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Impact of Fatty Waste on Anaerobic Digestion of Sewage Sludge at a Municipal Wastewater Treatment Plant - A Case Study

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Abstract Anaerobic digestion is a common method for utilization of sewage sludge at large-scale wastewater treatment plants. This process generates biogas, which is a source of renewable energy. Intensification of biogas production can be achieved, for example, through co-digestion, with fatty waste characterized by a high methane potential (0.85 Nm^3/kg VS versus 0.136 Nm^3/kg VS for excess sludge). However, due to high lipid content, fatty waste can cause incomplete degradation of organic compounds and accumulation of volatile fatty acids (VFA) in the digester.

The purpose of this study is to show the changes in the efficiency of the digestion process at a municipal wastewater treatment plant after feeding digester with fatty waste. Co-fermentation shortened HRT from 27.0 d to 23.7 d. The use of co-digestion had a positive effect on biogas production. Volume of biogas increased from 2750 Nm^3/d to 4004 Nm^3/d (average). It was noted that the percentage share of organic dry matter in the digested sludge decreased on average from 71.32% to 69.15%.

Keywords: anaerobic digestion, biogas, municipal wastewater treatment plant, co-digestion

1. Introduction

The wastewater treatment plant (WWTP) generates large amounts of sludge. In the years 2000-2020, the mass of sewage sludge produced in Poland increased by approximately 58 %, from 360 thousand tons to almost 570 thousand tons of dry matter, respectively (Environment, 2021). Anaerobic digestion (AD) is one of the most widely used processes for the stabilization of wastewater treatment plant sludge. The undoubted advantage of the digestion process is the production of biogas. Biogas from AD is the main product and counted as a form of renewable energy. It contains methane which can be utilized in a combined heat and power plant unit (CHPU) to generate electricity and heat to cover the entirety or parts of a WWTP's energy demand (Wehner at el., 2021). In recent years, co-digestion processes have been used to increase biogas production at municipal wastewater treatment plants. A range of substrates used to increase the performance of sewage sludge AD is very wide; for example, organic fraction of municipal solid waste, grass, fats, oils and greases, food waste, manure, and trade wastes (Berzal de Frutos at el., 2023). In 2021, 27302 Mg of fatty waste was used for agricultural biogas production in Poland (Data, 2023), which have a high methane potential. Fats, oil, and grease is considered to be a desirable substrate to enhance biomethane production through co-digestion as it has been reported to increase the methane yield by 250-350% (Salama at el., 2019, Skripsts at el., 2022). This paper presents changes in the efficiency of the anaerobic digestion process, following the co-digestion of sewage sludge and fats. The analysis showed that the addition of fats increased biogas production and improved digestate parameters.

2. Materials and Methods

2.1. Characteristic of WWTP

The research was conducted at a municipal WWTP located in the Mazowieckie Voivodeship in Poland. WWTP has a design capacity of 139 500 PE, with an average flow of 15 500 m^3/d. Sewage sludge at the WWTP is thickened (primary sludge by gravity, excess sludge by centrifuges) and directed to two digesters with a capacity of 3 000 m^3 each. In the digester, an anaerobic process takes place at 35ºC. The sludge retention time in the digester, assumed for the plant design, was 22 d, with a chamber load of 1.1 kg VS/m^3·d. The digestion process produces biogas. In 2020, fatty waste was dosed sporadically into the digesters to increase biogas production, and in 2021 continuous dosing took place.

2.2. Analytical methods

The volume of thickened sludge sent to the digester and fatty waste was measured daily with a flow meter. TS and VS were determined in the substrates and digested accordance with norms PN-EN 15934:2013-02 and PN-EN 15935:2013-02, at 105ºC and 550ºC respectively.

In liquid phase was determined:
- pH - PN-EN ISO 9963-1:2001
- volatile fatty acids (VFA) - use of standard LCK vial test kits (HACH-Lange) in the liquid phase
- alkalinity - PN-EN ISO 9963-1:2001

The liquid phase was obtained by centrifugation of the sample (30 minutes, 15,000 rpm, 19,621 x g), followed by high-pressure filtration through membrane filters (pore diameter of 0.45 µm).

