The conversion of food waste and biological sludge into bio-based products: a pilot scale platform for urban waste management

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This study focuses on the application of the concept of circular economy, where added-value and marketable products as well as energy are created from organic waste and the environmental impacts are consequently minimized (Demichelis et al., 2018). Within this purpose, an urban biorefinery technology chain has been developed at pilot scale in the territorial context of the Treviso municipality (northeast Italy) for the production of biopolymers (polyhydroxyalkanoates, PHA) and biogas from waste of urban origin. The highly efficient waste separate collection (87.9% on total waste, ISPRA, 2017) ensures a high-quality organic waste (namely the organic fraction of municipal solid waste; OFMSW), which is sent to mechanical pre-treatment with a screw-press for the separation of the liquid squeezed stream from the solid one. The current technology is the anaerobic co-digestion (ACoD), where the squeezed OFMSW (15-20% w/w of Total Solids; TS) is treated after mixing with the waste activated sludge (WAS) produced in Treviso full scale WWTP (70.000 PE). Hence, the actual scenario is completely devoted to biogas production only.

The piloting system (100-380 L) comprised the following units: a) acidogenic fermentation for volatile fatty acids (VFA) production; b) two solid/liquid separation step by means of a filter-bag (5.0 μm) equipped centrifuge and a tubular ultrafiltration membrane; c) Sequencing Batch Reactor (SBR) for PHA-storing biomass production; d) fed-batch PHA accumulation reactor; e) ACoD unit for biogas production from the residual bio-waste and excess WAS (Figure 1). The squeezed OFMSW and WAS were mixed in a volumetric quantity of 30-35% and 65-70% respectively.

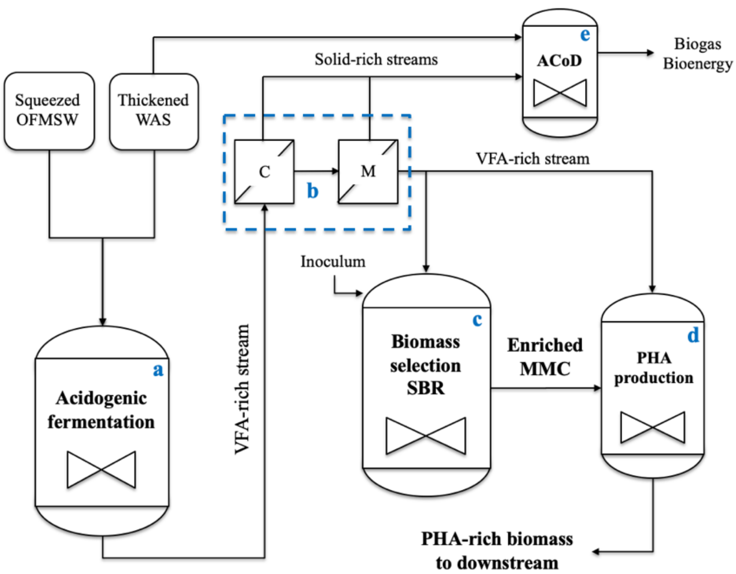

Figure 1. Pilot scale bio-refinery developed at Treviso WWTP.

The acidogenic fermentation was conducted in two steps: a preliminary thermal pre-treatment (72°C, 48 h), and a mesophilic fermentation (37°C) in batch mode (5 days). The thermal pre-treatment favored the organic matter solubilization and hydrolyzation, enhancing VFA production in the following fermentation stage. The overall acidification yield was in the range of 0.41-0.45 g COD_{VFA}/g VS_{fed}. Moreover, the pH maintained itself between 5.0-5.5 since the acidification process was balanced by the WAS buffering capacity. This allowed obtaining a VFA level around 30 g COD_{VFA}/L and a high COD_{VFA}/COD_{SOL} ratio (0.84 ± 0.02) in the fermented liquid phase. This pivotal feature enhanced the PHA-storing biomass selection in SBR by reducing the growth of non-storing microbial population.

