Effects of carbon-based materials on the anaerobic co-digestion of the organic fraction of municipal solid waste and thickened sludge: preliminary results

F. Fazzino[1], A. Pedullà[2], A. Gelsomino[3], M. Pittarello[3], P. S. Calabrò[2]

[1]Department of Civil Engineering and Architecture, University of Catania, Italy
[2]Department of Civil, Energy, Environmental and Materials Engineering, 'Mediterranea' University of Reggio Calabria, Italy
[3]AGRARIA Department, 'Mediterranea' University of Reggio Calabria, Italy
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Presenting author email: filippo.fazzino@unict.it

Introduction

Anaerobic digestion (AD) allows to convert biodegradable matter of organic waste into biogas (CH_4, 55-70%, and CO_2, 30-50%) and digestate (by-product containing stabilised organic matter and nutrients) potentially employable as renewable energy source and soil amendment, respectively. AD is driven by distinct groups of microorganisms which strive in syntrophic interrelation. The process is generally divided into four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Particularly, biogas generation can occur if either acetate (produced during acetogenesis) is converted to CH_4 and CO_2 by acetoclastic bacteria or if H_2 and CO_2 are used by hydrogenotrophic methanogens to form CH_4. These interactions consist of redox reactions. Mediated interspecies electron transfer (MIET), in which H_2 and formate act as electron carriers, is known as the major pathway. However, recent studies discovered that electrons can flow from one microbial cell to another through direct contacts between cells (Rotaru et al., 2013). This mechanism is known as direct interspecies electron transfer (DIET) and, compared to MIET, it makes CH_4 production faster and thermodynamically more efficient.

The presence in the AD processes of conductive materials (CMs) has been observed to promote DIET. Among others, carbon-based CMs are widely tested because of their high specific surface area and electrical conductivity. Biochar, granular activated carbon (GAC), and graphite (including graphene, graphene oxide) have been tested as additives in different AD experiments to enhance process performance at dosages of 1 – 100 g/L, in case of biochar and GAC, and of 0.2 – 10 g/L, in case of graphite (Lü et al., 2020; Xu et al., 2022).

The present study aims at evaluating and comparing the effects of four different carbon-based CMs (i.e., GAC, graphite, graphene oxide, and nanotubes) on the anaerobic co-digestion (AcoD) of organic fraction of municipal solid waste (OFMSW) and thickened sludge (TSL) in semi-continuous mode. To the best of authors' knowledge, continuous/semi-continuous AcoD of these very common substrates has been poorly studied in terms of enhancing process performance through DIET.

Materials and methods

The semi-continuous AcoD experiment involved five different reactors (designed as A, B, C, D, and E, working volumes of 1.9 L) equipped with internal stirrers and immersed in a thermostatic water bath (35°C). Feeding and discharge operations were simultaneously carried out five days per week. Produced CH_4 was automatically measured by a patented system based on water/gas displacement. Hydraulic retention time (HRT) and organic loading rate (OLR) were set at 21 days and 1.5 $g_{VS}/L{\cdot}d$, respectively. Inoculum was a residual digestate coming from a previous AcoD test running under the same experimental conditions but not involving supplements. OFMSW and TSL were jointly fed to all reactors according to a ratio of 50:50 (on VS basis). The former was prepared in laboratory according to the typical Italian composition (Calabrò and Pangallo, 2020), while the latter was collected from the gravity thickener of a full-scale municipal wastewater treatment plant located in Reggio Calabria (Italy). At the beginning of the test, carbon-based CMs were added to reactors at the optimal dosages found in literature. Specifically, GAC, graphite, graphene oxide, and nanotubes were respectively added to reactors B, C, D, and E in concentration of 10 g/L, 10 g/L, 0.2 g/L, 0.2 g/L, respectively. Moreover, specific quantities of materials were periodically loaded along with substrates during feeding operations in order to maintain the set dosages in the reactors. Reactor A was considered as a blank.

