condition of a viable and sustainable AD project is the uninterrupted supply of qualitative biomass feedstock. For food industry processing residues such as bakery or brewery wastes are potential feedstocks for AD due to consistent dry matter content and regular supplies of waste biomass. There is known strong interest from food and drink manufacturers on development of on-site AD facilities to convert the following waste-stream into a potentially valuable revenue source: biowaste from households, leftover dough from bakeries, expired bread and other organic waste from shops [9].

Bakery waste consists of bread, cookies, doughnuts, cakes etc. Bakery waste contains a lot of fat, sugars and fibres and is mostly used as feed for cattle [10]. Bakery waste can be divided into two categories. The first is the category of dry baking, including bread, buns and roll buns, and the second category contains pies, cakes, doughnuts etc. Bakery waste can produce around 650 m^3 $CH_4 \cdot t^{-1}$ with the methane percentage of 52 %. The estimation of the bakery waste in the Ostrobothnian region is between 21-25 million kg annually [11]. German and UK researchers also collected information [1], but there are limited data available. Biogas yield from a variety of damaged bread has not been studied so far in Latvia.

The aim of this study is evaluation of the biogas and methane production potential from various types of damaged bread used in Latvia.

Materials and methods

The raw materials (damaged bread) were analysed to evaluate the general elements. The data were used for planning of organic load of substrates.

16 bioreactors were filled with substrate and placed in a heated container (Memmert model), and the gas released from each bioreactor was collected into a separate storage bag located outside the container. For investigation of the fermentation process the widely applied methods were used [2].

Biomass moisture and total solids of the components or substrate samples were investigated with the electronic moisture balance (MOC-120H model) by providing the heating cycle at 105 ºC. Dry organic matter was investigated in the oven (Nabertherm model) by ashing at 550 ºC. All substrate components were prepared, carefully mixed and all bioreactors were placed into the heated container at the same time for anaerobic digestion in batch mode. Gases from each bioreactor were collected in flexible gas bags and the gas volumes were measured with a flowmeter (drum-type gasmeter). The composition of gases, e.g., O_2, CO_2 , CH_4 and H_2S was measured with the portable gas analyser (GA2000 model). The substrate pH value was measured before and after the AD process with the pH meter (PP-50 model). Scales (Kern, KFB16KO2 model) was used for weighting of the total weight of substrates before and after the anaerobic digestion process.

14 bioreactors with the volume of 0.75 l were filled with 500.0 ± 0.2 g inoculums with added biomass (7 ± 0.005g) and 2 bioreactors were filled with inoculums (500 g) only for control. Inoculums were obtained from cattle manure at final phase of its anaerobic fermentation process ongoing in 120 l bioreactor working in continuous mode. The batch mode anaerobic digestion process was provided at temperature 38 ± 0.5 ºC. Volumes of biogas and methane and the composition of gases were measured at regular time intervals. The fermentation process was provided until biogas production ceases.

Results and discussion

The results of investigation of sample substrates, including inoculums, various damaged bread before anaerobic digestion are shown in Table1. Digestate with very low organic dry matter content is used as inoculum. The anaerobic digestion process will not continue in such inoculums, but there are still enough bacteria starting to degrade new portions of the organic matter rapidly.

As it can be seen from Table 1 all types of bread are with high dry matter and dry organic matter content.

Such substrate rich in organic solids and containing many bacteria is appropriate for the production of biogas in the anaerobic fermentation process. The results of the analysis of digestate from bioreactors at the end of the anaerobic digestion process are shown in Table 2.

Inoculums still continued to degrade by 0.1 g DOM in the control bioreactors (R1; R16, as calculated from the data in Table 2 and Table 3. The dry organic matter (DOM) of damaged French bread was degraded by 5.92 g or by 97.97 % of DOM during the anaerobic fermentation process. Likewise, the dry organic matter of Wheat flour bread (WF) or White bread (WB) was degraded by 94.08 % or by 98.44 % of initial DOM respectively. The organic matter of Rye flour bread (RF) or

Toaster bread (TB) degrades completely and causes additional biodegradation of inoculums (compared to control) by 0.241 g or 0.081 g (by 5.58 % or 1.87 %) during the AD process respectively. It may indicate that Rye flour bread and Toaster bread contain substances promoting additional degradation of slowly degradable remaining substances in inoculums, e.g., lignin, or bacteria biomass itself.

