BIOGAS YIELDS FROM FOOD WASTE

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Abstract. The aim of this study was to determine the anaerobic digestion possibility of fish and rapeseed processing by-products to biogas. Different types of wastes from oil and fish processing industries were used – two samples of rape press cake (hulls, light dehulled and press cake, not dehulled) and two samples of fish wastes (fish waste after filleting and fish bones). The samples of rape press cake were with concentration of total solids in the range of 92.3-95.0 % and fish waste after filleting was wet – 41.6 % of total solids in the material. The waste from rape oil industry had 90.9-95.5 % volatile solids, while the fish waste after filleting had 92.5 % and fish bones contained only 50.4 % VS. Investigation was carried out on laboratory biogas digesters. The biogas yield from hulls varied in the range of 917 $l \cdot kg^{-1} \cdot VS^{-1}$ to 1064 $l \cdot kg^{-1} \cdot VS^{-1}$ and from rape press cake – in the range of 667 $l \cdot kg^{-1} \cdot VS^{-1}$ to 734 $l \cdot kg^{-1} \cdot VS^{-1}$. The biogas yield from fish waste after filleting varied in the range of 1006 $l \cdot kg^{-1} \cdot VS^{-1}$ to 1104 $l \cdot kg^{-1} \cdot VS^{-1}$ and from fish bones – in the range of 741 $l \cdot kg^{-1} \cdot VS^{-1}$ to 807 $l \cdot kg^{-1} \cdot VS^{-1}$.

Keywords: biogas, food waste, fish industry, rape press cake.

Introduction

The production of fish and rapeseed oil on an industrial level leads to a considerable quantity of by-products, which is considered as a waste or/and is used in agriculture. Processing of fish and rapeseed generates protein and oil containing co-streams, which are currently used mainly as feed for animals. Such by-products contain components upgradable into valuable products. The by-products after processing still are rich in oil, protein, amino acids and vitamins.

Fish and rapeseed processing co-streams are produced in bulk quantities both globally and at the European level. Estimates on the amount of co-streams from fish catch varies depending on the species, size, season and fishing ground and even 50-75 % of the fish is discarded when preparing seafood industrially [1; 2]. Fish waste and fish filleting co-stream are currently consumed as feed and biofuel production or even wasted. The biggest part of Norwegian salmon rest raw material is used for silage production (~74 %) with some production of oil (~13 %) and hydrolysate (~10 %) [3]. Currently fish residues are processed by the fish meal and silage processes. Techno-economically feasible but chemical-intensive fish silage process has been used for decades to separate oil from the rest of the waste. Enzymatic technology can be applied in order to recover high quality valuable fish protein hydrolysates from fish residue [4; 5].

Annual European Union (EU-27) production of rapeseed reaches 19,5 millions of metric tons (year 2012) [6] and fish – 13.2 million metric tons at the EU-27 level. The residue is 62 to 70 % from the produced rapeseed [11], which leads to over 12 million ton annual production of rapeseed press cake in the EU. Currently rapeseed waste is used as feed for the cattle, pigs and poultry.

After the recovery of valuable products of fish and rapeseed the remaining by-products could be used for biogas production. Anaerobic digestion is used as an effective treatment way of agricultural by-products due to the stabilization of digestate and biogas production for energy [7] as well as significant reduction of waste quantity, biofertilizer generation [8; 9].

The aim of this study was to determine the anaerobic digestion possibility of fish and rapeseed processing by-products to biogas.

Materials and Methods

Different types of wastes from oil and fish processing industries were used for the experiments. Inoculum was taken from a wastewater plant in Kaunas. There were two samples of rape press cake, prepared by IGV (Germany): hulls, light dehulled (KOR2-HU1) and press cake, not dehulled (KOR2-PC). Two samples of fish waste have been examined as well: fish waste after filleting obtained from Nutrimar (Norway) and fish bones prepared by SINTEF (Norway). The chemical composition of wastes has been analysed (Table 1).

The samples of rape press cake and fish were dry, with a concentration of total solids in the range of 92.3-95.0 %. Only fish waste after filleting was wet, with 41.6 % of total solids in the material. Organic materials (Volatile solids) were dominating in the waste from rape oil industry (90.9-95.5 %) and in fish waste after filleting (92.5 %). Fish bones contained only 50.4 % of organics. The samples of rape press cake and fish waste after filleting were suitable for the experiments. Only fish bones were dried before crushing.