Results and discussion

To date, AcoD test is still running. Preliminary results in terms of CH_4 yield and percentage of CH_4 yield increase are reported in Figure 1 (a and b, respectively). On the basis of reported data, in terms of CH_4 production, it can be clearly observed that the presence of carbon-based CMs has improved the conventional AcoD of OFMSW and TSL. To date (i.e., after 56 days of test), reactors A, B, C, D, and E show CH_4 yields of 0.174 NL/g_{VS}, 0.185 NL/g_{VS}, 0.186 NL/g_{VS}, 0.201 NL/g_{VS}, and 0.196 NL/g_{VS}, respectively (Figure 1a). CH_4 yield from AcoD of OFMSW and TSL (i.e., reactor A) is modest but anyway consistent with literature (Mehariya et al., 2018).

Improvements due to the supplementations of carbon-based CMs are depicted in Figure 1b in terms of percentage increase respect to CH_4 yield of blank reactor A.

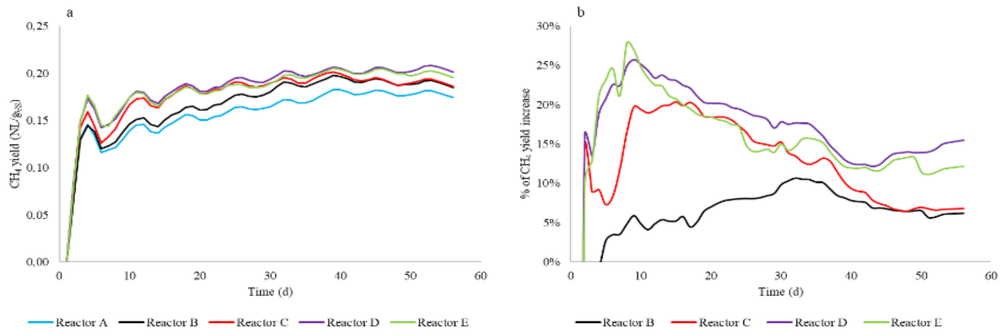

Figure 1. a) CH_4 yields; b) percentages of CH_4 yield increase compared to reactor A (blank)

Materials added at the lowest dosage (i.e., graphene oxide and nanotubes both at 0.2 g/L) have promoted almost immediately DIET with significant CH_4 yield increases in the first 10 days of the test (peaks of +27.0% and +25.7%, respectively, on day 9). Afterwards, downward trends have been recorded until day 44. This evidence could indicate that bacteria have had to adapt to regime conditions. A better understanding of this behaviour will be provided by analyses of the microbial communities scheduled in the next future. Conversely, GAC and graphite, dosed at 10 g/L, have not reached comparable values probably because microorganisms have taken more time to adapt to their higher concentration. However, unlike reactor C, which shows a trend of CH_4 yield increase similar to those of reactors D and E, the positive effect of GAC in reactor B has been increasing until day 34 (peak of +10.5%). This may be due to the progressive microbial colonization of the GAC pores so that establishing DIET.

In order to evaluate processes' stability, pH was periodically measured through a portable pH meter and volatile fatty acids' (VFAs) contents were determined in weekly composite digestates through a three-points titration method (data not shown). What emerges from these analyses is that promoting DIET results in more stable processes as blank reactor A has shown the lowest pH values and the highest VFAs contents over test time (even if these values have never exceeded respective tolerance thresholds). On account of that, it can be stated that the larger CH_4 yields of reactors B, C, D, and E are due to a faster and more efficient microbial conversion of acids to methane as expected as consequence of DIET establishment. Also in this case, further analyses on conductivity and microbial communities could be confirm this assumption.

Conclusions

Although the present test is ongoing, from preliminary results it emerges that supplementation of carbon-based CMs enhances the performance of the AcoD of OFMSW and TSL both in terms of larger CH_4 yield and process stability. However, long-term effects of materials (especially graphene oxide and nanotubes) are still not clear. Furthermore, a comprehensive economic analysis is essential to compare the costs related to the use of CMs with the benefits related to the higher CH_4 production.

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