Table1

Results of analyses of raw material samples before anaerobic digestion

Bio-reactors	Raw material	pH	TS, %	TS, g	ASH, %	DOM, %	DOM, g	Weight, g
R1, R16	500gIN	7.42	1.22	6.1	29.1	70.9	4.32	500
R2-R4	7gFB		87.57	6.13	1.42	98.58	6.04	7.0
R2-R4	500gIN+7gFB	7.41	2.41	12.23	15.29	84.71	10.36	507
R5-R7	RF7g		88.06	6.16	1.91	98.09	6.05	7.0
R5-R7	500gIN+7gRF	7.42	2.42	12.26	15.33	84.67	10.37	507
R8-R10	7gWF		85.72	6.0	8.88	91.12	5.47	7.0
R8-R10	500gIN+7gWF	7.41	2.39	12.10	19.09	80.91	9.79	507
R11-R13	TB7g		88.71	6.21	3.33	96.67	6.00	7.0
R11-R13	500gIN+TB7g	7.40	2.43	12.31	16.17	83.83	10.32	507
R14-R15	7gWB		83.06	5.81	13.37	86.63	5.04	7.0
R14-R15	500gIN+7gWB	7.42	2.35	11.91	21.41	78.59	9.36	507

Note:IN-inoculum; FB-French bread; RF-Rye flour bread; WF-Wheat flour(coarse)bread; TB-Toaster bread; WB-White bread (with egg and milk additives) ;ASH–ashes;TS–totalsolids;DOM–dry organic matter (on raw substrate basis); R1-R16–bioreactors.

The difference between the total weights of substrates before and after the AD process exceeds the actual values of biodegraded dry organic matter mass during the AD process. This evidence can be explained, as the water vapour escapes from bioreactors together with released biogas into gas measurement bags positioned outside the heated container.

The biogas and methane yields obtained from the bioreactors R2-R15 (with added biomass) are shown with already subtracted average values of biogas and methane obtained from the control reactors (R1; R16) in Table3 and Fig.2.

Table 2

Results of analyses of finished digestate

Reactor	Substrate	pH	TS, %	TS, g	ASH, %	DOM, %	DOM, g	Weight, g
R1	500gIN	7.31	1.20	5.996	29.62	70.38	4.220	499.7
R16	500gIN	7.30	1.21	6.038	30.08	69.92	4.222	499.0
R2	500gIN+7gFB	7.17	1.11	5.562	29.04	70.96	3.947	501.1
R3	500gIN+7gFB	7.24	1.20	6.02	26.32	73.68	4.441	502.3
R4	500gIN+7gFB	7.16	1.29	6.465	28.2	71.80	4.642	501.2
R5	500gIN+7gRF	7.18	1.23	6.181	29.66	70.34	4.348	502.5
R6	500gIN+7gRF	7.11	1.16	5.830	38.97	61.03	3.558	502.6
R7	500gIN+7gRF	7.14	1.26	6.353	36.44	63.51	4.034	504.2
R8	500IN+7gWF	7.12	1.26	6.319	30.52	69.48	4.390	501.5
R9	500IN+7gWF	7.19	1.32	6.621	30.38	69.62	4.609	501.6
R10	500IN+7gWF	7.11	1.33	6.685	30.66	69.34	4.635	502.6
R11	500gIN+7gTB	7.21	1.15	5.770	30.57	69.43	4.006	501.8
R12	500gIN+7gTB	7.28	1.2	6.034	27.1	72.9	4.398	502.8
R13	500gIN+7gTB	7.15	1.12	5.616	28.48	71.52	4.017	501.4
R14	500gIN+7gWB	7.16	1.09	5.461	27.27	72.73	3.972	501.0
R15	500gIN+7gWB	7.2	1.27	6.378	27.45	72.55	4.627	502.2

The production of biogas and methane from various damaged bread and from control reactors is presented in Table 3.