The ratio of carbon and nitrogen in the raw material is a very important indicator for the process of anaerobic digestion. High enough C/N ratio was found in the samples of hulls from press cake (19.4) and fish filleting waste (11.2), and lower from not dehulled press cake (8.9) and fish bones (4.9). The highest concentration of the total phosphorus was estimated in the fish bones (about 10 %) and the potassium in the not dehulled press cake (1.0 %). Calcium was dominating in the fish bones (12.0 %).A very high concentration of lipids was found in the fish filleting waste (54.0 %) and the hulls (32.8 %).

Table 1

Chemical composition of fish filleting wastes and rape press cake

Parameter	**Results of chemical analysis**			
	KOR2-HU1	**KOR2-PC**	**Fish waste after filleting**	**Fish bones**
Total solids (TS) %	92.26	92.88	41.58	95.01
In total solids:				
Organic material (volatile solids VS), %	95.54	90.90	92.48	50.41
Organic carbon (C), %	60.29	52.94	69.75	31.45
Total nitrogen (N), $mg \cdot kg^{-1}$	31047	59268	62357	64040
Total phosphorus (P), $mg \cdot kg^{-1}$	3876	9109	12912	100223
Total potassium (K), $mg \cdot kg^{-1}$	6997	10079	5583	1750
Calcium (Ca), %	0.79	0.69	2.29	12.0
Magnium (Mg) %	0.23	0.42	0.06	0.29
Cuprum (Cu), $mg \cdot kg^{-1}$	6.33	5.77	7.73	0.57
Zink (Zn), $mg \cdot kg^{-1}$	26.0	51.0	32.0	93.7
Manganum (Mn), $mg \cdot kg^{-1}$	32.2	57.4	5.50	34.6
Ferrum (Fe), $mg \cdot kg^{-1}$	149	137	20.4	42.7
Borum (B), $mg \cdot kg^{-1}$	37.3	27.7	17.9	2.93
Sulphur (S), $mg \cdot kg^{-1}$	1644	2045	294	2005
Fat (lipids), %	32.8	17.8	54.2	8.23

The experimental system was set up and monitored at the Energy and Biotechnology Engineering Institute located in the Aleksandas Stulginskis University in Lithuania. The nominal volume of laboratory anaerobic digester was 20 liters and the experiments were operated with an active volume (inoculums) of 19 liters. Starting inoculums were degassed before the experiments with the investigated samples. The design of anaerobic digester enables to perform experiments in mesophilic (25-40 ºC) and thermophilic (52-60 ºC) temperatures. Digester consists of: stainless steel vessel 1, substrate mixer 2, biogas flow meter 3 and gasholder 4, biogas analyser 5. The temperature in the digester is measured by temperature sensors 7 and controlled by the heating system 8 automatically as well as substrate mixing. Data of temperature and alkalinity of substrate, biogas yield and composition are registered by programmable logic controller and stored in the computer database.

The produced biogas is collecting at the top of the digester and goes through the biogas flow meter 3 to the gasholder 4. Later collected biogas is analysed by the biogas analyser SSM 6000. Biomass is added through the pipe on the top of the digester and the digested substrate drains to the output.

The digestion process takes place at mesophilic temperature conditions. The digester was operated at 38 ºC, the heating method controlled the internal temperature of the digesters within ± 0.5 ºC of the nominal temperature. The reactors were loaded with 2.0 kg·m^{-3}·d^{-1} organic load.

