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Physicochemical properties and sorption capacities of sludge-sawdust based biochars towards the removal of synthetic dyes in wastewaters

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Biological sludge is a widely available waste material of high environmental concern, the disposal of which involves a high cost, whereas its reuse is in line with the modern approach to the waste management and the circular economy. It should also be noted that thermal conversion of biological sludge for biochar production allows inhibiting the intrinsic toxicity related to the presence in this matrix of poorly biodegradable organic micropollutants and potentially pathogenic organisms. It is therefore evident that the conversion of biological sludge into biochar as a sorbent for wastewater treatment seems to be a ‘‘win–win’’ solution for both improving sludge management and protecting the environment. Based on the above-mentioned considerations, the objective of this research was the production of biochars from mixtures of biological sludge and waste woody biomass, their in-depth product characterization, the assessment of their environmental compatibility towards European Standards, and the evaluation of their applicability for the removal of selected synthetic dyes. The biochars were produced following the “design of experiment” approach, using a “reduced combinatorial design” that allowed to balance the number of experiments with the efforts required for the analysis of the multiple parameters necessary for achieving their in-depth characterization. The matrix of the experiments, which includes the production of nine biochars (plus three replicates) is shown in Table 1.

Biochar	Woody waste	Sludge	Temperature (°C)	Contact time (min)	Sludge percentage
B1	A	n.a.	450	120	0
B2	A	n.a.	650	60	0
B3(a)	B	n.a.	850	120	0
B4	B	Calice	450	60	15
B5	A	Vernio	650	120	15
B6	B	Vernio	850	60	15
B7	A	Vernio	450	60	30
B8(b)	B	Calice	650	120	30
B9(c)	A	Calice	850	60	30
B10(a)	B	n.a.	850	120	0
B11(c)	A	Calice	850	60	30
B12(b)	B	Calice	650	120	30

Table 1. Matrix of the production experiments of biochars. The same superscript letters refer to different productions under the same experimental conditions. Woody waste was mainly oak (A) or poplar (B); n.a. = not available.

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Moreover, this design allows to treat multilevel (i.e. pyrolysis temperature, contact time, sludge percentage) and qualitative (feedstock and sludge type) factors equally. Biochars were characterized for ash content, water leachable polycyclic aromatic hydrocarbons (PAHs) and trace metals, elemental composition, specific surface area (SSA) and porosity distribution, pH of the point of zero charge, and presence of crystalline phases, as elsewhere described [1,2]. None of the biochars produced met the European standards 12915-1 for materials suitable for water treatment [3], most of them being characterized by ash percentage higher than 15% and/or release of some elements and/or PAHs higher than the corresponding limit. Moreover, the chemometric approach adopted did not offer any valuable indication to overcome this issue. Accordingly, the materials most promising from the SSA viewpoint (i.e. B5, B6, B8, B10, and B11) were subjected to a chemical activation using a by-product of the gasification of woody biomass, followed by washing with tap water, and final thermal activation. All the treated materials met the requisites requested by the EN 12915-1, and their SSA values were not negatively affected by the treatments, with the only exception of B10, the SSA of which dropped from about 700 to about 400 m^2/g. The material deriving from the highest percentage of sludge and providing the highest SSA (i.e. B11, with 30% of sludge, SSA ≈ 400 m^2/g) was tested for the removal of methylene blue and selected pharmaceutical compounds, in comparison with a commercial activated carbon, obtaining similar sorption efficiencies. This research has shown, albeit on a laboratory scale, the possibility of producing carbonaceous materials from a feedstock containing high percentages of biological sludge (up to 30%) characterized by performances comparable to those of commercial activated carbon in terms of adsorption of organic compounds. In this way, it is possible to state that it has been set up a process for the recycling of biological sludge, capable of reaching the "end-of-waste" condition for this waste.

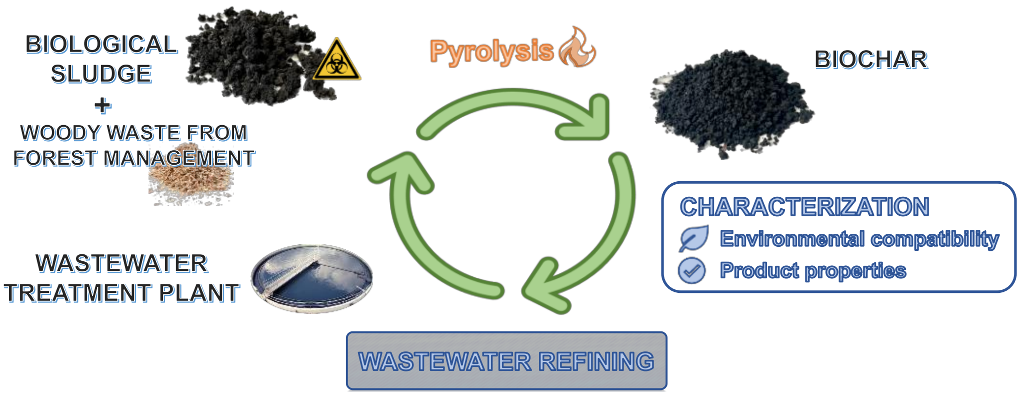

Figure 1. Graphical abstract

References

[1] Del Bubba, M., et al., Science of The Total Environment, **2020**. 708: p. 135217.
[2] Castiglioni, M., et al., Chemosphere, **2022**. 288: p. 132538.
[3] European Committee for Standardization. EN-12915-1/2009, Products used for the treatment of water intended for human consumption – Granular Activated Carbon, 2009.