A circular economy approach for recovering multiple resources form different wastewater treatment sludges

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Introduction

Every year, around 450 km^3 of domestic and agro-industrial wastewaters are discharged around the world. As a result, and depending on the country, wastewater source and technology being applied, approximately 30.000.000 dry metric tons (Mateo-Sagasta et al., 2015) of sludge is generated which needs to be managed in an ever increasing efficient and environmentally suitable way. The sludge is considered to be a heterogeneous and complex mixture of organic compounds, microorganisms, inorganic compounds and water (Oladejo et al., 2019). As such, the potential recovery of high value-added resources from this stream, including energy, is gaining considerable attention so to comply with the new European Green Deal, and particularly with the Circular Economy approach.

The objective of the present work was to show the technical viability for obtaining multiple valuable products from dairy and domestic sludges. Both sludges were produced by means of an Enhanced Biological Phosphorus removal (EBPR) process. Briefly, EBPR consist of successive anaerobic and aerobic conditions which leads to polyhydroxyalkanoates (PHA) (anaerobic phase) or poly-P (aerobic phase) accumulation within phosphate accumulation organisms cells (Oehmen et al., 2007). Consequently, EBPR provides sludges of contrasting characteristics according to the moment of the cycle in which the material is withdrawn.

Material and Methods

The multiple valorization alternatives were performed over two EBPR sludges with different origin. The first derived from real dairy wastewater treated in lab scale (5 L) sequential batch reactors. This sludge was harvested sequentially from the anaerobic phase (PHA-Rich), and aerobic phase (P-Rich). The second, was produced in a full scale EBPR facility for domestic wastewater and collected in the aerobic phase (P-Rich).

Suitability of these sludges as feedstock to produce value-added products was evaluated by means of PHAs content, biological methane production, biosolid stability through the dynamic respiration index, calorimetric potential, nutrients and metals content. Furthermore, and as a novel valorization pathway, water extracts of aerobic dried sludge were used as a medium to grow microalgae (MA) (*Chlorella sorokiniana*) and purple phototrophic bacteria (PPB) *(Rhodopseudomonas palustris)* in 1 L photobioreactors with the objective of producing valuable biomass which was then evaluated for nutrient content and aminoacidic profile.

Results and discussion

Interestingly, lab scale EBPR performance was not hindered by the sequential sludge collection while the produced materials exhibited remarkably high valorization opportunities. Our results (Table 1) show that, on one side, the dairy anaerobic sludge resulted in a material with a higher heating value (HHV) comparable with wood bark, olive husk and walnut shell (Acar & Ayanoglu, 2012) thus, making it suitable for biomass fuel production via biodrying. At the same time, aerobic sludge showed P concentrations about two times higher than conventional activated sludges striking, once biodried, as a potential feedstock for biobased fertilizers manufacturing according to the requirements of the category solid organic fertilizer (FPC1(A)I). Moreover, according to the measured metal contents, the potential sludge-derived biobased fertilizers after aerobic post processing, are expected to comply with the mandatory heavy metals' threshold values (REGULATION (EU) 2019/1009).

Table 1: Summary of the main results for anaerobic and aerobic EBPR dairy and domestic sludge. Average values (± standard deviation)

Variable / Type of Sludge	Units	Anaerobic Dairy PHA Rich Sludge	Aerobic Dairy P Rich Sludge	Domestic P rich sludge
PHAs	$g.g^{-1}$ CDW	0,08 (± 0,003)	0,04 (± 0,002)	0,42 (± 0,010)
BMP	Nml CH_4.g.VS^{-1}	83,15 (± 1,05)	49,12 (± 0,46)	-
HHV	MJ Kg^{-1} TS	21,99 (± 4,50)	10,59 (± 1,30)	22,53 (± 2,42)
DRI_{24h}	g $O_2 \cdot h^{-1} \cdot kg^{-1}$ VS	5,37 (± 0,21)	5,93 (± 0,19)	-
N	% Vs TS	2,51 (± 0,35)	5,70 (± 0,40)	7,68 (± 0,65)
P	% Vs TS	1,11 (± 0,73)	4,72 (± 0,23)	4,22 (± 0,13)
K	% Vs TS	0,31 (± 0,08)	0,25 (± 0,04)	0,37 (± 0,06)

(BMP: Biological Methane Production; CDW: Cell Dry Weight; DRI_{24h} Dynamic respiration index; HHV: Higher heating value; K: Potassium, N: Nitrogen; PHA: polyhydroxyalkanoates; P: Phosphorus; TS: Total Solids; VS: Volatile solids)

Additionally, results from cultures of MA and PPB growing over the dried aerobic sludge water extracts showed satisfactory growing yields (similar to yields obtained growing over standard mediums) with replication times of 12 and 13h, producing 1.01 and 0.91 g L^{-1} CDW respectively. The obtained biomass of MA contained 15.40 (± 1.05), 8.13 (± 0.12), and 0.41 (± 0.05) %.TS of NPK, while PPB biomass exhibited 25.12 (± 2.15), 0.50 (± 0.07), and 1.40 (± 0.08) %.TS of NPK. Regarding total amino acid content, Figure 1 shows the amino acid profile for both, MA, and PPB freeze dried biomass.

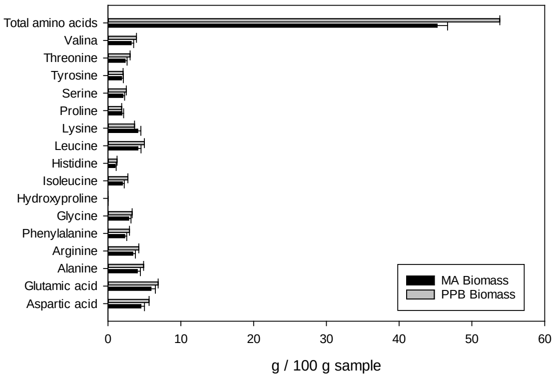

Figure 1. Amino acid content and amino acid profiles for MA and PPB biomass (g 100 g^{-1} of sample).

Following these results, MA biomass can be used as a nutrient rich component for biobased fertilizers production, while according to the essential aminoacidic score, PPB biomass can be employed as a protein rich ingredient for animal feed or either as a biostimulant product as stated by Zarezadeh et al. (2019).

Conclusions

This study presents the data of different EBPR sludges subjected to downstream valorization alternatives and highlights the opportunity for recovering several value-added products. Firstly, we achieved direct multiple resource recovery from sludges to be used as biofuels and as biobased fertilizers without hindering the EBPR effluent quality. Alternatively, and as a novel valorization pathway, the produced sludge was also derived for safe biomass production of nutrient rich MA and protein rich PPB biomass. The former alternative could help reducing the pressure for obtaining mineral fertilizers while the latter can lower the use of expensive protein rich meals in animal production chains. The proposed valorization pathways create a mindset in which sludge is seen as a pool of resources rather than a waste.

For direct sludge valorization, and in contrast to other necessary sludge drying methods, our proposed biodrying process is more environmentally friendly and economically efficient, due to low energy demand and no steam or gas requirements. Regarding MA and PPB biomass production, initial cost analysis and market benchmarking, show that production costs are somehow still high when compared to commercial fertilizers and animal feed meals, respectively. Nonetheless, reduction in production costs is likely to occur as more research is performed and trials are upscaled. Novel resource recovery pathways, such as the ones presented in this study, are highly needed to accomplish circular schemes in domestic and agro-industrial wastewater treatments in line with the circularity principles of the EU environmental strategy.

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