Anaerobic Fermentation of Certain Products of Food Industry – Food Waste, Spent Grain and Grape Pomace

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Abstract—**Biodegradable products of food industry represent input substrates of biogas plants. Of these, food waste, grape pomace and spent grain were the products of choice for analyzing which tested biogas production and quality. The latter being in particular determined by methane and hydrogen sulfide content. Anaerobic fermentation was underway 26 days at mesophylic temperature 42 ℃ in a batch labscale reactors with volume 120 dm^3. The following values were measured in relation to specific yield of methane: food waste: 0.347 m^3 per kg, grape pomace: 0.238-0.246 m^3 per kg, spent grain: 0.283 m^3 per kg. The specific production of hydrogen sulfide: food waste 752 mg per kg, spent grain: 585 mg per kg, red pomace: 74 mg per kg and white pomace 98 mg per kg.**

Index Terms—**biogas, anaerobic fermentation, food waste, spent grain, grape pomace**

I. Introduction

Renewable sources of energy include methane generated in biogas plants. In Europe, the input substrate generally involves crops cultivated for this purpose and combined with cattle/swine slurry. Biodegradable products present another potential alternative [1], [2]. Options in this regard include the use of waste from food industry. Making the process of anaerobic fermentation well balanced and stable however necessitates good knowledge of properties of such waste products. Materials specified for testing comprised grape pomace, food waste and spent grain; Table I.

Grape pomace is a side-product of wine making. It consists of grape skins, fruit stems and uncrushed seeds. For this material, the seasonal production pattern is the main drawback in terms of use. Subjected to testing were the side-products of both red wine and white wine production.

Food waste produced at the dining hall of Mendel University in Brno became another input substrate. This involved mixed waste collected from the local organic waste container over the period of 14 days, with each collected quantity weighing 10 kg. The samples were homogenised and fed into reactors in batches, the mass loading rate being 0.35 kg per kg. There were four reactors, their volume was 120 dm^3 each. The results obtained were averaged.

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TABLE I. Tested Material Quantity

Material	Dry matter	Combustible matter	Batch	Mass loading rate	Combust. heat
	[%]	[%]	[kg]	[kg.kg^{-1}]	[MJ.kg^{-1}]
Inoculum	3.69	59.73	100	-	-
Food waste	22.96	96.57	5.63	0.35	-
Grape pomace, red	33.69	91.19	3.83	0.35	17.30
Grape pomace, white	36.65	84.27	3.52	0.35	20.17
Spent grain	19.70	94.89	6.56	0.35	19.60

Mixed waste produced by dining hall of Mendel University in Brno was another material tested. Studied were only the remnants of meals. Sampling was underway over the period of 5 days with 20 kg of waste collected on a daily basis; the waste was homogenized and 5 kg were removed for testing.

Spent grain was the last of the materials tested. Spent grain involves a solid waste product of beer filtration. It contains plumes and plume fragments, precipitated protein sediment and other suspended matter [3].

The analyzing activities tested and compared volumes of biogas produced from food waste sourced from the dining hall, spent grain with barley malt from Mendel University's brewery and grape pomace sourced from South Moravia (ther Blauer Portugieser variety). Testing took place by means of anaerobic fermentation in agitated reactors, their volume being 130 dm^3 per unit. Since generally biogas operators in the Czech Republic make use of liquid substrates for anaerobic fermentation that they maintain to run under mesophilic conditions, our analysing operations were run under the same settings with used inoculum transported from a reactor based at a biogas plant operated in the field being the liquid substrate.

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II. Methodology

Initially, the baseline parameters were determined of tested materials, such as the content of dry matter and organic dry matter as well as calorific values. Dry matter was determined at 105 ± 3 °C as per ČSN EN 14346. Organic dry matter was also determined at 550 ±25 ℃ as per ČSN EN 15169. The dry matter figures were used for computing the quantity of each substrate per batch to ensure that the fermentor mass loading rate was 0.35 kg of dry matter added per kilogram of dry matter of the inoculum.

Anaerobic fermentation testing was underway for 26 days in the national reference laboratory of biogas transformations. The testing activities made use of 130 dm^3 reactors that were heated up to the constant temperature of 42 ℃ and agitated for 60 seconds once per 600 seconds [4]. Inoculum was added into the reactors in batches, the amount being 100 kg per unit. One of the reactors was maintained each time as a reference unit and the quantity of the tested material was fed into the remainder in batches as per Table I. Subtracting biogas and methane production of the reference reactor from the production of the other units yielded the quantity equaling the production of the tested material.