Table 3

Production of biogas and methane

Reactor	Raw material	Biogas, l	Biogas, $l \cdot g^{-1}_{DOM}$	Methane, %	Methane, l	Methane, $l \cdot g^{-1}_{DOM}$
R2	500gIN+7g FB	4.7	0.778	52.51	2.468	0.409
R3	500gIN+7g FB	3.6	0.596	41.97	1.511	0.250
R4	500gIN+7g FB	4.8	0.795	55.17	2.648	0.438
R2-R4average FB		4.367±0.6	0.723±0.10	50.58±6.60	2.209±0.57	0.366±0.09
R5	500gIN+7g RF	3.9	0.645	51.92	2.025	0.335
R6	500gIN+7g RF	3.9	0.645	53.56	2.089	0.340
R7	500gIN+7g RF	3.7	0.611	43.81	1.621	0.268
R5-R7average RF		3.833±0.1	0.634±0.02	49.88±4.88	1.912±0.23	0.314±0.04
R8	500IN+7g WF	4.3	0.786	50.00	2.15	0.393
R9	500IN+7g WF	4.2	0.768	51.1	2.146	0.392
R10	500IN+7g WF	3.5	0.640	51.71	1.810	0.331
R8-R10average WF		4.0±0.4	0.731±0.07	50.88±0.86	2.035±0.17	0.372±0.03
R11	TB7g+500IN	4.4	0.733	42.68	1.878	0.313
R12	TB7g+500IN	3.8	0.633	46.05	1.750	0.292
R13	TB7g+500IN	4.3	0.717	46.19	1.986	0.331
R11-13average TB		4.167±0.3	0.694±0.05	44.9±1.76	1.871±0.12	0.312±0.02
R14	WB7g+500IN	4.7	0.933	49.00	2.303	0.457
R15	WB7g+500IN	4.8	0.952	41.83	2.008	0.398
R14-R15average WB		4.75±0.1	0.943±0.01	5.38±3.81	2.156±0.15	0.427±0.03
R1	IN500g	0.1			0.005	
R16	IN500g	0.1			0.005	

Note: Lg^{-1}_{DOM}*–litres per1g dry organic matter added (added fresh biomass into inoculums).*

The relatively good results can be explained by the fact that the chemical composition of the investigated raw materials was suitable for bacteria media growth as well as by co-digestion of the added biomass with inoculum in small extent.

The specific average biogas and methane production yields ($l \cdot g^{-1}_{DOM}$) calculated for bioreactors with added various damaged bread are shown in Fig. 1.

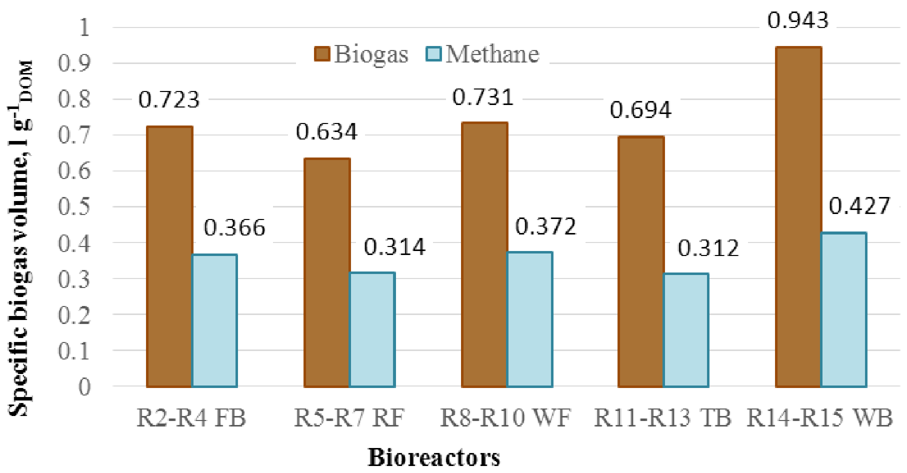

Fig. 1. **Specific average biogas and methane yield from different types of damaged bread:**
FB – French bread; RF –Rye flour bread; WF-Wheat flour bread;
TB – Toaster bread; WB – White bread

The average specific methane yield from White bread (with the addition of egg and milk additives) was higher by 16.67 %, 14.78 % or 36.85 % compared to the methane yield obtained from French bread (FB), Wheat flour bread (WF) or Toaster bread (TB) respectively. The average specific methane yield from Rye flour bread (RF) was only slightly higher (by 0.64 %) compared to the methane yield obtained from substrates with Toaster bread (TB).

