Operational parameters affecting dry batch anaerobic digestion of the organic fraction of municipal solid waste

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- Introduction

Dry-batch AD is a common treatment for high solid organic wastes like the organic fraction of municipal solid waste (OFMSW) (Rocamora et al., 2020), producing biomethane and reducing disposal to landfill. However, the impact of the different operational parameters on process stability and optimisation in full-scale assets are still poorly understood. For this reason, the present study aimed to understand process performance in relation to biogas yields and formation kinetics by elucidating optimal solid inoculum to substrate ratio (I:S), total solids (TS) content, percolate addition and feedstock particle size.

- Materials and methods

For the study, triplicates with 0.5 kg of substrate (S) and solid inoculum (I) mixture were placed at mesophilic conditions (38 °C) in 2.6 L squared and monitored for methane and biogas. To understand the impact of the I:S ratio the ADs were loaded with different ratios: 1:2, 1:4, 1:8 and 1:16 in VS. Experiments to understand the impact of TS content were operated with a I:S of 1:4 and different amounts of water were added to achieve TS contents of 25, 30, 35 and 40 %. Influence of percolate in the process was tested by using the same I:S ratio previously used (1:4), but different amounts of percolate were added instead of water, bringing the TS content to 27, 30, 33 and 36%. Finally, the impact of particle size was investigated in reactors with the same amount of percolate (26% TS) and same I:S (1:4), but with different particle sizes. Additionally, methane formation was modelled for all experiments trying to find the best fit. For these 5 models widely used in literature were used: first order kinetics, two stage model, modified Gompertz equation, logistic function (LM), and transference function (TF) (Pellera and Gidarakos, 2016).

- Results and discussion

When the effect of different TS was tested, higher biogas and methane yields were observed for ratios 1:2 and 1:4, with methane values of 1.7 and 2.2 $L/kgVS_{added}$, respectively. A performance drop was recorded for higher ratios, consistently with values reported in literature (Liu et al., 2009). This drop was attributed to the increasing quantities of substrate in the ADs, producing an overload of the system, due to the insufficient microbial community, like methanogenic archaea. This increase in substrate ratio produced a drop in pH by volatile fatty acids (VFA) accumulation, as the reduced microbial communities were insufficient for the high concentration of substrate. Results indicate decoupling of the anaerobic digestion stages and ultimately inhibition of the digestion process, as the highest biogas and methane yields were obtained for the blank ADs (no feedstock added), with a methane yield of 10.1 $L/kgVS_{added}$, almost 5 times higher than the experiment of 1:4.

As water was added to reduce TS content, a gradual increase of biogas production was observed, obtaining an increase of 85% in biogas at 25% TS (40.9 $L/kgVS_{added}$), compared to 40% TS (22.2 $L/kgVS_{added}$). The increase of water content resulted in better homogenisation in the ADs, reducing diffusion problems, increasing interaction between microorganisms and nutrients and diluting potential inhibitors (Forster-Carneiro et al., 2008). However, methane production remained low, reaching a maximum of 1.9 $L/kgVS_{added}$ at 35% TS. These results indicated that water addition cannot avoid acidification, which was evident from the final pH values in the range of 5.7 to 6.2, produced by total VFA concentrations from 17.7 to 20.6 g Ac-eq/L, while the corresponding blanks had a much lower concentration of 0.4 g Ac-eq/L and higher methane yields from 5.9 to 11.1 $L/kgVS_{added}$.

Percolate addition for moisture control led to significantly higher methane yields (Figure 1), with values of 200.2, 164.6, 199.4 and 277.8 $L/kgVS_{added}$ for ADs at 36, 33, 30 and 27% TS, respectively. The highest ultimate methane yield (277.8 $L/kgVS_{added}$) was achieved by the lowest TS content (27%). This experiment had also the fastest methane formation kinetics, emphasized by the results of kinetic modelling by logistic function model with reactors at 27% TS resulting in 12.6 days lag phase as opposed to the 29.9 days of reactors at 36%TS. Fastest kinetics was a result of the increase of moisture and solid-liquid mass transfer achieved as the TS content was reduced. These increase on the total yields resulted from the increased buffering capacity of the system associated with the high alkalinity of the percolate (Kusch et al., 2008). Percolate addition, unlike water, succeeded at maintaining the pH of the ADs over 8.