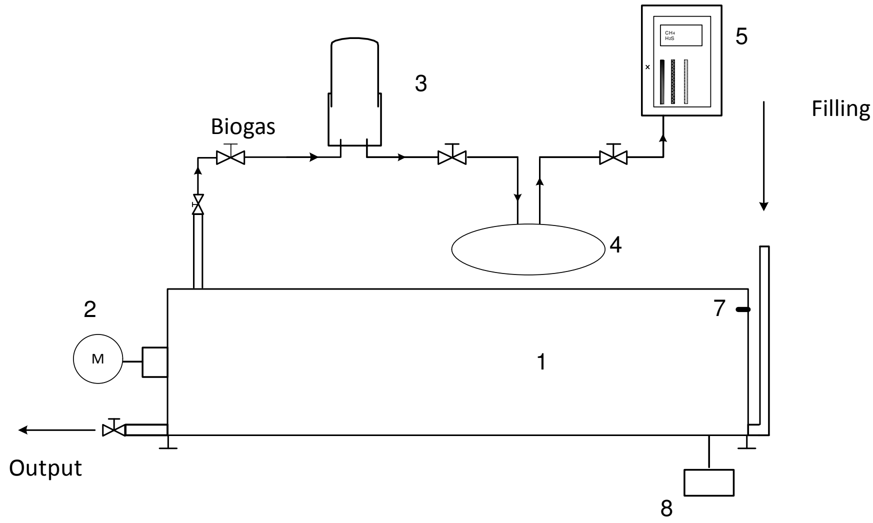

Fig. 1. **Laboratory anaerobic digester:** 1– reactor; 2 – stirrer gear; 3 – biogas flowmeter; 4 – gasholder; 5 – biogas analyser; 7 – thermometers; 8 – temperature controller

Three experiments were performed with each type of wastes. The results of biomass anaerobic digestion can be evaluated using the following indicators: intensity of biogas production, biogas yields from biomass B_M, biogas yield from biomass total solids B_{TS} and biogas yield from biomass volatile solids B_{VS}. The biogas production intensity b indicates the duration of biomass biological degradation. The biogas yields were calculated with elimination of the residual yield of the starting inoculums.

The biogas yield from biomass, from biomass total solids and from biomass volatile solids B_M, B_{TS}, B_{VS} is calculated by equations [10]:

$$B_M = \frac{b_{dt}}{m}; B_{TS} = \frac{b_{dt}}{m_{TS}}; B_{VS} = \frac{b_{dt}}{m_{VS}}; \tag{1}$$

where b_{dt} – volume of produced biogas during the time interval dt, l;
m – mass of example, kg;
m_{TS} – mass of total solids in the sample, kg;
m_{VS} – mass of volatile solids in the sample, kg.

Results and discussion

The potential of biogas production using the batch system was investigated with four different agroindustrial wastes (fish waste after filleting, fish bones, hulls (KOR2-HU1) light dehulled and rape press cake (KOR2-PC) not dehulled.

The biogas yield from hulls (KOR2-HU1) was found digesting 40 g samples on the batch laboratory digester. The biogas yield varied in the range of 808 l·kg^{-1} to 938 l·kg^{-1} of raw biomass, in the range of 876 l·kg^{-1}·TS^{-1} to 1017 l·kg^{-1}·TS^{-1} from total solids and in the range of 917 l·kg^{-1}·VS^{-1} to 1064 l·kg^{-1}·VS^{-1} from volatile solids (Fig. 2). The biogas yield average was 882.5 l·kg^{-1} of raw biomass 946.3 l·kg^{-1}·TS^{-1} and 990.9 l·kg^{-1}·VS^{-1}. The duration of biomass biological degradation in the digester was 10 days. It indicates that biological degradation of rape press cake is intensive. Methane concentration in the biogas was very high – 63.1-65.1 % and H_2S was found (415-655 ppm) in the biogas.

The biogas yield from rape press cake (KOR2-PC) was found using 45 g samples on the batch laboratory digester. The biogas yield varied in the range of 564 l·kg^{-1}to 592 l·kg^{-1} raw biomass, in the range of 607 l·kg^{-1}·TS^{-1} to 667 l·kg^{-1}·TS^{-1} from total solids and in the range of 667 l·kg^{-1}·VS^{-1} to 734 l·kg^{-1}·VS^{-1} from volatile solids (Fig. 3). The biogas yield average reached 583 8 l·kg^{-1} of raw biomass 615.2 l·kg^{-1}·TS^{-1} and 680.2 l·kg^{-1}·VS^{-1}. The duration of biomass biological degradation in the digester was 5 days. It indicates that biological degradation of not dehulled rape press cake is intensive, too. Methane concentration in the biogas was very high – 62.2-64.9 % with H_2S (698-934 ppm) in the biogas.