In order to compare the gas yields from different biomass the output of gases is attributed to the unit of dry organic matter ($l \cdot g^{-1}_{DOM}$) before AD treatment usually. However, if the purpose is to estimate the biogas or methane yield per unit of natural biomass than the total solid content and moisture of biomass (before fermentation) should be included in calculations as follows:

$$V_{NM} = V_{DOM}\, k_{DM}\, k_{DOM}\ , \quad (1)$$

where V_{NM} – specific gases volume per unit of the initial natural mass, $l\ kg^{-1}_{NM}$;
V_{DOM} – specific gases volume per unit of the initial dry organic matter, $l\ kg^{-1}_{DOM}$;
k_{DM} – coefficient featuring the dry matter content in natural mass (before AD process);
k_{DOM} – coefficient featuring the organic dry matter content in dry matter of natural mass (before the AD process).

The specific biogas and methane volumes ($l \cdot kg^{-1}_{NM}$) calculated per 1 kg of bread natural mass (NM) are shown in Fig. 2.

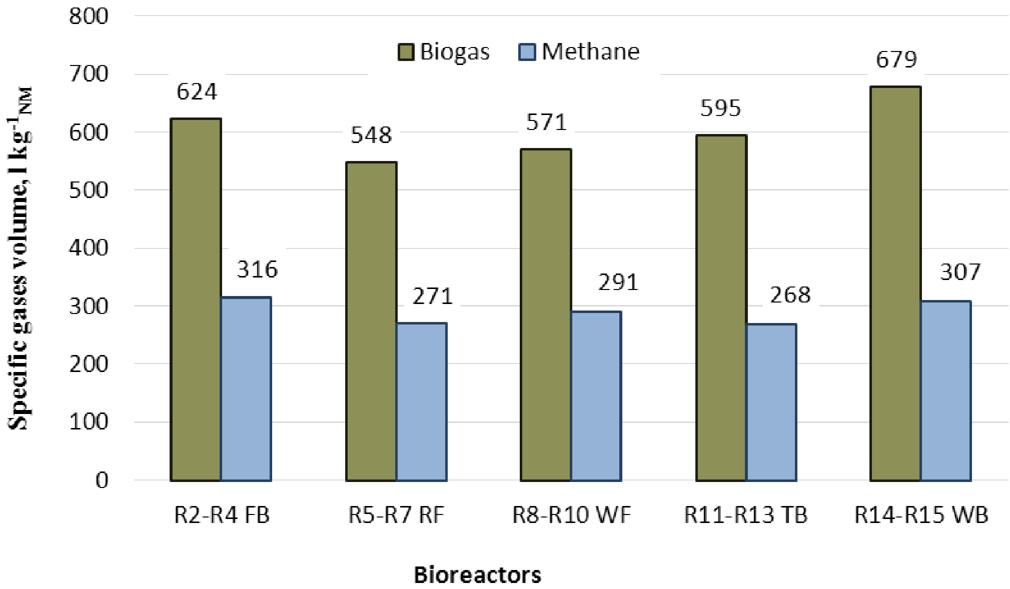

Fig. 2. **Specific biogas and methane yield obtainable from 1 kg of natural damaged bread mass**

There are shown (in Table3 and Fig. 2) the average data calculated from all bioreactors containing various damaged bread biomass. Comparison of the obtained results with other researchers' data would not be correct, as the samples of biomass may contain different ingredients compared to biomass investigated in other studies.

Conclusions

1. The highest average specific methane yield (316 $l \cdot kg^{-1}_{NM}$) was obtained from French bread as calculated per 1 kg of natural mass (NM).
2. The lowest highest average specific methane yield (268 $l \cdot kg^{-1}_{NM}$) was obtained from Toaster bread natural mass.
3. The highest average specific methane yield (427 $l \cdot kg^{-1}_{DOM}$) was obtained from White bread (containing egg and milk additives) and it was by 26.9 % higher compared to lower specific methane yield obtained from Toaster bread, as calculated per 1 kg of dry organic matter (DOM).
4. The highest average methane content in biogas 50.9 % was obtained from French bread, and a lower one was observed in biogas from Toaster bread.

5. Organic matter of Rye flour bread or Toaster bread degrades completely and causes additional biodegradation of inoculums by 5.58 % or 1.87 % during the AD process respectively. It may indicate that Rye flour bread and Toaster bread contain some substances facilitating biodegradation of slowly degradable components, e.g., lignin or bacteria biomass itself.

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