Integrated anaerobic digestion and pyrolysis of organic fraction municipal solid waste

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In EU28 the annual production of organic fraction of municipal solid waste (OFMSW) is 65-75 % of the total organic waste produced, which means around 88-103 Mt of OFMSW (No, 2020). The composition of OMSW depends on many factors such as the economic development, the population density, the seasonality, and the legislation about waste minimization initiatives. The OFMSW are produced by residential sources as household and commercial sources as hospital, restaurant, and schools. The composition of OFMSW varies according to the countries and it is mainly made up of 25.7-33.2 %w/w lipids, 16.2-29.4 %w/w starch, 23.5-18.3 %w/w proteins and a moisture content around 85–90% w/w (Carmona-Cabello et al., 2020).

In EU28, OFMSW is currently composted, anaerobic digested, and incinerated despise of its high moisture content (Ricci-jürgensen, 2020). OFMSW are bio-degradable and putrescible fraction and the uncontrolled decomposition contribute to the global warming, climate change, and contamination of soil and water. According to (Macias-corral et al., 2008) the uncontrolled decomposition of 1 t of OFMSW can realised around 50–110 m^3 of CO_2 and 90–140 m^3 of CH_4. Anaerobic digestion (AD) is an implemented biochemical technology to bio-stabilise organic waste by producing biogas, which is a renewable energy resource able to face the rapid increase in energy demand and mitigate the greenhouse gas emissions. The solid digestate coming from AD is generally employed directly in agriculture as fertilise due to its high nutrient contents like P, N and K, but this application is currently discussed due to some negative effects as odour, heavy metals, and greenhouse gas emissions. To overcome these problems, pyrolysis of solid digestate could be a valuable solution to reduce environmental impact and improve the economic profitability of AD plant, by producing biochar.

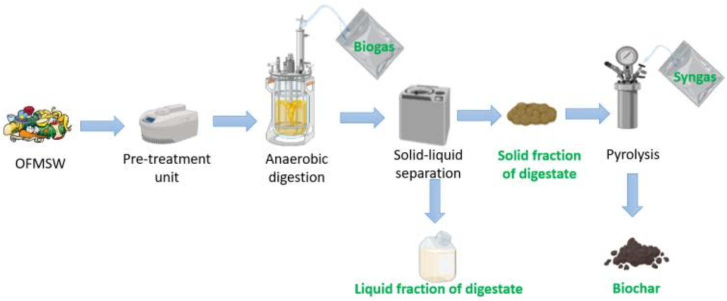
The **aim** of the present study is the development of an integrated OFMSW biorefinery system made up of sequential anaerobic digestion and pyrolysis. The proposed integrated biorefinery consists into AD of OFMSW with production of biogas and digestate and the solid fraction of the digestate is employed as feedstock for the slow pyrolysis to produce biochar. Both the processes, AD and slow pyrolysis are studied and optimised to improve the quality and yields of the products. The AD is optimised to enhance the CH_4 content in the biogas and to produce a digestate with proper quality to be pyrolyzed. The slow pyrolysis is optimised to produce biochar employable in agriculture and either bio-oil or syngas to support the whole proposed biorefinery system. The scheme of the proposed integrated biorefinery is depicted in Figure 1.

The **adopted approach** consists of both experimental and modelling activities. The OFMSW used in the experimental test-comes from a North Italy waste plant. AD is carried out in 1 L batch reactor and pyrolysis in a 1 L fixed bed reactor. Both processes are carried out in duplicate. To enhance biogas production OFMSW is physical pre-treated according to (Ma et al., 2011). Mesophilic AD is performed at 6 % total solids and Substrate Inoculum (S:I) ratio 2:1, employing as inoculum the mesophilic digestate of cow agriculture slurry according to (Mateescu and Constantinescu, 2011). The slow pyrolysis is performed on the solid fraction of the digestate from OFMSW as well and pre-treated to compare the yields and performances. The slow pyrolysis is carried out at three temperature 400, 500 and 600 °C according to (Liu et al., 2020) and two heating rate 5 and 10 °C/min in agreement with (Noor et al., 2012) at three holding times 60, 90 and 120 min in accordance with (Yuan et al., 2014). Biogas and syngas quantity and quality are analysed by water displacement and gas-chromatography. Biochar physical and chemical properties are measured through elemental analysis, BET, FTIR, fixed Carbon and the high heating value is measured by calorimetric bomb. The bio-oil composition is analysed by liquid-chromatography. Modelling activity consists into AD evaluation by means of Angelidaky's kinetics, Gompertz modified models and Disintegration rate.

The **novelty** of the present study is the evaluation of the whole biorefinery to exploit and valorise the OFMSW into high added value products as energy and biochar, by combining technical feasibility with environmental sustainability and economic profitability. Environmental sustainability is performed with Life Cycle Assessment (LCA), while economic profitability with Life Cycle Cost (LCC).

The **preliminary results** of the present study concern 1) the OFMSW physical characterisation, 2) the specific biogas productions of AD of OFMSW as well and physical pre-treated by cavitation at 50 °C for 10 min and 3) the biochar production at 400 °C with heating rate of 5 °C/min and holding time of 60 min for solid digestate of OFMSW as well and cavitated OFMSW. The OFMSW has a moisture content equal to 89 %$\pm$ 2.3, a volatile solids of 12.7 %$\pm$ 1.8, and an elemental composition as following reported: Carbon 45.7 %$\pm$ 2.7, Hydrogen 6.10 %$\pm$ 0.3, Nitrogen 2.4 %$\pm$ 0.2 and Oxygen 45.4 %$\pm$ 3.1 according to (Manczarski and Rolewicz-kali, 2020). The specific biogas production of AD of OFMSW as well and cavitated are equal to 575.21 $\pm$ 2.2 and 784.74$\pm$ 1.9 NL/kg vs, according to (Manczarski and Rolewicz-kali, 2020). The CH_4 content of cavitated OFMSW is 26 % higher than the CH_4 content of OFMSW as well and respectively equal to 69.0 and 51.1 % v/v. The pyrolysis of the solid fraction of the digestate of OFMSW as well and cavitated is performed in duplicate at 400 °C and heating rate of 5 °C/min for 60 min. The biochar of solid fraction of digestate of OFMSW as well and cavitated OFMSW have yields of 40.1 %$\pm$ 2.0 and 40.9%$\pm$ 1.8 and fixed Carbon respectively equal to 29.43 %$\pm$ 1.1 and 34.5 %$\pm$ 1.3. The biochar characteristics of the solid fraction of the digestate of OFMSW agrees with (Liu et al., 2020).To conclude, the preliminary results prove that higher specific biogas production and biochar with higher fixed Carbon are achieved by performing sequential and integrated AD and pyrolysis on pre-treated OFMSW. The complete result of the proposed study will be the technical, environmental, and economic validation of an integrated and sequential OFMSW biorefinery system made up of AD and pyrolysis. This biorefinery system tries to be a concrete realisation of the Circular Economy policies and Agenda 2030 goals.

Figure 1: Scheme of the proposed integrated biorefinery. In green are depicted the obtained products.



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