New concept for valorization of OFMSW: coupling steam explosion pre-treatment with PHA production by purple phototrophic bacteria, and anaerobic digestion.

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Introduction

Currently a huge amount of municipal solid waste (MSW) is produced world-wide (2 billion tons annually), of which 34-53% is represented by organic fraction (OFMSW) (Abad et al., 2019). This biowaste typically contains organic residues like food and kitchen waste, discarded supermarket products, and pruning waste. Therefore, OFMSW represents an untapped source for energy and resource recovery (Fava et al., 2015).

MSW is typically sent to landfill. Alternative methods include thermal treatment (pyrolysis and gasification) and biological technologies like composting and anaerobic digestion. The latter is a viable option for waste stabilization and energy recovery. However, the degradation rate is limited by the hydrolysis of solid substrates. The hydrolysis can be accelerated by thermal treatment like the steam explosion pretreatment, which allows deep disintegration of internal cell structures in biomass by a sharp pressure change. This process also increases the biodegradability of the resultant solid biomass (Cano et al., 2014a), and partially solubilizes the organic matter to a liquid fraction that can be furtherly processed.

In recent years, the use of MSW to produce high-added value products such as polyhydroxyalkanoates (PHA) is gaining interest. A step forward in the attempt to reduce production costs is the use of mixed culture of phototrophic purple bacteria (PPB). PPB are highly metabolically diverse, allowing the assimilation of different carbon sources including sugars and organic acids in anaerobic conditions, which makes them perfect candidates for the treatment of heterogeneous materials as well as do not need equipment sterilization or aeration, two of the most expensive processes in the production of PHA (Koller et al., 2017).

The current work aims to evaluate this new concept for the valorization of OFMSW. The effects of temperature and time on biodegradability of the streams generates from steam explosion (hydrolised and liquid fraction), were studied by biochemical methane potential (BMP) test and batch specific phototrophic activity (SPA).

Materials and Methods

The MSW samples came from a municipal waste processing plant located in Madrid (Spain). Samples were blended and homogenized and then stored in a cold chamber at 4 ºC until further use. The effect of process temperature (122-178 ºC) and reaction time (6-69 min) in the thermal hydrolysis of OFMSW was studied by a response surface methodology based on a central composite rotatable design. By using the Minitab® 19 software, 13 runs were generated (4 factorial point, 4 axial point and 5 replicates of the central point). The experiments were performed in a reactor and flash tank with volumes of 10 and 100 L, respectively. For each experiment, 6 kg of (OFMSW) with a solid concentration of 7.5%, was used. The working temperature was reached at a 20 ºC/min heating rate. The hydrolysate was centrifuged at 6000 rpm for 10 min and then separated into solid and liquid fractions. Both fractions were stored at 4ºC until further use. Upon pretreatment, mesophilic anaerobic digestion experiments of hydrolysate were performed according to Holliger et al. (2016). An inoculum to substrate ratio of 2 on a VS basis with final concentration of 15 g VS/L inoculum, were selected as operational conditions. Besides, biodegradability of the liquid fraction was studied by batch specific phototrophic activity test (SPA) using a mixed consortium of PPB, with initial soluble COD of 2 g/L and inoculum spiked at 100 mgVSS/L. All analyses were based on Standard Methods.

Results and Discussion

The performance of the thermal hydrolysis was measured in term of VS based solid destruction efficiencies, which ranged from 23-57%. Soluble chemical oxygen demand (SCOD), total Kjeldahl nitrogen (TKN), and phosphates ranged from 34-44 gCOD/L, 535-796, mgN/L and 323-653 mgPO_4^+/L. Regarding the volatile fatty acids (VFA), values lower than 370 mgCOD/L were found. Figure 1 shows the methane potential along the anaerobic digestion experiments. No lag periods were observed, and final values ranged within 255-400 NmlCH_4/gVS. The lowest CH_4 production was observed for test 1, probably due to the presence of inhibitory nitrogen-containing aromatics, which are formed at high temperatures. The methane production was not significantly improved by thermal hydrolysis, except to run 122 ºC-38 min (c.a. 8% respect to control run). Similar optimal condition (120 ºC-10 min) was reported by Cano et al., (2014b).

