Effect of thermal and thermo-chemical pre-treatments on OFMSW anaerobic digestion

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Introduction

Management of urban waste is a critical issue for municipalities that are directing towards a sustainable urban environment (Di Matteo et al., 2017). Landfills have been the answer for many years although the well-known disadvantages related to their use (GHG emissions, smells and sanitary issues). However, as defined by the European Union, 65% of municipal solid waste (MSW) must be recycled by 2035 whereas only 10% will be disposed in landfills (Rolewicz-Kalinska et al. 2020). With this in mind, particular attention must be given to the Organic Fraction of Municipal Solid Waste (OFMSW). Indeed, 40–60% of the 486 Kg of MSW produced in EU per capita in 2018 was represented by OFMSW (Allegue et al., 2020). About 64% of the bio-waste treated in Europe is subjected to anaerobic digestion (AD), 26% is composted and 10% is sent to integrated anaerobic/aerobic treatments (Scrinzi et al., 2021).

AD is an extremely promising strategy for OFMSW treatment as it allows the production of energy (in the form of biogas) and fertilizers such as compost (Campuzano and González-Martínez, 2016). However, OFMSW generally contains recalcitrant compounds, making this feedstock hard to be degraded under the AD conditions. As result of OFMSW scarce biodegradability, hydrolysis becomes the rate-limiting step, unavoidably affecting the whole AD process (Dasgupta et al. 2020). Recently, pre-treatments of OFMSW have been performed prior to AD with the aim to accelerate hydrolysis of complex organic matter, hence enhancing biogas production. Regarding thermal pre-treatment (50 to 250 °C), the increase in temperature caused organic matter solubilization as well as pathogens destruction, dewatering and reduced digestate thickness (Paritosh et al. 2018). Particularly, autoclaving was found to significantly aid the solubilization of slowly degradable compounds such as starch and hemicelluloses (Pecorini et al. 2016). Chemical treatments involved the usage of strong acids, alkali or oxidants. Solvatation and saponification reactions that occur during alkali treatment increase the contact area between substrate and microorganisms (Paritosh et al. 2018). Acid pre-treatment causes condensation and precipitation of lignin and solubilization of hemicellulose (Paritosh et al. 2018).

This study was aimed at comparing the potential enhancement of anaerobic biodegradability of OFMSW by means of thermal and thermo-chemical treatments. Biochemical Methane Potential (BMP) assays were performed in order to evaluate the effects of the selected pre-treatments on biogas production.

Material and methods

Anaerobic sludge inoculum was collected from an anaerobic digester located in Verona (Italy) fed with organic waste. 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 mixer-grinder. Both samples were analyzed for chemical oxygen demand (COD), soluble COD (sCOD), total nitrogen (TN), total phosphorous (TP), total suspended solids (TSS), volatile suspended solids (VSS), total solids (TS) and volatile solids (VS). Electrical conductivity (EC) and pH were measured by selective probes.

75 g of OFMSW were suspended in 500 ml distilled water and the obtained mixture was subjected to pre-treatments. Thermal pre-treatment was performed by autoclaving the mixture at 121 °C for 20 minutes. Acid thermal pre-treatment (pH 2) and basic thermal pre-treatment (pH 10) were conducted by adding HCl (1 M) and NaOH (1 M) to the mixture, respectively. After autoclaving, samples were neutralized and pH value adjusted to 7 ± 0.1. 100 ml of pre-treated and un-treated samples were withdrawn and analyzed for the parameters above mentioned in order to verify the effects of pre-treatments on OFMSW composition. BMP tests were performed in 1 L glass flasks under mesophilic conditions (37 ± 1 °C). The selected inoculum/substrate ratio was 1:1. The experimental set-up consisted of 9 batch units, including a unit inoculated with anaerobic sludge only in order to quantify endogenous methane production (control unit). BMP tests were conducted in duplicate for both un-treated (NT) and treated (121 °C; 121 °C-HCl and 121 °C- NaOH) samples. Before starting the experiment, samples were flushed with nitrogen gas in order to ensure anaerobic conditions. 2 g/L of sodium bicarbonate were added to each mixture. Mixing was ensured by magnetic stirrer. Biogas production was collected daily through a eudiometric tube connected to each flask and normalized for the biogas volume produced by the control unit. Biogas composition was analyzed using a gas-chromatographer Agilent 8890.

Results

OFMSW was subjected to hydrothermal and thermo-chemical treatments prior to anaerobic digestion. Results obtained from BMP assays of the thermally treated samples were compared to those one observed during the anaerobic digestion of un-treated OFMSW. Before being anaerobically digested, treated and un-treated samples were characterized and sCOD values were found similar among all the samples with values around 56 mg/L, 58 mg/L, 59 mg/L and 63 mg/L for NT, 121 °C, 121 °C- NaOH and 121 °C-HCl, respectively. These findings revealed that autoclaving at 121 °C and acidic and basic thermo-chemical treatments did not significantly affect solubilization of particulate organic matter. Conversely, BMP tests demonstrated that all the three treatments improved biogas production. **Figure 1** shows the profiles of four flasks, each representative of each different condition. Although no higher concentrations of soluble COD were detected, an exponential production of biogas was highlighted from units inoculated with treated substrate. After six days, cumulative biogas production from treated units was 3 times higher than the biogas volume produced by un-treated samples and also represented about 90% of the overall biogas production obtained at the end of the tests. Biogas production from flasks inoculated with un-treated OFMSW started later and reached 2,919 Nml after 19 days. At the end of the experiment, 4,020 Nml, 3,821 Nml and 4,028 Nml of biogas were produced for autoclaved, alkali and acid bottles, respectively. Similar values of biogas yields were recorded for autoclaved (319 Nml/gVS) and alkali (307 Nml/gVS) flasks whereas a slightly higher yield equal to 377 Nml/gVS was reached by acid unit. Conversely, a yield of 236 Nml/gVS was measured for the un-treated OFMSW. Biogas composition analysis was performed in order to estimate methane concentration. Average values of 55% (54-55%), 77% (72-82%), 68% (61-75%) and 84% (82-86%) were measured for un-treated, autoclaved, alkali and acidic samples, respectively. These results are in accordance with those reported by Dasgupta and Chandel (2020) demonstrating that strong acid pre-treatment of OFMSW with HCl at pH 3 allowed reaching the highest biogas yield (389.4 ml/gVS) compared to 301.9 ml/gVS of un-treated sample. Soluble COD removal exceeded 90% under all conditions whereas COD removal efficiencies of 38, 41, 37 and 42% were obtained for un-treated, autoclaved, alkali and acidic samples, respectively. Preliminary results here reported suggest thermal pre-treatment of OFMSW would significantly reduce the hydraulic residence time (HRT) required for OFMSW treatment in anaerobic digesters (i.e. typically 15 days) with apparent positive effects on digester treatment capacity, whereas the addiction of chemical reagent does not provide clear further benefits.

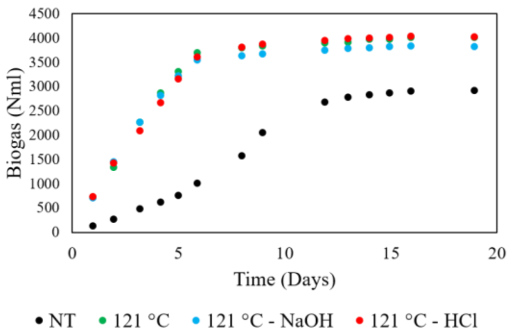

Figure 1. Biogas production during anaerobic digestion tests of un-treated OFMSW and OFMSW subjected to thermo and thermo-chemical pre-treatments.

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