Evaluation of the optimal sewage sludge pre-treatment technology through lab-scale CSTRs – Performance and reliability assessment prior to pilot implementation.

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As a result of global energy demand and intensification of climate change's impacts, a growing sense of urgency has been raised for the establishment of new practices that would aim at the use of renewable energy sources and the valorization of wastes for bioenergy production as an alternative to fossil-based fuels (Atelge et al., 2020). In the context of this impending transition to sustainable energy generation, the methane content of biogas produced by anaerobic digestion (AD) of sewage sludge plays a pivotal role. Considering sludge's complex floc structure and poor content of biodegradable compounds, a variety of successful pre-treatment technologies (Mitraka et al., 2022) has been developed to simplify its composition and enable the release of some intracellular substances for microbial degradation. This way, the efficient performance of AD is ensured, and methane production is enhanced (Junior et al., 2021).

On account of the above, in our previous work, preliminary Biochemical Methane Potential (BMP) batch experiments were conducted to evaluate fourteen (14) different methods for sewage sludge pre-treatment (Table 1) and identify the two that led to the most promising results, regarding sludge disintegration and methane productivity. In continuation of this experimental procedure, the present work was undertaken to further evaluate these optimal pre-treatment methods through lab-scale continuous reactor operation. The aim was to optimize their performance and efficiency before choosing the most reliable prior to implementation at a pilot scale.

Table 1. Conditions examined for sewage sludge pre-treatment.

	Thermal Hydrolysis
1	45º C for 48 h and then 55º C for extra 48 h
2	45º C for 72 h and then 55º C for extra 72 h
3	45º C for 72 h and then 55º C for extra 72 h under 0.5 bar of CO_2 pressure
4	45º C for 72 h and then 55º C for extra 72 h under 1.0 bar of CO_2 pressure
5	90º C for 3 h
6	90º C for 3 h under 0.5 bar of CO_2 pressure
7	90º C for 3 h under 1 bar of CO_2 pressure
	Alkaline Hydrolysis
8	NaOH 2% v/v
9	NaOH 4% v/v
	Thermo-chemical Pre-treatment
10	NaOH 4% v/v, 45º C for 72 h and then 55º C for extra 72 h
11	NaOH 4% v/v, 45º C for 72 h and then 55º C for extra 72 h, under 0.5 bar of CO_2 pressure
12	NaOH 4% v/v, 45º C for 72 h and then 55º C for extra 72 h, under 1 bar of CO_2 pressure
13	NaOH 4% v/v and 90º C for 3 h, under 0.5 bar of CO_2 pressure
14	NaOH 4% v/v and 90º C for 3 h, under 1 bar of CO_2 pressure

The substrate used for the performance of all the examined pre-treatment methods was a mixture of primary and secondary sludge (PSS) collected from the feed of the three mesophilic digesters that operate in Thessaloniki's Municipal Wastewater Treatment Plant (MWWTP). Thermal pre-treatments appeared to be the most efficient for enhancing biogas production. Specifically, the first method involved the treatment of sludge at 45º C for 48 h and then at 55º C for additional 48 h, while the second one indicated sludge heating at 90º C for 3 h. The statistically significant increments achieved in methane yield compared to the untreated sludge were 24% and 22%, respectively (data not shown).

To evaluate the two optimal methods, a set-up of three replicate continuous stirred reactors (CSTR) was settled with a total and working volume of 2.0 L and 1.5 L, respectively. The reactors operate under mesophilic (37º C) conditions. The first reactor (R1) is fed with untreated PSS. On the contrary, the second one (R2) is fed with PSS treated at 45º C for 2 days and then at 55º C for additional 2 days, while the third (R3) is fed with the same feedstock but treated at 90º C for 3 h. The experimental procedure is divided into 3 periods, in each of which the organic loading rate (OLR) will be gradually increased. In the first two periods, the hydraulic retention time (HRT) for all reactors is set at 22 days, whereas in the third period it is set equal to 18 days. The biogas produced by reactors is recorded daily, while methane content and volatile fatty acid (VFA) concentration are measured twice per week.

Up to now, the first experimental period at OLR of 1.04 g VS $L^{-1}_{reactor}$ d^{-1} has been completed. As anticipated and based on the results obtained from the batch experiments, R2 revealed the highest average performance in terms of methane yield (Figure 1), equal to 206 ± 20.29 mL CH_4/g VS. Particularly, this value corresponded to a 56% higher average yield, compared to that observed for the reactor fed with untreated sludge (R1) (132 ± 17.01 mL CH_4/g VS). The average methane yield observed for R3 was 169 ± 14.19 mL CH_4/g VS.