3. Results and Discussion

In 2020, 79190 m^3/year of thickened sludge and only 215.8 m^3/year of fats were diverted to the digester (fats were only fed in January, June, September, and December). In 2021, the total volume of sludge increased to 87089 m^3/year and that of fats to 1139.8 m^3/year. The volume of fats thus represented only 1.3% of the substrate sent to the digester. However, in 2021, fats were fed every month and the volume ranged from 33.2-167.25 m^3/month.

Despite the increase in volume, the organic mass of substrate directed to digestion decreased from 3303 Mg VS/year (2020) to 2772 MgVS/year (2021). The quality of the substrates is shown in Table 1 and the quality of the digestate in Table 2.

Table 1. Quality of substrate directed to the digester

Parameter	Year	Min	Average	Max
TS [%]	2020	2.2	4.2	9.3
	2021	1.94	3.84	7.46
VS [%]	2020	70.94	80.01	86.73
	2021	62.14	81.71	85.98

Table 2. Quality of digestate

Parameter	Year	Min	Average	Max
TS [%]	2020	1.99	2.50	5.13
	2021	1,03	1,45	4,70
VS [%]	2020	67.23	71.32	88.91
	2021	63,71	69,15	76,88
pH [-]	2020	6.0	7.2	7.4
	2021	7.0	7.3	7.6
Alkalinity [mg/L]	2020	800	3028	5650
	2021	2100	2798	3600
VFA [mg/L]	2020	112	200	351
	2021	128	192	390

The substrates dosed to the fernet chambers were characterized by a high VS content, which increased slightly to an average of 81.71 as a result of fat dosing, while the average TS content decreased from 4.2. to 3.84.

VS, and VFA contents in the digestate were lower in 2021 than in 2020, indicating a more efficient digestion process.

Table 3. Operational parameters of digester

Parameter	Year	Min	Average	Max
HRT [d]	2020	10	27.0	46.2
	2021	16.8	23.7	37.5
OLR [kgVS/m^3·d]	2020	1.04	1.23	1.43
	2021	0.80	1.05	1.43
T[ºC]	2020	32.4	35.5	38.7
	2021	29.7	35.3	37.3

In both years, the digestion process was carried out at the same temperatures, while the increase in substrate volume resulted in a reduction in HRT to 23.7 d.

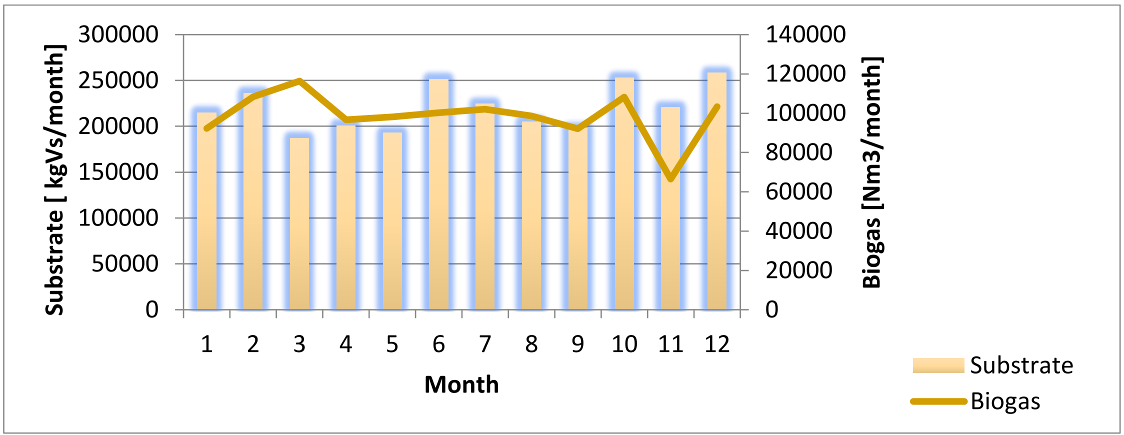

Figure 1. VS of feedstock and biogas production in 2020.

Figure 1 shows that not in all cases does the increase in biogas volume correlate with the dosage of fats into the digester. The reason for this may be that the chamber is adapting to the new substrate. However, only in September, the addition of fats resulted in a decrease in biogas.

