Comparison among thermal pre-treatments effectiveness in increasing anaerobic digestibility of OFMSW

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Introduction

The constant growth of world population (~ 1%/year), together with urbanization and economic development are leading to an increase of the municipal solid waste (MSW) production (Shah et al. 2021). The latter has been estimated as high as 2 billion tons/year (Shah et al 2021), generating serious issues for its proper treatment and disposal and representing a constant risk for the environment. Furthermore, the recent energy shortage experienced by several developed Countries and the negative effects of fossil fuels use on climate change are leading to an increasing interest toward alternative and renewable energy sources (Zamri et al. 2021).
A wide fraction of MSW is actually represented by organic material (46%), suggesting the organic fraction of MSW (OFMSW) might represent an important source of alternative energy if utilized as feedstock for anaerobic digestion (AD) process. AD is an attracting strategy for OFMSW treatment because it allows the production of energy, in the form of biogas or hydrogen, and compost for agricultural use, after a proper stabilization of the digestate (Campuzano and González-Martínez, 2016).

However, OFMSW is characterized by high heterogeneity and includes a variable share of poorly or slowly biodegradable materials such as lignocellulosic biomasses or greases. Therefore, several studies focuses on pre-treatments of OFMSW in order to improve its anaerobic digestability leading to an increase in the biogas yield and/or a reduction of the hydraulic retention time (HRT) required by the AD process (Ahmed et al. 2021). Among them, the thermal pre-treatment are considered more sustainable as they do not require the addiction of chemicals and the thermal energy required can be obtained by the biogas produced, as well as, recovered and reused for heating the anaerobic digester. However, conflicting results are available in the literature reporting positive but also negative effects on the AD process (Ahmed et al. 2021), therefore suggesting further investigations.

In the present study, we conducted an experimental campaign comparing the effectiveness of different thermal pre-treatments in increasing OFMSW anaerobic digestability. Thermal pre-treatments were also compared with OFMSW shredding, considered as minimum pre-treatment required.

The thermal pre-treatments were conducted under different operating conditions in terms of temperature, pressure and gas phase (in presence of air or nitrogen). They were performed in autoclave (121 °C and 2 bar for 20 min) or in an ad hoc hydrolysis reactor designed for the experimental trial (140 °C and 7 bar for 30 min).

Material and methods

Anaerobic sludge was collected from an anaerobic digester treating waste activated sludge and located in Monopoli (Puglia, Italy). OFMSW was collected from an OFMSW collection plant based in Corato (Bari, Italy). To obtain a homogenized mixture, substrate was subjected to trituration using a home garbage disposals and a mixer-grinder. The OFMSW suspension after shredding or thermal pre-treatment, and the digestate were analyzed for chemical oxygen demand (COD), soluble COD (sCOD), total nitrogen (TN), total phosphorous (TP), total and volatile suspended solids (TSS and VSS), total and volatile solids (TS and VS), electrical conductivity (EC) and pH.

During shredding operation, 1.7 kg of raw OFMSW were diluted to 1.5 L with tap water. Successively, the shredded OFMSW was diluted to a final volume of 5 L with the anaerobic digester effluent (digestate), or thermally treated and diluted, and then supplied to the AD plant. This approach allowed reducing: the energy required for thermal pre-treatments (less waste volume to be heated), the freshwater demand and the addiction of nutrients (nitrogen and phosphorous) to the feedstock. Furthermore, it allowed extending the AD sludge retention time without affecting the organic loading rate (OLR) applied to the digester. Nevertheless, the ORL applied to the plant ranged 1.4-3.0 kg_{COD}/m^3•d also due to heterogeneity of the OFMSW collected during the experimental campaign. The digester operated in semi-continuous mode with feeding/drawing operations occurring twice a week.

The AD process was performed in a 60 L steel reactor equipped with pH and temperature control and operating in the range 38 ± 2°C. The liquid phase was maintained under mixing by a mechanic stirrer and biogas production and quality were on-line monitored (with an infrared biogas analyzer, ADEV 4400). Periodically, biogas samples were also collected and analyzed by an Agilent 490 Micro-GC for a more accurate and complete biogas characterization. The plant included the hydrolysis reactor for OFMSW pre-treatment, the garbage disposals and a feeding/drawing pump.

