A pilot-scale multi-purposes approach for volatile fatty acid, hydrogen and methane production from an automatic controlled two-phases anaerobic process for food waste valorisation.

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Keywords: Organic Fraction of Municipal Solid Waste (OFMSW); Anaerobic Digestion; Methane; Anaerobic Fermentation; Volatile Fatty Acid (VFA)
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Introduction

Nowadays AD treatments of organic waste with energy recovery remain the most attractive strategy (Fernandez-Rodriguez et al., 2013). A two-stage fermentation-digestion AD configuration better connects to the biorefinery concept as it allows to obtain added value streams rich in VFA from fermentation and integrates the digestion stage to obtain methane in the biorefinery chain. In order to avoid the inhibition or a metabolic change of the fermentation process towards less appetite by-products (such as lactic acid and alcohols) with consequent reduction of hydrogen and VFA, it is necessary to control and maintain the fermentation parameters much stable as possible. In particular, the pH in the fermenter must be kept over 5.0 to promote the fermentative activity and below 6.0 to avoid the proliferation of methanogenic bacteria.
A combined two-levels control method has been developed and tested on a long period of operation for the management of a two-phases pilot scale anaerobic process, designed for the treatment of biowaste of urban origin (OFMSW). The optimized control method was set based on the inputs of three online probes: pH-meter in the fermentation reactor (AnF), a pH-meter and conductivity probes in the digestion reactor (AnD). The first control level (1CL) overseed the pH in AnF while the second control level (2CL) managed the ammonia concentration in AnD.

Methods

The renewable substrate was the organic fraction of municipal solid waste (OFMSW) coming from the separate source-sorted waste collection in the municipality of Treviso (northeast Italy). Before its use, the OFMSW was pre-treated in a dedicated plant by using a screw press, which allowed to obtain a squeezed and homogeneous organic waste matrix. Two stainless steel CSTR reactors (AISI 304) were used for VFA and biogas production. The first reactor was dedicated to the fermentative step (AnF; 0.2 m^3) and the second reactor (AnD; 0.6 m^3) to the methanogenic step. Both reactors were heated by a hot water recirculation system and maintained at 55°C ± 0.1 using electrical heater controlled by a PT100-based thermostatic probe. The AnF reactor was filled up with a mixture of OFMSW and tap water; over the course of operation, it was daily fed with a liquid mixture of OFMSW, sludge recycled from the AnD reactor and dilution water in order to reach the required organic loading rate (OLR). The AnD reactor was inoculated with the anaerobic digested sludge coming from the full-scale digester of Treviso WWTP and daily fed with the effluent from the AnF reactor. The first AnF reactor had a hydraulic retention time (HRT) of 3.3 days and an organic loading rate (OLR) of 19.0 kg TVS/(m^3d). In the methanogenic stage, an HRT in the range 12.5-12.6 days and an OLR of 4.0-4.2 kg TVS/(m^3d) were applied.
Figure 1 shows the flow diagram of the pilot scale anaerobic reactors system described above.

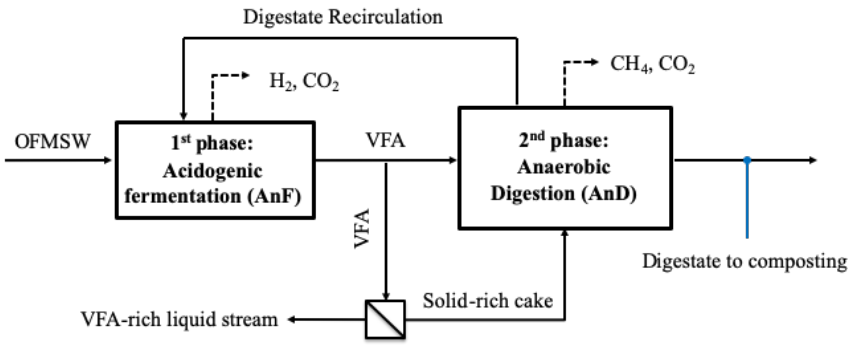

Figure 1. Process configuration for the production of VFA, bio-hydrogen and bio-methane from the OFMSW anaerobic treatment.

Results

The two-phases process has been followed for a long operation period of 300 days approximately. Figure 2A shows the pH of the AnF reactor together to the adopted digestate Recirculation Ratio (RR), defined as the volumetric fraction of digestate with respect to the total volume (digestate and OFMSW) fed to AnF reactor. The digestate was automatically dosed based on the measured pH of the AnF reactor, preventing unavoidable pH decreases and ensuring stable fermentation activity.

