Valorisation of the organic fraction of municipal solid waste by hydrothermal carbonization and anaerobic digestion

G. Mannarino[1,2], M. A. de la Rubia[2], E. Diaz[2], R. Gori[1], A. F. Mohedano[2]

[1]Department of Civil and Environmental Engineering, University of Florence, Florence, 50139, Italy
[2]Department of Chemical Engineering, Universidad Autonoma de Madrid, Madrid, 28049, Spain

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Presenting author email: gemma.mannarino@estudiante.uam.es

Abstract
The mesophilic anaerobic digestion of the organic fraction of municipal solid waste (OFMSW) and of the process water (PW) from hydrothermal carbonization (HTC) of OFMSW has been studied. HTC was performed on OFMSW (1 hour at 200 and 230 °C), and PWs were subjected to anaerobic digestion (AD). Batch AD tests were developed directly on OFMSW, and on PWs obtained at both HTC temperatures (PW200, and PW230). AD trials were monitored during the experiment duration in order to study the time-course of main parameters (e.g. soluble chemical oxygen demand, pH, and alkalinity). The PW230 test showed a methane yield (326 mL CH_4 STP g VS_{added}^{-1}) higher than OFMSW and PW200 ones (298 mL CH_4 STP g VS_{added}^{-1}, and 286 mL CH_4 STP g VS_{added}^{-1} respectively). Therefore, the results reported indicate the potential advantage to apply AD on PWs obtained from hydrothermal carbonization treatment on OFMSW.

Introduction
At global level, the municipal solid waste production is about $1.3 \cdot 10^9$ t $year^{-1}$, and it is expected to raise up to $2.2 \cdot 10^9$ t $year^{-1}$ in 2025 (Campuzano and González-Martínez, 2016). The major pathways for disposal of the organic fraction of municipal solid waste (OFMSW) are incineration and landfill, which are low cost but polluted technologies. Besides them, composting and anaerobic digestion (AD) are considered more environmentally friendly processes but with high costs and long treatment time, up to 30 days (Campuzano and González-Martínez, 2016). In this framework, hydrothermal carbonization (HTC) is gaining attention for OFMSW treatment.

During HTC, wet biomass is heated in subcritical water at mild temperature (180 - 250 °C), and under autogenic pressure, obtaining three different fractions: a carbon-rich solid fraction (hydrochar), a liquid phase (process water; PW), and a small gaseous fraction (1 - 5 %). Hydrochar is a valuable product, which may find applications in several fields (e.g. as combustible, soil ameliorant, and adsorbent). Further, PW is reported to be advantageously valorised by AD (Marin-Batista *et al.*, 2019).

In this study, the valorisation through AD of PW obtained by HTC application on OFMSW was investigated.

Material and Methods
OFMSW, collected from a municipal solid waste treatment plant (MSWTP) located near Madrid (Spain), was characterised as follows: 88.2 ± 2.8 g total solids (TS) kg^{-1}, 77.2 ± 2.2 g volatile solids (VS) kg^{-1}, and total chemical oxygen demand (TCOD) of 102 ± 2 mg O_2 g TS^{-1}. It was subjected to HTC process (1 h at 200 and 230 °C), performed in a ZipperClave® pressure vessel electrically heated. The obtained slurries were separated into wet hydrochar and process water (PW) (Table 1) by filtration.

Table 1. Analytical characterization of process waters.

Parameter	PW200	PW230
TS (g kg^{-1})	39 ± 1	36 ± 0
VS (g kg^{-1})	30 ± 1	28 ± 0
TCOD (g O_2 L^{-1})	73 ± 4	67 ± 1

A granular anaerobic sludge from an industrial digester treating brewery wastewater under mesophilic conditions was used as inoculum. AD trials on OFMSW, PW200, and LPW230 were carried out in 120 mL glass serum vials. The initial inoculum concentration was set at 15 g VS L^{-1} and the inoculum-to-substrate ratio at two on a VS basis. The test lasted 30 days, while biogas volume and composition (H_2, CO_2, and CH_4), pH, alkalinity, soluble chemical oxygen demand (SCOD), ammoniacal nitrogen (N-NH_3), and volatile fatty acids (VFA) were monitored.