No difference was observed when particle size was reduced, 202.3 and 182.7 L/kgVS$_{added}$ for biogas and 127.3 and 113.2 L/kgVS$_{added}$ for methane at 50 and 10 mm particle sizes. These results were not statistically different, and together with the very similar VFA concentrations suggested no benefit on the hydrolysis step of the process. Although the differences in biogas and methane yields were not statistically significant ($p>0.05$), the lowest performance in terms of gas production was recorded for the smaller particle size. Two hypotheses could explain this behaviour. First, a release of inhibitory compounds as particle size is reduced for digestion (Izumi et al., 2010), and second a compaction of the media as digestion took place, blocking micro and macro-porous structures, which might be accelerated as the particle size is reduced (Shewani et al., 2017). This would reduce homogeneity on the ADs with time, explaining the faster methane production at the beginning followed by a decrease later on.

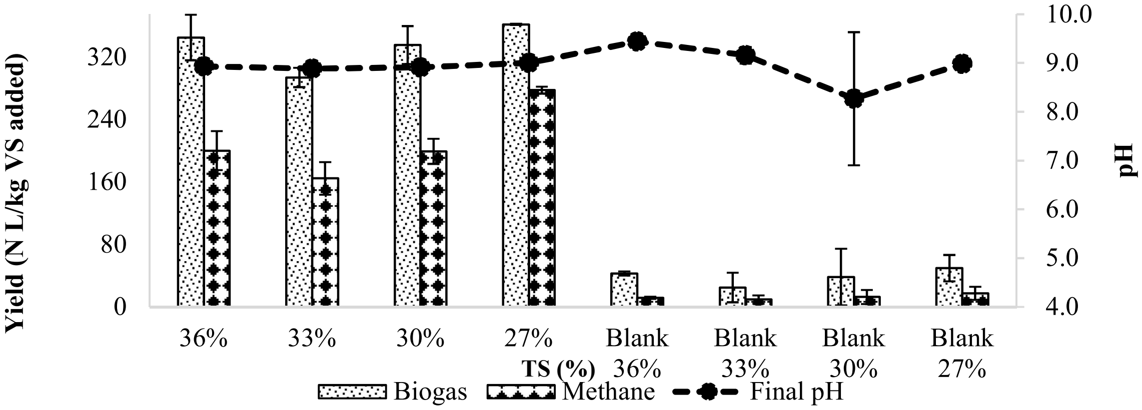

Figure 1. Biogas and methane yield and final pH for different TS contents with initial percolate addition.

- Conclusions

This study focused on the impact of operational parameters on dry AD performance treating OFMSW as feedstock, where literature is not abundant. Results showed that as TS were increased over 27%, homogeneity was reduced and localised inhibition occurred, reducing biogas and methane yield. When I:S ratios used were reduced (increased feedstock volumes treated), results showed that ratios below 1:4 overloaded the microorganisms of the process, but inhibition could not be avoided only by varying the I:S ratio. TS reduction by water and percolate addition improved biogas yield, but only percolate buffered the system's pH, avoiding acidification due to percolate's high alkalinity and boosting methane yield from 1.9 to 277.8 L/kgVS$_{added}$. Particle size reduction showed no yields improvement, although a reduction moderately increased methane formation kinetics for the sizes considered in this study. These results emphasise the benefits of percolate use in dry batch AD of OFMSW, as improves mass transfer and buffers the system, especially at the most vulnerable time for VFA accumulation, as it is the start-up of the digestion process.

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