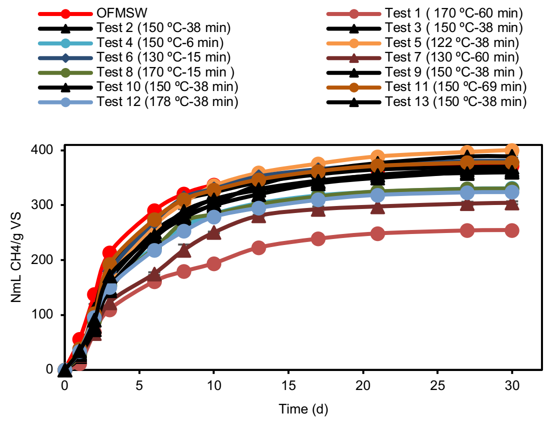

Figure 1. BMP during the AD of OFMSW at different temperatures and times. Control (red line) represents the BMP of the raw substrates without thermal treatment. Error bars represent 95% confidence intervals

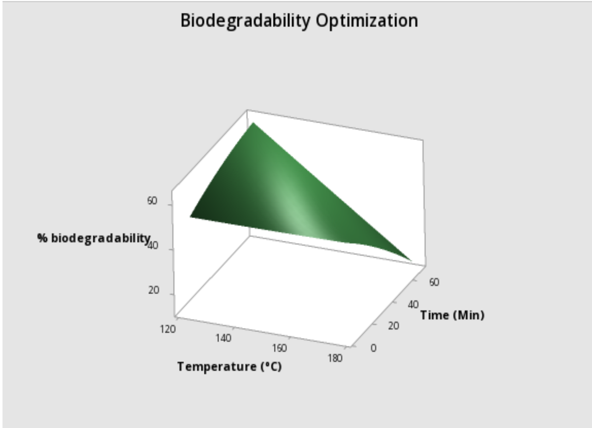

Figure 2. Surface graph of response of SPA test biodegradability.

In addition, a soluble organic mixture was produced upon hydrolysis. This fraction was checked for biodegradation with mixed cultures of PPB. As shown in figure 2, between 25-65% of the soluble COD was assimilated. A p-value lower than 0.05 indicates the model and variable terms (temperature and time) significantly affected the biodegradablity. Lower performance at higher temperatures and higher times was evidenced, probably due to formation and solubilization of recalcitrant compounds such as hydroxyl-methyl-furfural (Steinbach et al., 2019). A higher performance was found at lower temperatures and higher times. A mixed consortium of adapted PPB may improve these results. Besides, the liquid fraction obtained contained a very low COD/N/P ratio of 100/0.3/0.6, far from the optimal ratio, which has probably prevented further growth of PPB biomass. High COD and nutrients limitation have been described as optimal conditions for PHA accumulation (Fülöp et al., 2012).

Preliminary results show up to 11% of PHA content in mass basis. This study shows an improvement from previous results, where 4% of PHA content had been found using a mixed consortium of PPB and a MSW hydrolysate (Allegue et al., 2020). This is the first instance where a non-volatile fatty acids waste is fed to a PPB-based system and it is partially converted into PHA, and it enlarges the PHA production potential of PPB-based technologies.

Summarizing, these results are promising and encourage future research to maximize the production of PHA and evaluate its implementation in a continuous process using OFMSW as a low-cost feedstock, in an integrated PPB-based photo-biorefinery.

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References

Abad, V., Avila, R., Vicent, T., Font, X., 2019. Promoting circular economy in the surroundings of an organic fraction of municipal solid waste anaerobic digestion treatment plant: Biogas production impact and economic factors. Bioresour. Technol. 283, 10–17.

Allegue, L.D., Puyol, D., Melero, J.A., 2020. Novel approach for the treatment of the organic fraction of municipal solid waste: Coupling thermal hydrolysis with anaerobic digestion and photo-fermentation. Sci. Total Environ. 136845.

Cano, R., Nielfa, A., Fdz-Polanco, M., 2014a. Thermal hydrolysis integration in the anaerobic digestion process of different solid wastes: Energy and economic feasibility study. Bioresour. Technol. 168, 14–22.

Cano, R., Nielfa, A., Fdz-Polanco, M., 2014b. Thermal hydrolysis integration in the anaerobic digestion process of different solid wastes: Energy and economic feasibility study. Bioresour. Technol. 168, 14–22.

Fava, F., Totaro, G., Diels, L., Reis, M., Duarte, J., Carioca, O.B., Poggi-Varaldo, H.M., Ferreira, B.S., 2015. Biowaste biorefinery in Europe: opportunities and research & development needs. N. Biotechnol. 32, 100–108.

Fülöp, A., Béres, R., Tengölics, R., Rákhely, G., Kovács, K.L., 2012. Relationship between PHA and hydrogen metabolism in the purple sulfur phototrophic bacterium Thiocapsa roseopersicina BBS. Int. J. Hydrogen Energy 37, 4915–4924.

Holliger, C., Alves, M., Andrade, […], 2016. Towards a standardization of biomethane potential tests. Water Sci. Technol. 74, 2515–2522.

Koller, M., Maršálek, L., de Sousa Dias, M.M., Braunegg, G., 2017. Producing microbial polyhydroxyalkanoate (PHA) biopolyesters in a sustainable manner. N. Biotechnol. 37, 24–38.

Steinbach, D., Wüst, D., Zielonka, S., Krümpel, J., Munder, S., Pagel, M., Kruse, A., 2019. Steam explosion conditions highly influence the biogas yield of rice straw. Molecules 24, 1–14.