Results

Despite the evidences suggested by the literature (Ahmed et al. 2021, Zamri et al. 2021), no effects of thermal pre-treatments were observed in terms of COD solubilization, the ratio sCOD/COD being almost constant independently from the applied pre-treatment (on average 0.40%).

Furthermore, the high-pressure thermal pre-treatments occurring in the hydrolysis reactor caused a net loss of organic matter (about 40% of VS). This phenomenon was not observed during autoclaving and was attributed to the different pre-treatment conditions. During autoclaving, pressure and temperature were gradually decreased in order to avoid OFMSW suspension boiling. In the hydrolytic reactor, the higher operating temperature and pressure (140°C and 7 bar), the faster cooling and the larger steam discharge caused OFMSW suspension boiling. Therefore, some organic matter was supposed to leave the suspension due to evaporation. When comparing with the other treatments, the organic matter loss reflected in a moderate reduction of the average COD removal efficiency, which nevertheless was usually above 80% (Figure 1). Considering the mean values, the AD process resulted more effective in terms of COD and VSS removal after autoclave pre-treatment with the second best performances obtained in absence of thermal pre-treatments. The autoclave pre-treatment allowed an average COD and VSS removal, as high as 93 and 94%, respectively, showing also less variability.

The poor positive effects of the thermal pre-treatments on particulate matter removal are likely to be caused by the long HRT of the system, deriving by the partial recycle of the AD plant effluent for OFMSW dilution. This feeding strategy provided the anaerobic microorganisms enough time to hydrolyzed particulate organic matter even in absence of the thermal pre-treatments. The long HRT might have had detrimental effects on sCOD removal efficiency, due to a not negligible presence of recalcitrant soluble compounds, which are recycled back to the digester with the digestate.

The volatilization of VS during the high-pressure thermal pre-treatments negatively affected biogas production rate due to a reduction of the OLR applied to the digester (Table 1). Nevertheless, the methane yield even increased reaching 0.6 ± 0.1 $NL_{CH4}/gVS_{removed}$ when the pre-treatment was performed in presence of nitrogen (Table 1). Conversely, autoclave pre-treatment (in line with the higher COD and VSS removal) enabled an increase in biogas production rate with an average value of 2.9 NL_{biogas}/h (Table 1). However, reasonably due to the speed up of the AD process, in this operating condition methane content in the biogas decreased to about 50% whereas it was usually above 60% during the other experimental phases.

The results described suggest autoclaving as the best pre-treatment allowing an increase in removal performances and biogas production rate. However, the benefit of this treatment are limited if long HRT is applied.

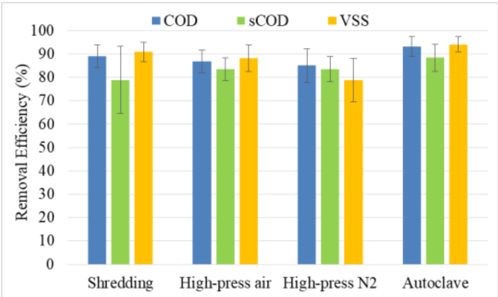

Figure 1. Average COD, sCOD and VSS removal efficiency for OFMSW subjected to different pre-treatments.

Table 1. Biogas production rate, methane yield and methane concentration in the biogas during anaerobic digestion OFMSW subjected to different pre-treatments.

	Shredding	**High-press air**	**High-press N_2**	**Autoclave**
Biogas rate (NL/h)	2.2 ± 1.1	1.4 ± 0.5	2.0 ± 0.1	2.9 ± 0.4
Methane yield ($NL_{CH4}/gVS_{removed}$)	0.3 ± 0.3	0.3 ± 0.2	0.6 ± 0.1	0.4 ± 0.3
Methane content (%)	66 ± 7	65 ± 8	68 ± 4	50 ± 5

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