Turning wastewater treatment plants into biorefineries: global value chain from bioresources to valuable products

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Abstract: Environmental sustainability is a major goal for 21st century and high demand is being put for upgrading wastewater treatment plants (WWTP) into Biorefineries, addressing the recovery of nutrients (P, as phosphate rock is at EU Critical Raw Material List, and N, as N-fertilizers production are energy intensive) as well as sustainable sludge management promoting the Waste Hierarchy. At a case study at Murcia Este UWWTP (Spain), an innovative integrated process for nutrient and sludge recycling has been validated, consisting in a full-scale elutriation process for release and concentrate phosphates from sludge, followed by pilot units for P-recovery (struvite crystallization pilot plant of 1 m^3/h capacity) and N-recovery (zeolite adsorption followed by membrane contactors with 1 m^3/h capacity to produce ammonium salts). Results showed a potential nutrient recovery of 42% and 11% for P and N of WWTP influent and a reduction of 20% in sludge production due to the improvement in sludge dewaterability. Different fertilizer mixtures of sludge, struvite and ammonium nitrate were tested in crop cultivation, demonstrating its suitability for agricultural application with agronomic properties similar to those of conventional fertilizers.

Introduction

Resource recovery from waste streams deals with United Nations Sustainable Development Goals 6 and 11. It is a major goal of interest due to the alarming increase in worldwide pollution levels and raw materials depletion mainly caused by the overuse of fossil fuels and natural resources; hence, putting high demand on turning wastewater treatment plants (WWTPs) into wastewater resource recovery facilities (WRRFs) also called Biorefineries. An issue for long term global food security is the sustainable supply of phosphorus, a key resource for soil fertilization that cannot be substituted. Hence, the proper management of its reserves is a global concern as its scarcity is expected to take place in the next decades. The agricultural sector consumes also large amounts of nitrogen as fertilizers. The production of nitrogen (NH_3) through the Haber-Bosch process is associated with a negative environmental impact due to its high energy demand. However, nitrogen recovery figures are insignificant today, i.e., the current practice in WWTP is its removal into the gas phase as N_2. Considering the large amount of sludge generated in the different EU countries, up to 10 million tonnes of dry matter in 2010, and considering that only 23.4% is on-site incinerated, 7.76 million tonnes per year must be transported off-site. Thus, there is a need for both reduction of production volumes and sustainable recycling strategies for sludge management following Waste Hierarchy stablished in EU Waste Framework Directive. Agricultural use of sludge allows it recycling instead of other less environmentally friendly applications. While WWTPs are an important source for the recycling of these elements, nowadays nutrient recovery rates are still very low and the agricultural use of sludge is far from being exploited due to sludge poor quality and low promotion of this practice. A promising way to overcome the challenges associated to the sustainability of waste(water) management and the agricultural sector is to transition from WWTPs to optimized resource recovery and fertilizer production facilities.

Materials and methods

The integrated process for resource recovery and sludge management optimization is achieved by combining different innovative technologies in Murcia Este WWTP (Spain) that treat wastewater generated from the city of Murcia (Spain) (ENRICH, 2021). The plant was designed for a flow of 100,000 m^3/d and a medium wastewater strength with approximately 600 mg/L of BOD_5. Currently most spread P-recovery techniques take place downstream the anaerobic digestion and their recovery yields are reduced as these processes takes place after the uncontrolled P-precipitation. Therefore, the sludge line of the full-scale installation was modified to implement P-elutriation and maximize P-recovery while improving sludge dewatering properties. P-recovery takes place in a crystallization reactor for struvite production designed to treat 1 m3/h and to produce 5 kg/d. The N-recovery treatment train is designed to treat 1 m^3/h of anaerobic digestion centrates, and an estimated production of 4.8 kg fertilizer/m^3 centrates. Figure 1 shows different units of prototype implemented in Murcia Este WWTP.

Figure 1 Elutriation tank (700 m^3) (left) and pilot P&N recovery units (right) located at Murcia Este WWTP

Results and discussion

Murcia-Este WWTP was characterized to afterwards calibrate a model BNRM2. Modelling and current experimental data have shown the feasibility of implementing P-management strategy (elutriation) to carry out the recovery before the anaerobic digestion in the Murcia-Este WWTP, increasing the available P amount for recovery, reducing the uncontrolled precipitation in the sludge line and improving dewaterability properties of digested sludge, thus, reducing maintenance and sludge management costs. A potential production of 1100 t/y of struvite and 1937 t/y of ammonium nitrate (recovery of 42% of P and 11% of N influent to WWTP) would account for a revenue of 1.18 M€/y. Sludge reduction of 5.6 kt w.m./y (20%) would account for 119 k€/y of savings, while sludge produced can be used with agricultural purposes. Revenues together with total savings from sludge dewatering improvement due to elutriation, minimization of uncontrolled P precipitation problems and reduction of N load to biological reactor would account for a 3.3% reduction in WWTP OPEX compared to baseline.

Struvite complies with Regulation (EU) 2019/1009 for its commercialization as fertilizer, while ammonium nitrate was free of metals and OMPs, suitable for fertilizer use. The fertilizer products have been tested in horticultural crops (greenhouse and open-air conditions) and extensive crops (open-air) in different locations in Catalonia (Spain), achieving similar yields in crop production to conventional fertilizers in terms of fruit size, weight, colour and P content (horticultural crops) and specific production (extensive crops) (figure 2). Also, no soil detriment was observed in terms of heavy metal or nutrient content after using alternative fertilizers and sludge compared to conventional ones.

Figure 2 Struvite (left) used in tomato greenhouse agronomic tests (centre) and oat cultivated in open-air conditions with sludge (right).

Based on these results, a new value chain across water and agricultural sectors was defined, and its replicability and transferability has been assessed in 3 other European countries apart from Spain: Italy, Denmark and Netherland. The assessment highlights that Italy could benefit most from the implementation of this new value chain regarding high sludge production (400 kt d.m./y from main 3,034 WWTPs) and management costs, low agricultural sludge application (23.9%) and non-compliances in nutrient WWTP discharges.

Conclusions

A sustainable innovative integrated nutrient recovery and sludge management approach has been demonstrated in Murcia Este WWTP, showing high potential for resource valorisation as fertilizing products and thus, proving the suitability of a new value chain across water and agricultural sectors for alternative fertilizers. Adaptation of the business model for the new value chain through different WWTPs and European territories is possible, pulling for the transition towards Biorefineries and sustainable agriculture.

References

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