Results and Discussion

Fig. 1 shows the time-course of SCOD (Fig. 1a) and cumulative methane yield (Fig. 1b) during AD tests. The SCOD immediately decreased significantly in PWs runs because of the conversion of soluble organic matter in CH_4. Similar values of SCOD were obtained for both PWs trials during AD tests. As is reported in Fig. 1b, the cumulative methane yield increased during tests up to 298 ± 12 mL CH_4 STP g VS_{added}^{-1} (OFMSW at day 26), 286 ± 15 mL CH_4 STP g VS_{added}^{-1} (PW200 at day 26), and 326 ± 22 mL CH_4 STP g VS_{added}^{-1} (PW230 at day 26) (STP: atmospheric pressure and 273 K).

The latest values of cumulative methane yield for all the trials were strictly comparable. The yield resulted for OFMSW trial was in accordance with values described elsewhere in literature. Indeed, methane production of 210 – 290 mL CH_4 g VS_{added}^{-1} were reported for AD of OFMSW in mesophilic conditions (Fruteau de Laclos *et al.*, 1997). PW200 test resulted in a last methane yield close to the OFMSW one, whereas the highest methane production was observed for PW230 run. Both PW200 and PW230 AD tests resulted in a similar time-course of cumulative methane yield: the CH_4 production increased in time up to day 22. Differently, the CH_4 yield for OFMSW test reached a value approximately close to the maximum one at day 10. It suggested that, in case of OFMSW test, the conversion of organic matter in methane was almost completed in the first 10 days, whereas it was still in progress for PWs trials.

As is mentioned above, the highest cumulative methane yield resulted for PW230 trial, which is the PW obtained applying the highest HTC temperature. Opposite results are reported elsewhere for different feedstocks (e.g. microalgal biomass, Marin-Batista *et al.*, 2019). So, it will certainly worth to investigate this discrepancy.

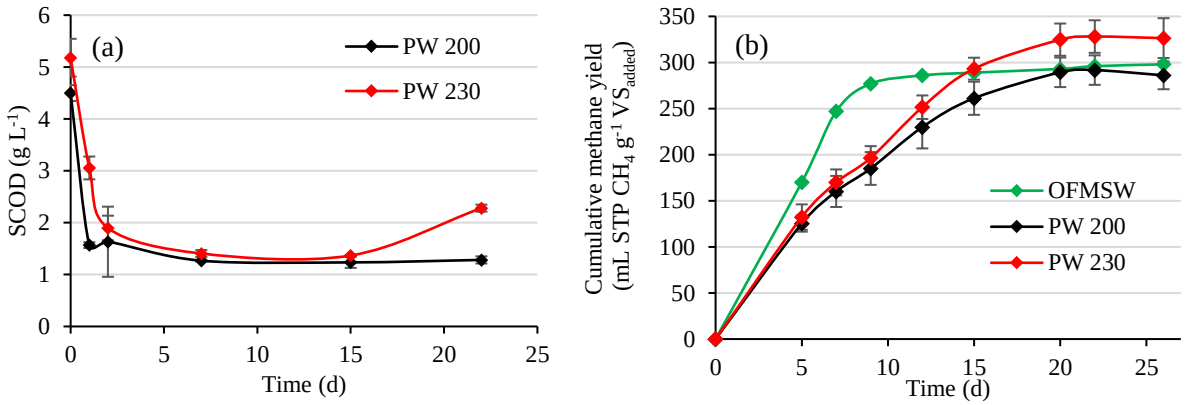

Figure 1. Time-course of soluble chemical oxygen demand (a) and cumulative methane yield (b).

Thus, as is described in this study, hydrothermal carbonization of organic fraction of municipal solid waste produces a spent liquor with a high content of organic matter that can be advantageously valorised by AD. Indeed, the cumulative methane yields of PWs were respectively similar (PW200) and higher (PW230) than the CH_4 production obtained for direct anaerobic digestion of OFMSW. Further, HTC produces also hydrochar, which is a value-added product that may find applications in different fields.

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