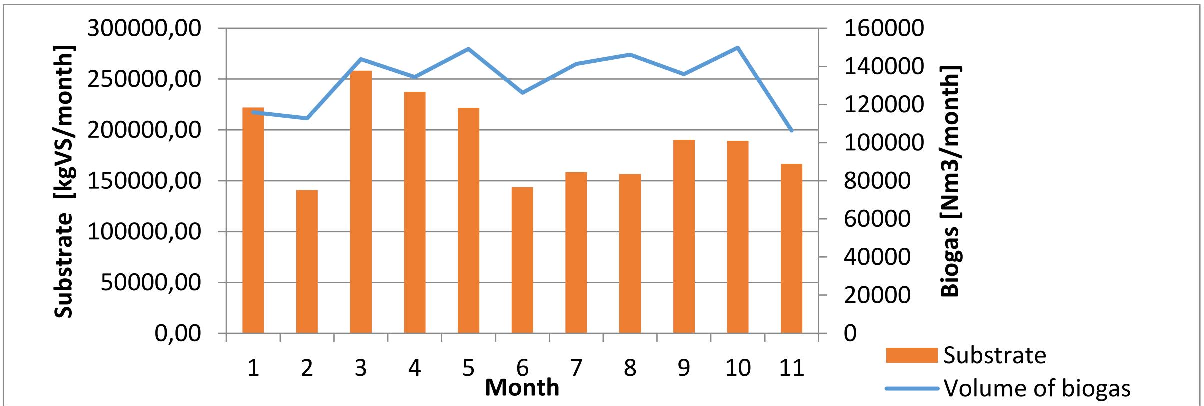

Figure 2. VS of feedstock and biogas production in 2021.

The highest volume of fats was dosed to the chambers in the months of June, September, and November. A decrease in biogas volume is noticeable in these months. Lipid content in the feed mixture resulted in incomplete degradation, in accumulation of volatile fatty acids in the digester, and subsequent decrease in biogas production (Luostarinen, 2008). This was explained by methanogenesis step inhibition by long chain fatty acids.

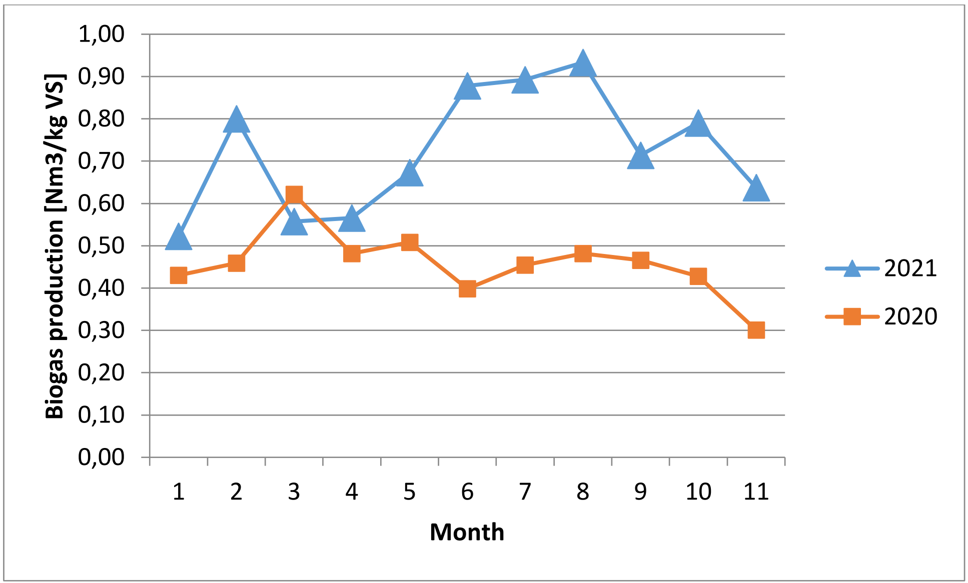

Figure 3. Specific bigas production (SBP)

Increasing the volume of added fats resulted in a significant increase in specific biogas production from 0.452 Nm^3/kgVS to 0.724 Nm^3/kgVS.

Conclusion

In the case of the Otwock wastewater treatment plant, co-digestion had a positive effect on both the quality of the digestate, the operational parameters (OLR, HRT), and the amount of biogas produced, which increased by 23.6%.

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