Textile sludge valorization: a challenge toward a more sustainable system

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Introduction

The sludge (TXS) generated as a by-product in the textile wastewater biological treatment could contain some toxic organic compounds, such as dyes, additives, polycyclic aromatic hydrocarbons, aromatic amines, and heavy metals (Zhou et al., 2021). Therefore, due to its composition, landfilling and incineration are the destination of TXS. However, these waste management methods do not conform to the concept of circular economy (Tapsoba et al., 2020), and a sustainable treatment towards TXS is urged.

Anaerobic digestion (AD) is a sustainable process that leads to the production of biogas, a mixture mainly composed of CH_4 (45-55%) and CO_2 (35-40%) (Corsino et al., 2021), while decreasing organic content of sludge (Aksu Bahçeci et al., 2021). The biochemical methane potential (BMP) test is a laboratory method to assess the digestibility and methanogenic potential of a variety of substrates (Filer et al., 2019). Regarding TXS, abundant organic compounds provide the possibility for AD treatment (Xiang et al., 2016). However, the process could be adversely affected by the toxicity of pollutants contained in the sludge.

This work aimed to assess AD as a sustainable pathway for TXS valorization. For this purpose, BMP tests using TXS from different origins were carried out comparing their performance with sludge from an urban wastewater treatment plant (WWTP). During these tests, the optimal Inoculum-to-Substrate ratio (ISR) for TXS was also established. In addition, the biogas production using sludge from an Italian WWTP, treating a mixture of urban (30%) and textile (70%) wastewater (Muoio et al., 2019), was also evaluated.

Materials and Methods

The inoculum for AD was collected from the anaerobic digestors of the urban WWTP in Manresa (Spain). The urban sludge used as substrate was also collected downstream of the dewatering section of the sludge treatment line of the same WWTP. Additionally, TXS samples (as AD substrate) were collected from two Catalan textile facilities (TXT I and TXT II) and finally, the mixture of urban and textile sludges was collected from the WWTP of the district of Prato (Italy). For all samples total and volatile solid contents (TS and VS) were analyzed using the Standard Methods 2540 B and E APHA.

BMP tests were conducted in triplicate for each assay at 35°C for 32 days. TXT I tests were performed ranging ISR from 1 to 2 to determine the optimal ratio. TXT II, urban, and mixed tests were evaluated using an ISR of 2. The monitoring of biogas production throughout the experiment was carried out based on the measurement of the accumulated pressure inside the glass vials and the volume of biogas was calculated under normal conditions. Finally, the biogas composition (CH_4 and CO_2 contents) was analyzed using a 990 Micro GC gas chromatograph by Agilent.

Results and Discussion

Results obtained in the BMP tests using different sludges as substrates are presented in Table 1. For TXT I, the highest and lowest biogas productions were observed at an ISR of 1.25 and 2.00, respectively. Considering the quality of the biogas, it is characterized by a methane content higher than 60% and a carbon dioxide content lower than 16% in all considered cases. Despite the highest quantity produced, an ISR equal to 1.25 is associated with the lowest purity level of the gas (the lowest CH_4/CO_2 ratio). In this sense, the ISR value that leads to the highest methane content was 1.75.

Table 1. Comparison of BMP test results (mean ± SD).

Sludge	VS (%)	ISR	Inoculum (g VS/L)	Biogas production (mL)	CH_4 (%)	CO_2 (%)	CH_4/CO_2
Urban	0.41	2.00	3.17	14.18±0.20	47±0.08	10±0.001	4.80
Mixed	17.1	2.00	3.17	11.70±2.71	43±0.11	10±0.02	4.22
TXT II	13.4	2.00	3.17	4.25±0.74	37±0.05	9±0.02	4.09
TXT I	6.6	2.00	3.17	4.49±0.54	41±0.13	8±0.01	5.03
		2.00	9.75	9.81±2.66	61±0.30	15±0.03	4.08
		1.75	9.75	18.67±8.20	64±0.04	14±0.06	4.53
		1.50	9.75	15.13±2.57	63±0.33	14±0.03	4.39
		1.25	9.75	19.15±0.82	61±0.05	15±0.08	4.02
		1.00	9.75	17.26±10.1	61±2.68	14±0.88	4.35

The BMP tests applied to different types of substrates demonstrated that the digestion of urban sludge produces the highest quantity of biogas. In contrast, the lowest biogas volume is associated with the digestion of both TXS. Finally, the amount of biogas produced by the digestion of mixed sludge is close to the volume produced by urban sludge. This trend is in accordance with results reported by (Tapsoba et al., 2020) who found that the co-digestion of TXS with urban sludge leads to an increase in biogas volume as the content of TXS decreases. Despite the lowest amount, the digestion of TXT I sludge produces a very high quality of biogas (CH_4/CO_2 equal to 5), even better than the biogas from urban sludge (CH_4/CO_2 equal to 4.8).

Conclusions

The results of the BMP test applied to TXS show that the highest amount of biogas is obtained through an ISR of 1.25, but its composition is the worst in terms of CH_4/CO_2. The ISR value of 1.75 turns out to be the best value from a process efficiency point of view. Regarding the biogas composition, it results in a CH_4 content higher than 60%. The BMP test applied to the different types of substrates shows that the digestion of TXS produces the lowest amount of biogas. Nevertheless, the CH_4/CO_2 ratio from TXT I is better than that from urban sludge. The biogas production could be improved by mixing textile and urban wastewater, as demonstrated by the BMP test applied to the mixed sludge. This solution implemented in Prato also avoids the logistical problems of transporting textile sludge for co-digestion with urban sludge.

These results demonstrate how the anaerobic digestion of TXS could represent a sustainable alternative to landfilling. In addition, they show that the digestion of textile sludge with urban sludge can lead to an improvement in efficiency. In the future, more tests will be needed to determine the best process parameter values for possible full-scale applications.

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