Figure 4A clearly shows how the 1CL allowed to maintain the pH value above 5, necessary condition to apply the 2CL for the determination of the correct RR. Moreover, the minimum pH value to produce VFA and hydrogen from biowaste is 5.2 (Lee et al., 2014) as it was maintained for such long period. The high RR adopted around 100 days was due to the slight drop of the pH for a fluctuation in the dosage of the feedstock and, consequently, the overloaded AnF. However, the 1CL allowed to quickly re-establish the desired acidity condition. Regarding to the AnD reactor, Figure 4B shows the evolution of the total ammonia concentration. The 2CL has effectively managed the ammonia content in the AnD reactor, which has settled at 0.756 g/L. The above discussed increase of the RR has increased the ammonia level in the AnD reactor. At the end of day 110, when the 1CL was switched off, the system had dynamic recirculation according to the calculation through the modelling algorithm and the ammonia values were around 0.800 g/L for the entire following period. In other words, when the optimal working condition of the AnF was re-established, the production of VFA (which lead unavoidable AnF acidification), did not create instability in the whole system. The merit of this process control strategy was due to the model, which optimally predicted the AnD ammonia concentration, accurately allowing its management in the system. The control method consists in a mathematical model (equation I), which evaluates the ammonia concentration from pH and conductivity values as follows: $[NH_3]_{Pred} = - 682.2\ (pH_{a2}) + 235.5\ (C_{b2}) + 3874.9$ (I)

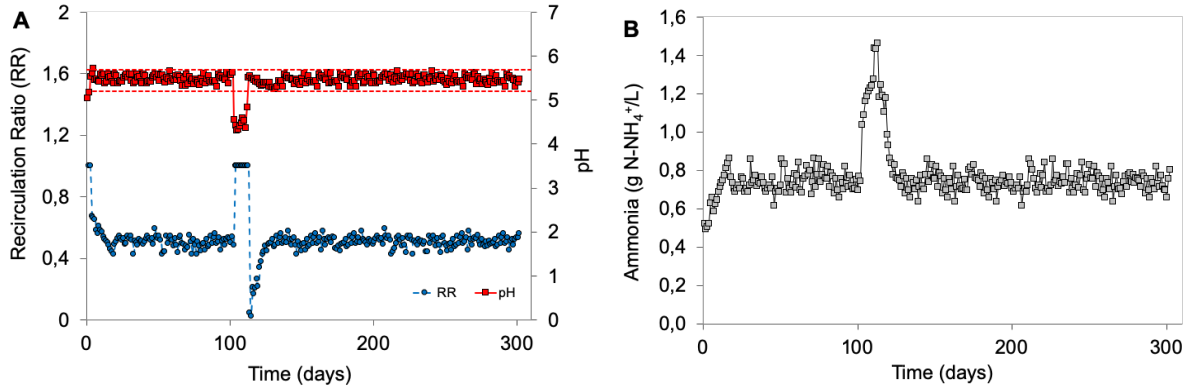

Figure 2. Trends of pH value monitored in AnF reactor and of the adopted RR (A); Evolution of the total ammonia concentration in the AnD reactor (B).

This combination of 1CL and 2CL established the volume of the digestate recirculation from AnD to AnF, optimizing the yield of volatile fatty acid (0.31-0.32 kg COD_{VFA}/kg COD_{fed}) and the specific hydrogen production (SHP; 0.070-0.074 m^3 H_2/kg TVS_{fed}) in AnF and the specific methane production (SMP; 0.48-0.55 m^3 CH_4/kg TVS_{fed}) in AnD. Moreover, this process configuration allowed to remove part of the VFA-rich liquid stream from the AnF effluent, maintaining the corresponding solid-rich effluent in the whole system (as feed for AnD) by using a solid/liquid separation unit. In this way, the concentration of VFA in AnD was kept at low level, even with high loading rates, so maintaining a satisfying efficiency of methane production and utilising the excess VFA (out of the system) as building blocks for other purposes. This approach opens new perspectives for the OFMSW valorisation; the production of bio-products, other than hydrogen or biogas only, from building blocks VFA is technically feasible and future technical-economic analysis may be useful for more innovative bio-refinery platforms.

Acknowledgements

The authors gratefully acknowledge the Italian National Institute for Insurance against Accidents at Work (INAIL) for financial support in the frame of national Call BRIC 2013-2015 (ID15). This work was also supported by the REsources from URban BIo-waSte" - RES URBIS (GA 7303499) project in the European Horizon2020 (Call CIRC-05-2016) program.

References

Fernández-Rodríguez J, Pérez M, Romero LI, Comparison of mesophilic and thermophilic dry anaerobic digestion of OFMSW: Kinetic analysis, Chem. Eng. J. 232 (2013) 59-64. https://doi.org/10.1016/j.cej.2013.07.066.

Lee WS, Chua ASM, Yeoh HK, Ngoh GC, A review of the production and applications of waste-derived volatile fatty acids, Chem. Eng. J. 235 (2014) 83-99. https://doi.org/10.1016/j.cej.2013.09.00.