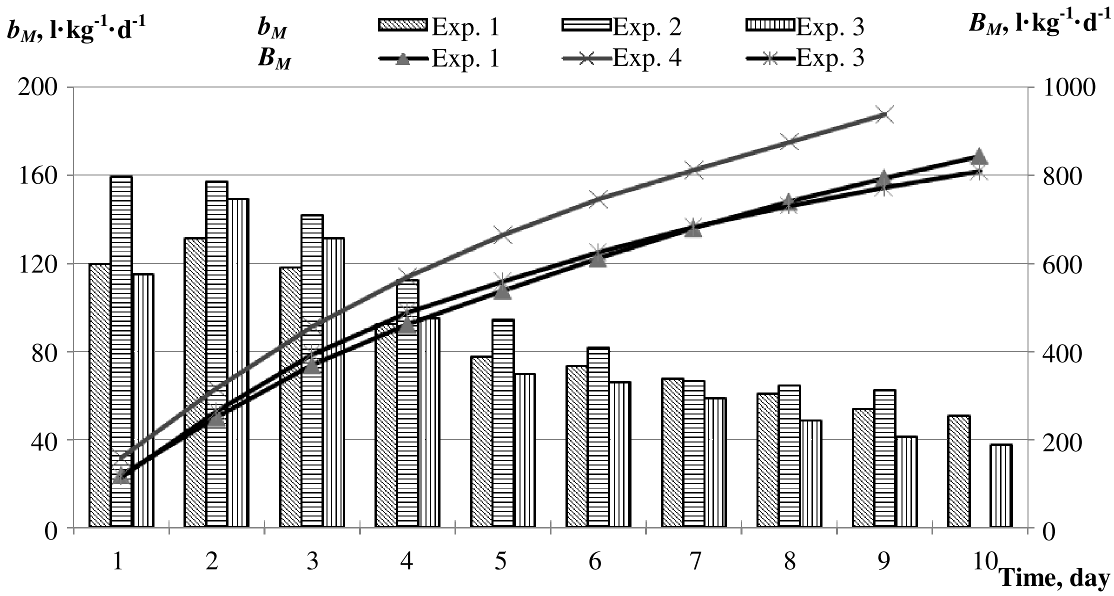

Fig. 2. **Daily (b_M) and cummulative (B_M) biogas yields from rape press cake (KOR2-HU1) during batch experiments**

Batch experiments with 50 g samples of fish filleting by-products were performed as well. The biogas yields varied in the range of 387 $l \cdot kg^{-1}$ to 425 $l \cdot kg^{-1}$of raw biomass, in the range of 930 $l \cdot kg^{-1} \cdot TS^{-1}$ to 1022 $l \cdot kg^{-1} \cdot TS^{-1}$ from total solids and in the range of 1006 $l \cdot kg^{-1} \cdot VS^{-1}$ to 1105 $l \cdot kg^{-1} \cdot VS^{-1}$ from volatile solids (Fig. 4). The average biogas yield from raw biomass was 401.0 $l \cdot kg^{-1}$, from TS – 968.3 $l \cdot kg^{-1} \cdot TS^{-1}$, and from VS – 1063.9 $l \cdot kg^{-1} \cdot VS^{-1}$.