Under fully aerobic feast-famine regime, the selection reactor was operated for two years, at OLR range 3.0-4.0 g COD/L d, short HRT (1-2 days, equal to SRT) and cycle length of 6-12 hours. The effect of SRT/cycle length ratio (range 2-8 d/d) on the biomass storage properties was also evaluated. Under the optimal selection/enrichment condition (SRT/cycle length = 2.0 d), the selected consortium was characterized by a specific storage rate (qP^{feast}) of 375 mg COD_{PHA}/g COD_{Xa}/h and a storage yield ($Y_{P/S}^{feast}$) of 0.46 COD_{PHA}/COD_{SOL}. The trends of both parameters as a function of SRT/cycle length ratio is depicted in figure 2. This consortium was able to accumulate up to 60% g PHA/g VSS. An overall production yield of 107 g PHA/kg VS was estimated.

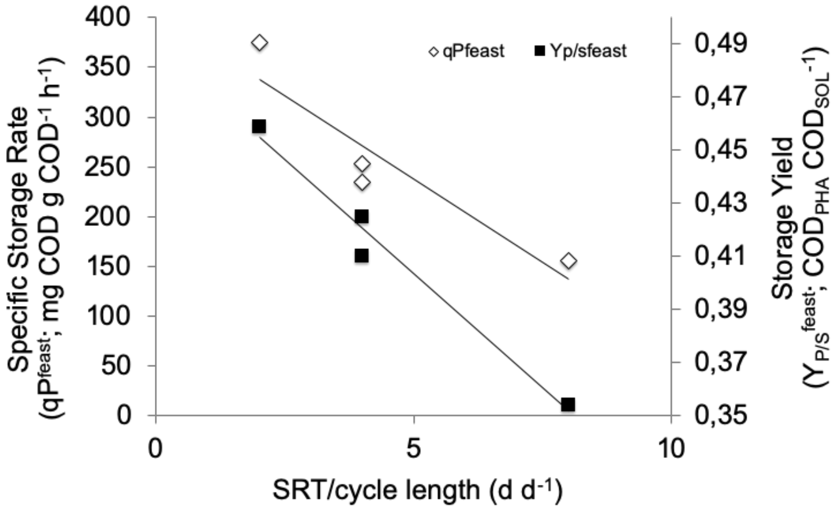

Figure 2. Specific storage rate (qP^{feast}) and storage yiled ($Y_{P/S}^{feast}$) in different SBR runs performed at different SRT/cycle length ratio (range 2-8 d/d).

The mesophilic ACoD process (HRT 13-14 days, OLR 2-2.5 kg VS/m^3 d) allowed recovering biogas from the solid-rich overflows produced from the two solid/liquid separation units, and opportunely diluted with WAS of the same WWTP. In the mesophilic co-digestion process (more energetically efficient than thermophilic one), a specific gas production (SGP) of 0.4 m^3/kg VS was quantified and the CH_4 content in the biogas was in the range 60-65% v/v during the steady state.

By taking into account the best conditions of each stages, the scaled-up version (70,000 PE) of the present pilot biorefinery is characterized by a production of 114 tons PHA/year, 2314 m^3 biogas/d and 5.9 MWh/d of electrical energy. Compared to the actual ACoD scenario, this scheme can be more profitable, provided that an efficient strategy for polymer recovery/purification is applied. The resolution of this bottleneck, together with a detailed market exploitation can easily overcome the economic loss from that fraction of biogas not produced in the biorefinery, being part of the initial COD diverted to biopolymer synthesis and not fully used for biogas production. In conclusion, the application of a biorefinery technology chain in which two added-value products were obtained (PHA and biogas) was fully examined and assessed. The integration of different organic waste treatment allowed reducing environmental problems associated with their traditional disposal while valorizing them and generating marketable products and energy.

Acknowledgements

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