Optimisation of anaerobic digestion of organic fraction municipal solid waste

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Keywords: organic fraction municipal solid waste, anaerobic digestion, modelling, pre-treatments

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Organic Fraction Municipal Solid Waste (OFMSW) is one of the most produced bio-waste. The reasons are due to urbanisation growth, dietary change and food preservation policies (FAO, 2018).

Currently, OFMSW management consists in landfill disposal and incineration, which carry out both environmental and economic issues as greenhouse gases emissions, resource depletation and high economic disposal costs (Nayak and Bhushan, 2019). Across different countries and dietaries OFMSW general composition consists in 10-26 %w/w total solid content and high organic fraction (85% ± 5%) and Carbon content higher than 70%w/w, which can become a secondary raw material valorisable through biological treatments.

One of the most attractive valorisation of biowaste is anaerobic digestion (AD), through which climate protection (Zamanzadeh et al., 2016) and renewable energy production (Braguglia et al., 2018) can be achieved. The aim of the present work is the evaluation and optimisation of mesophilic AD of OFMSW as pivoting process in integrated biorefinery system, both as energy vector and added-value products producer. The target of biorefinery system is to produce value added product and energy from a given feedstocks in a timely and energy efficiently.

In details, AD key process parameters are studied considering currently and available technologies provided by scientific literature and evaluated by means of predictive modelling. Both experimental and modelling studies are performed. The main tools adopted to study the optimisation of AD and then, to carry out experimental process are: first order Angelidaky's kinetics, Gompertz modified models and ADM1 with Matlab software. Angelidaky's kinetics defines the disintegration rate (k_d), assuming a first order kinetic model, and it is calculated through the first part of the cumulative methane curve (Angelidaki et al., 2009). Gompertz modified model is employed as a deterministic function, based on non-linear regression, calculated with Solver Tool-Pak of Microsoft Excel. Gompertz modified model allows to estimate the lag-phase, maximum biogas production rate and maximum biogas yield potential (Nguyen et al., 2016). ADM1 allows to split AD in two subprocess: biological reaction considering micro-organisms activity and chemical physical reactions, considering possible inhibitory compounds (Kovalovszki et al,2019).The parameters of AD considered as key factors are: 1) feedstock pre-treatments (physical, biological, chemical and combined), 2) the inoculum source- ratio -origins and 3) volatile fatty acids (VFAs) concentrations.

The analysis and interpretation of data, collected from scientific literature, are based on energy, Carbon and mass balances proved by Super Pro design software. Anaerobic digestion is carried out in 1L reactor at 35°C in batch feeding with 6 % of total solid and biogas is measured quantitative and qualitative with water displacement and GA200 gas analyser, respectively

The result of this study will be the validation of an optimised mesophilic AD to insert in integrated biorefinery system, maximising FW conversion into value added products and energy, minimising and re-integrating the residual by-products and secondary waste streams in the same integrated biorefinery system. In this way, according to Circular Economy policies and Agenda 2030 goals, economic profitability and environmental sustainability can be reached and biorefinery system can be scale at industrial levels.

The preliminary obtained results concern 1) OFMSW chemical and physical characterisations, 2) optimisation of physical pre-treatments and 3) inoculum conditions. OFMSW characterisation is based on more than 32 papers published between 2010-2020, in order to have a robust statistical datum and it consists of: 18.0 ± 0.29 % total solid, 75.00± 0.41 % VS/TS, 49.66 ± 8.23 % Carbon, 2.64 ± 0.34 % Nitrogen, 0.436 ± 0.27 % Sulphur, 6.026 ± 1.03% Hydrogen, 35.98 ± 6.52% Oxygen (Venus et al, 2018) (Cerda et al, 2018). Based on CHNSO analysis, OFMSW can be expressed as biochemical product $C_{42}NH_3O_{12}$. A detailed OFMSW macromolecular compound composition (proteins, carbohydrates, lipids, and lignocellulosic matrix) is a crucial step to select the most suitable AD strategy (Pagliaccia et al., 2019). In this way, according to CE policies and Agenda 2030 goals, OFMSW concept is transformed from waste to secondary raw material and from problem to resource. Mainly, FW composition consists of 55.2 ± 13.08 carbohydrate, 13.00 ± 3.54 % protein, 3.60 ± 0.85 % oil/fat, 4.8 ± 0.34 cellulose, 3.1% hemicellulose and 2.64 ± 0.14 lignin (Cerda et al, 2018) (the roughly 20% of residual substrate is not detected). Carbohydrate components are easily hydrolyzed in AD, while cellulose, hemicellulose and lignin compounds are hardly degradable fractions, which require pre-treatments able to disrupt the lignocellulosic matrix and release the organic matter for microbial degradation. Since OFMSW is mainly composed of fruit peels and vegetable scraps, which are hardly degradable fractions, it requires pre-treatments to be properly valorizable by biological processes. Pretreatments enhance organic matter solubilization, maximizing the kinetics of AD and the whole anaerobic biodegradability (Nayak and Bhushan, 2019). The preliminary studies of pre-treatments are focused on physical pre-treatments: mechanical and thermal pre-treatments. These pretreatments are adopted for OFMSW and lignocellulosic biomasses (Ariunbaatar et al., 2014); because they can improve the solubilization of the substrate (Montecchio et al., 2017) reduce lignocellulosic matrix and improve digestate quality and hygienization (Ariunbaatar et al., 2015). Moreover, AD of physical pre-treated OFMSW can be carried out with higher organic loading rate (OLR) than AD of untreated OFMSW. In details, mechanical pre-treatment is performed for 15, 30 and 45 min, and thermal pre-treatments is performed for 15, 30 and 45 min at 60, 90 and 120 °C. Combined to pre-treatment of OFMSW, we carried out pre-treatment of inoculum. Two inocula are employed, one coming from wastewater active sludge (WAS) and the second from cow agriculture sludge (CAS) These inocula are incubated for 0, 5 and 10 days to cultivate a biomass more suitable to convert OFMSW into biogas with higher methane content. Moreover, three Substrate:Inoculum (S:I) ratio are tested: 1:2, 1:1 and 2:1.The preliminary obtained results prove that increasing the incubation time of the inoculum (from 0 to 10 days) it is possible to work with higher S:I (1:1 and 2:1). Among physical pre-treatments, the anaerobic digestion performed at 90°C for 30 min wit CAS at S:I = 2:1 incubated for 10 days reaches the highest biogas production, around 1000 NL/kgvs with 69.3%v/v of methane.

Among the mechanical pretreatments, the anaerobic digestion performed for 15 min wit CAS at S:I = 2:1 incubated for 10 days reaches the higher biogas production, equal to 967.8 NL/kgvs.

Moreover, compared to the anerobic digestion of no pre-treated OFMSW, the anerobic digestion of physical pre-treated FW reduced the lag phase and time process of 2 and 8 days, respectively.

Further steps of this study will be the performance of biological, chemical and combined pre-treatments, the environmental sustainability evaluation by means Life Cycle Assessment and the economic profitability estimation through Life Cycle Costing.

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Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors declare no conflict of interest.