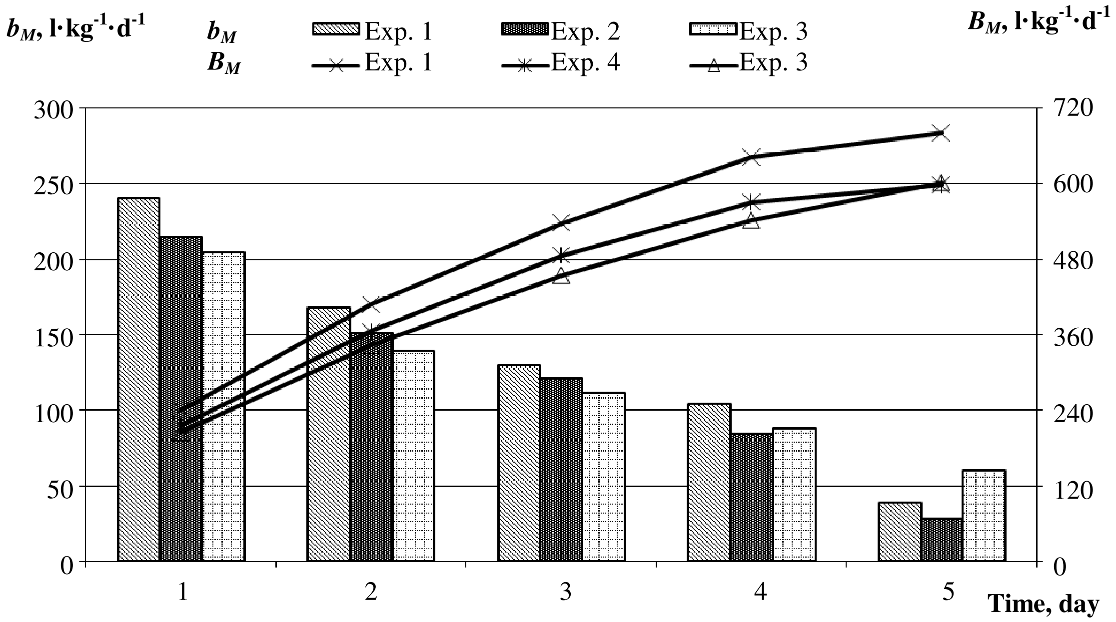

Fig. 3. **Daily (b_M) and cummulative (B_M) biogas yields from rape press cake (KOR2-PC) during the batch experiments**

The duration of biomass biological degradation in the digester was 5 days. Methane concentration in the biogas was significant – 64.2-65.1 % with high concentration of H_2S (428-620 ppm).

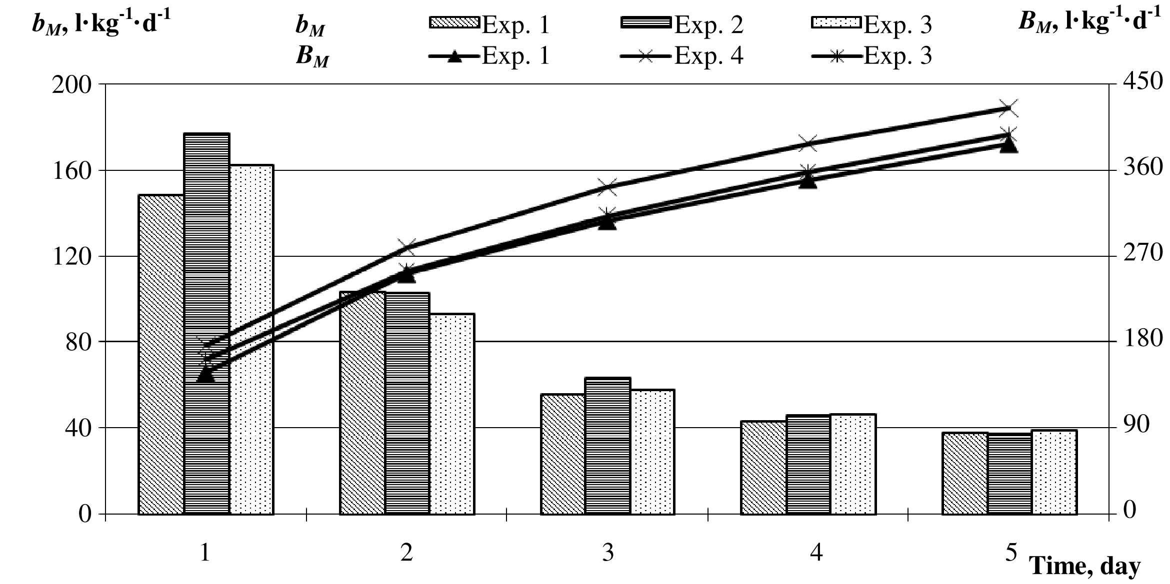

Fig. 4. **Daily (b_M) and cummulative (B_M) biogas yields from fish filleting by-productsduring batch experiments**