The above was followed by analyzing the biogas quantity and quality. The biogas quantity was measured once per day using the BGK4 gas meter while analyzing biogas composition (CH_4, CO_2, O_2, H_2, H_2S) by means of the Combimass GA-m device.

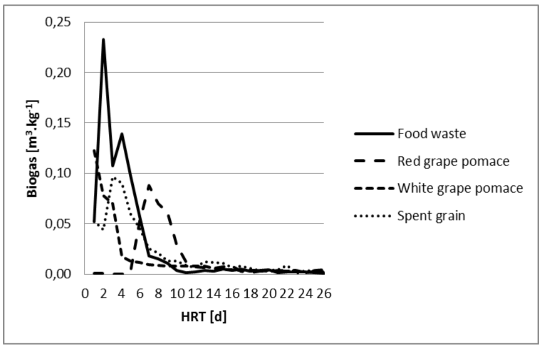

Figure 1. Biogas specific yield.

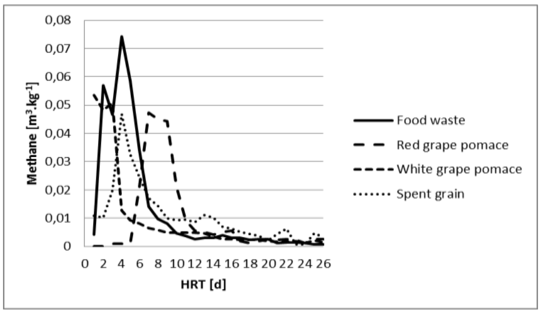

Figure 2. Methane specific yield.

III. Results and Discussion

The daily biogas and methane production was the highest in the initial days of testing in the majority of tested materials; Fig. 1 and Fig. 2. This was due to the use of batch processing technology. Red grape pomace formed the only exception when the output of biogas and methane was at a minimum level over the initial five days, with the subsequent sharp onset of production.

The methane content in biogas is a very important parameter especially in terms of biogas application potential. In the Czech Republic, biogas is most often used as a source of energy in cogeneration units with combined generation of electricity and heat. Such facilities run on the basis of combustion engines, requiring fuel of predefined quality for their gas operations. The minimum content of methane for combustion in CI engines and SI engines is 45% to 50 % as reported by, while for internal-combustion turbines it is 55% [5].

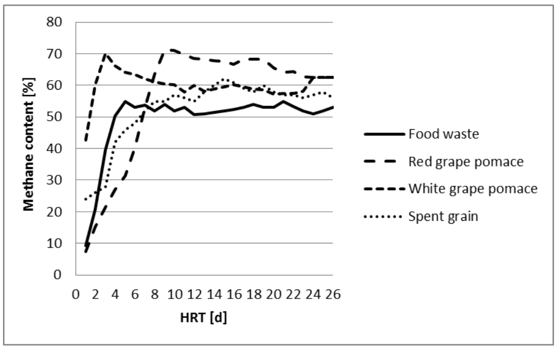

Figure 3. Methane content.

The highest average content of methane in biogas was found for red grape pomace while the lowest value was found for food waste; it was even below the lower threshold for direct usability; Fig. 3. It was caused by the biogas production being extremely high particularly in the earlier part of the test when the methane concentration was below 50%. [6] reports that the average concentration of methane generated from food waste was 69% at 35 ℃. [7] provides the average methane content being 73% at fermentation temperature of 45 ℃. This means that methane content in biogas is highly variable when fermenting food waste and can be influenced particularly by the composition of the mixture fermented or by the fermenting temperature.

The total output of biogas and methane determines the energy potential of the materials tested. The time of delay at operational biogas plants ranged from 30 to 60 days, with the optimal period being 90 days in terms of maximum usage of the energy potential. Since well-balanced conditions under laboratory testing make the processes to run faster, the biogas production is nearly zero after a period of 26 days; Fig. 1. The total of 12% to 53% organic material is decomposed during anaerobic fermentation [8].

Hydrogen sulfide is toxic and highly reactive gas, so its presence in biogas is undesirable from the standpoint of safety and equipment protection [9]. The high content of hydrogen sulfide must be removed from the biogas. The feasible hydrogen sulfide concentration in biogas used in combustion unit is up to 200 ppm.

During the test, the hydrogen sulfide content reaches over the concentration threshold. The batch system is used to validate the absolute production of hydrogen sulfide and its formation dynamic from the raw material.