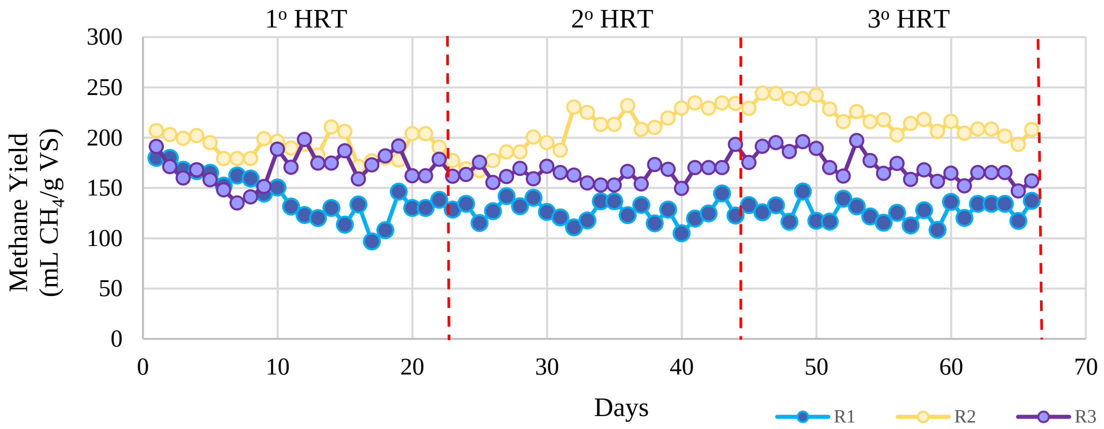

Figure 1. Reactors' performances in terms of methane yield during the first experimental period.

Currently, the second experimental period is in progress, and all the reactors are operating with an OLR of 2.00 g VS $L^{-1}_{reactor}$ d^{-1}. The OLR of all the reactors was increased using thickened PSS (raw and treated) as feedstock. On this basis, an increase in the performance of each reactor is expected compared to that observed during the first experimental period.

Once the second period is completed, all reactors will operate at the HRT of eighteen (18) days, aiming for a further increase in OLR, equal to 2.85 g VS $L^{-1}_{reactor}$ d^{-1} (third period). The gradual increase of OLR from 1 to 2.85 g VS $L^{-1}_{reactor}$ d^{-1} aims at investigating the correlation between the sludge loading and foaming in the digester. This way, useful conclusions can be drawn that will contribute to scrutinizing how to obtain maximum energy recovery, while avoiding operational problems that can disturb the efficient performance of anaerobic bioconversion. Along with this, at the end of each period, samples for microbial analysis will be collected to distinguish the microbial community regarding its relative abundance and diversity as a response to the changes in OLR. Therefore, it will be possible to correlate the microbial profile of each reactor with the biochemical parameters (pH and VFA concentration) monitored throughout the whole experiment. Consequently, an inference can be reached that will help in filling knowledge gaps regarding the various parameters affecting microbial population dynamics in AD. Thus, valuable key information will be revealed and assist in determining the digester's optimum operational conditions, while coming to a conclusion on the most reliable pre-treatment method for pilot implementation.

Specifically, the pre-treatment method leading to the most appreciable results in terms of AD performance enhancement while ensuring process stability will be validated on a larger scale, using a pilot-scale reactor with a total and working volume of approx. 800 L and 600 L, respectively. The reactor will operate under mesophilic conditions (37º C). Moreover, once per week, PSS from Thessaloniki's MWWTP will be collected and treated according to the optimal pre-treatment method so as to be used as feedstock. Based on the operational input and output data obtained throughout the whole experimental procedure in the pilot size unit, a techno-economic and environmental assessment will be performed to evaluate the viability of the studied system. The results will be available upon the conference time.

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References

Atelge, M. R., Atabani, A. E., Banu, J. R., Krisa, D., Kaya, M., Eskicioglu, C., ... & Duman, F. A. T. İ. H. (2020). A critical review of pretreatment technologies to enhance anaerobic digestion and energy recovery. Fuel, 270, 117494.

Mitraka, G. C., Kontogiannopoulos, K. N., Batsioula, M., Banias, G. F., Zouboulis, A. I., & Kougias, P. G. (2022). A Comprehensive Review on Pretreatment Methods for Enhanced Biogas Production from Sewage Sludge. Energies, 15(18), 6536.

Junior, I. V., de Almeida, R., & Cammarota, M. C. (2021). A review of sludge pretreatment methods and co-digestion to boost biogas production and energy self-sufficiency in wastewater treatment plants. Journal of Water Process Engineering, 40, 101857.