Batch experiments with 79 g samples of fish bones were performed as well. The biogas yields varied in the range of 354 $l \cdot kg^{-1}$ to 407 $l \cdot kg^{-1}$raw biomass, in the range of 374 $l \cdot kg^{-1} \cdot TS^{-1}$ to 428 $l \cdot kg^{-1} \cdot TS^{-1}$ from total solids and in the range of 741 $l \cdot kg^{-1} \cdot VS^{-1}$ to 807 $l \cdot kg^{-1} \cdot VS^{-1}$ from volatile solids (Fig. 5). The biogas yield average varied 583.8 $l \cdot kg^{-1}$ raw biomass, from TS – 615.2 $l \cdot kg^{-1} \cdot TS^{-1}$ and from VS – 680.2 $l \cdot kg^{-1} \cdot VS^{-1}$. High biogas yield was gained from fish bones because they contain high percentage of proteins and some fat that was left after preparation (Table 1). The duration of biomass biological degradation in the digester was 8 days. Methane concentration in the biogas was very high – 64.4-66.9 % and H_2S – 824-1012 ppm.

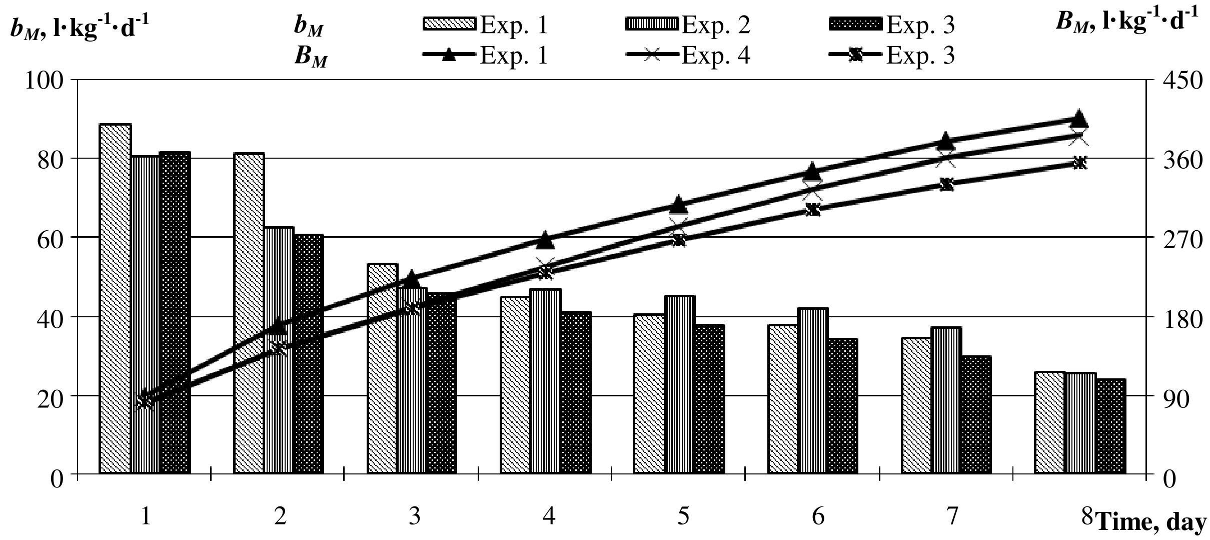

Fig. 5. **Daily (b_M) and cummulative (B_M) biogas yields from fish bones during the batch experiments**

The highest biogas yield was achieved while KOR2-HU1 using with the yield averaging 872 $l \cdot kg^{-1} \cdot d^{-1}$. The lowest biogas yield was achieved using fish bones, the yield averaging 38 $l \cdot kg^{-1} \cdot d^{-1}$. High concentration of H_2S in the biogas in all experiments was found due to the high concentration of proteins in a raw material.

Conclusions

1. The biogas yield from raw material light dehulled rape press cake (KOR2-HU1) was 32 % higher than from not dehulled press cake (KOR2-PC). The methane concentration in the biogas from light dehulled rape press cake was up to 0.5 % higher than from not dehulled press cake.
2. The biogas yield from raw material fish bones dropped by only 10 % comparing with fish waste after filleting, but the methane content was higher up by 1 % from fish bones then fish waste after filleting.
3. By-products from raw material rape oil processing and fish filleting generating high yields of the biogas with a high concentration of methane. These materials are suitable for biogas production. However, high concentration of hydrogen sulphide requires means for gas cleaning.

Acknowledgements

The research leading to these results has received funding from the European Community Seventh Framework Programme FP7/2007-2013 under grant agreement No. 289170 – APROPOS.

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