To compare continuous process with batch system the average content of hydrogen sulfide in the biogas for the entire test is used. The highest hydrogen sulfide content was found at the spent grain 469 ppm and 365 ppm for food waste, Fig. 4. This value exceeds the limit value for direct combustion. It is necessary to desulfurize the biogas. The hydrogen sulfide concentration content was measured for red pomace 190 ppm and for white pomace 210 ppm. Both values are very low. Specific production of hydrogen sulfide is calculated from measured biogas production and hydrogen sulfide concentration contained therein. It also subtracts the amount of hydrogen sulfide produced from the inoculation of the substrate. The resulting value is then recalculated to the amount of solids added test material; Fig. 5.

For all tested materials, differences in the dynamics, as well as, the total amount of produced hydrogen sulfide were detected. The highest concentration was measured in a food waste sample [10], where the total hydrogen sulfide production was 752 $mg.kg^{-1}$. High level of produced hydrogen sulfide was detected at sample spent grain (585 $mg.kg^{-1}$). For grape pomace samples the hydrogen sulfide production was 74 $mg.kg^{-1}$ at red pomace and 98 $mg.kg^{-1}$ at white pomace.

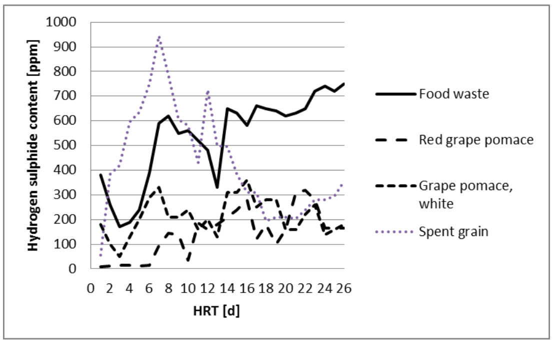

Figure 4. Hydrogen sulphide content.

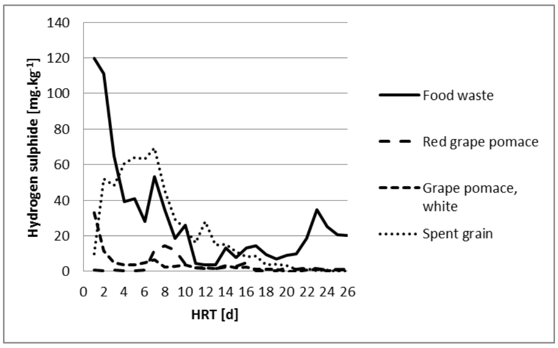

Figure 5. Hydrogen sulphide production.

To evaluate the usability of the tested materials at biogas plants, their specific yield of methane can be analyzed against that of the most frequent material, which is ensilaged maize. According to various authors, specific yield of methane ranges from 0.282 to 0.419 m^3 per kg for ensilaged maize [10], [11]; the comparison thus shows that food waste presents a very good material, while the other types of matter do not achieve the qualities of the raw material now used.

IV. Conclusion

The study tested four selected types of biodegradable waste by subjecting them to anaerobic fermentation which was underway 26 days at 42 ℃. The materials involved food waste, red grape pomace, white grape pomace and spent grain.

Of these, mixed food waste was found to exhibit the highest specific yield of methane, 0.347 m^3 per kg, with the average methane content being 44.4%; Fig. 6. In terms of methane production, food waste presents a highly advisable material for use at biogas plants. It's very low methane concentration however disables direct combustion, thus has to be increased by treatment of the input mixture. Red wine pomace and white wine pomace reached very similar values of total methane production (0.238 and 0.246 m^3 per kg) as well as methane content in biogas (59% and 62%).

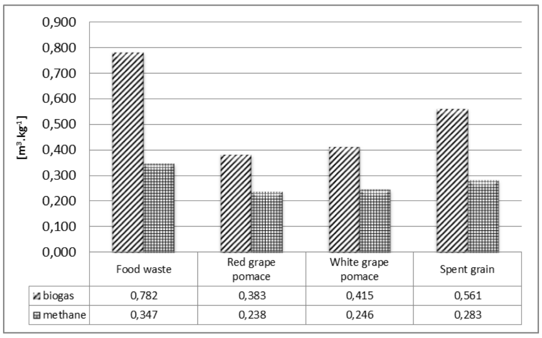

Figure 6. Biogas and methane specific yield.

The difference between the two was found in the process dynamics when biogas generation from red wine pomace started as late as day 5 of testing.

Spent grain was the last of the materials tested. The specific yield of methane was measured to be 0.238 m^3 per kg, and the average methane content was 50.5%.

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