Close the loop: study of the effect of digestate derived biochar on anaerobic digestion of organic fraction municipal solid waste.

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The European Green Deal stated that Europe must reach the carbon neutrality by 2050, to guaranty a sustainable development. With the "Fit for 55 %", the greenhouse gas (GHG) emissions must be reduced by 55 % by 2030, and the zero-emission target must be achieved by 2050.

In Europe, the main contributors to GHG emissions are: 77 % energy production and consumption, 10.55 % agriculture, 9.10 % industrial process and 3.32 % waste treatment.

The anaerobic digestion (AD) is a valid and mature technology able to reduce the GHG emissions in most of the above-mentioned sectors. AD is well established in energy and waste treatment sectors because AD stabiles, treats and converts organic waste into biogas, which plays a significant role in the renewable energy in the world. The main criticisms of AD process are due to possible inhibitor presence, ammonia, and volatile fatty acid accumulations and digestate management. The digestate could be used as a fertilizer but it is problematic if not monitored or produced properly. This is due to digestate composition, which may contain heavy metals and organic pollutants (Brandli et al., 2007); physical impurities, pathogens, viscosity, and odour (Novak 2009). In the last few years, it has been proposed to employ digestate as feedstock for the pyrolysis to produce the biochar (Wang et al., 2022).

The present study aims to investigate the technical and environmental feasibilities of adopting a circular economy model to perform the anaerobic digestion of organic fraction municipal solid waste (OFMSW). In details the circular model comprises the optimisation of AD both in terms of process stability, CH_4 production and H_2S low concentration in the biogas by adding the biochar produced through the slow pyrolysis of the dried digestate.

The novelty of this study is the development of a sequential and integrated biorefinery system able to promote a win-win strategy to improve the energy production, to minimise the AD process instability and to eliminate the problems related to the digestate management. Both AD (bio-chemical process) and slow pyrolysis (thermos-chemical process) can stabilise organic matter, produce valuable products and energies (biogas, and pyro-gas, and bio-oil respectively) to partially or completely cover the energy required by the biorefinery system.

The adopted method to carry out this study can be divided in four phases. The phase I is the performance of AD of real OFMSW supplied by San Carlo plant (Fossano, Italy) to produce biogas. Th AD is performed in batch mode in a 2 L (glass Duran Bottle, Germany) with a working volume of 1.6 L incubated in a thermos-bath at 37 °C and at 6 % w/w total solid (TS). The substrate: inoculum ratio (S:I) is 1:1 and the inoculum is the mesophilic digestate of cow agricultural sludge (CAS). The reactor is connected through a Teflon pipe to a 5 L Tedlar gas bag. The digestate is dried at 105° C and employed as feedstock for the pyrolysis.

The phase II concerns the slow pyrolysis of the dried digestate performed in a fixed bed reactor at 500 °C at 5°C/min for 1 h as residence time according to (Zhao et al., 2022), Before doing the pyrolysis, the dried digestate was divided in two samples. The first sample (named AB) was activated by impregnating it with a 1:1 (mass ratio) KOH solution for 12 h according to (Peng et al., 2023), whereas the second sample (named B) was feed as well to the pyrolysis. For each biochar (AB and B) two doses are tested 5 and 10 g/L (Ovi et al., 2023)

The phase III consists in the performances of AD in 500 mL reactor (glass Duran Bottle, Germany) with a working volume of 400 mL incubated in a thermos-bath at 37 °C and at 6 % w/w TS. Each AD configuration (consisting into type of biochar and dose of it) was tested in triplicates. The AD without biochar addition was performed and used as reference and tested in triplicate. The OFMSW, digestate and biochar are physical and chemical characterised through the elemental analysis CHNSO (Elemental Macro Cube system (Vario, Germany), the total and volatile solids according to (APHA, 2006), total and soluble COD and Ammonium were detected through a COD LCI 400 and a LCK 304 (HACH LANGE GHB, Germany) and quantified by a spectrophotometer 5000 D, (HACH, Canada), pH with a pH340 WTW pH-meter (Mettler Toledo, Germany), the metal contents of digestate and biochar is measured with(ICP-MS and the specific surface of biochar was measured with the Brunauer-Emmett-Teller (BET) through N_2 physisorption isotherms at −196 °C on 110-190 mg sample previously outgassed at 240 °C for 6 h to remove molecular water and other atmospheric contaminants (Micrometrics Tristar II, USA instrument); the total pore volume (Vp) was calculated at P/P0 = 0.97.

Biogas and pyro-gas were quantitatively measured by water displacement and qualitatively analysed with SRA Micro-GC, equipped with a Molsieve 5A column (for the analysis of permanent gases like hydrogen, nitrogen, methane, and carbon monoxide) and argon as carrier (column temperature: 100 °C); and the detection of the species was due to a TCD detector. The phase four of the study is the environmental assessment performed with Sima Pro 9.2 and Ecoinvent 7 to compare the environmental impacts of the different tested configurations.

The preliminary results concern the phase I and II of the study. Specifically with the performances of the AD of OFMSW (Figure 1) which achieved 700 NL biogas /kg_{VS} with 56.37 % v/v of CH_4 and the production of biochar. At 500 °C, the production of biochar, referred to the feed dried digestate, was 34.01 % for AB and 33.30 % w/w for B, and the chemical-physical properties are reported in Table 1.Table 1 underlined that the AB reached higher ashes content, pH and specific surface rather than B according to (Peng et al., 2023) and these properties are promising for adsorption capacities in the AD process of phase III of the study.

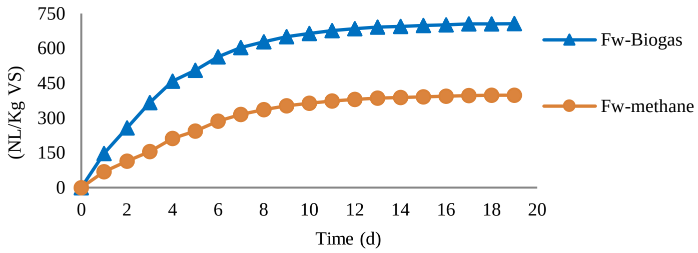

Figure1: Specific biogas (blue) and methane (orange) production of AD of OFMSW

Table 1: chemical-physical characterisation of feedstock (OFMSW), digestate and biochars (AB and B)

	OFMSW		Inoculum CAS		Digestate		Activated biochar (AB)		Biochar (B)	
	mean	dev.st	mean	dev.st	mean	dev.st	mean	dev.st	mean	dev.st
TS (%)	19	2,3	6	0,1	5,7	0,99	1,01	0,009	1,2	0,02
VS/TS (%)	97	1,8	67,9	1	52	2,76	/		/	
C (%)	45,7	2,7	40,6	0,6	39,34	1,34	30		42,96	
H (%)	6,1	0,3	3	0	6,08	2,1	1,81	0,86	3,13	0,75
N (%)	2,4	0,2	7,9	0,1	3,4	0,45	3,57	0,34	3,79	0,29
S (%)	0,2	0,1	0	0	1,45	0,01	1,67	0,01	1,16	0,01
O /%)	45,4	3,1	48,5	2,1	49,73		9,6	1,12	4,10	0,966
pH	5,3	0,2	7,7	0,1	6,9	0,15	9,88	1,1	9,40	0,96
Ashes	/	/	/	/			64,67	2,2	50,01	1,89
VM (%)	/	/	/	/			10	1	16,79	0,86
CF (%)	/	/	/	/			25,33	1,09	33,20	0,94
BET (m^2/g)	/	/	/	/			47,61	1,98	17,59	1,71

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