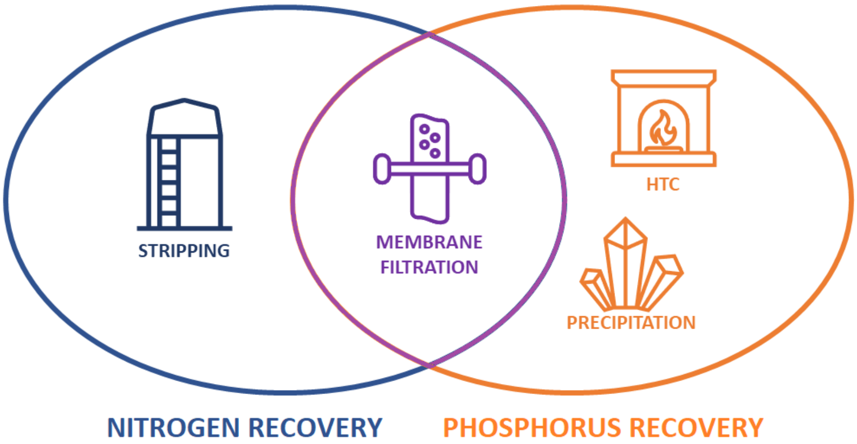
Nutrient Recovery from agricultural digestate at high TRL: A European State of Art

F. Rizzioli, D. Bolzonella, F. Battista

Department of Biotechnology, University of Verona, Strada Le Grazie 15, 37134 Verona, Italy
Keywords: Anaerobic digestion, agricultural digestate, nutrient recovery, stripping, precipitation, membrane separation.
Presenting author email: fabio.rizzioli@univr.it

Graphical Abstract



According to the European Biogas Association (EBA)'s Statistical Report 2020, a total of 18,943 biogas plants is present in Europe producing 167 TWh of biogas. A major part of the plants (70%) treats agricultural wastes, composed mainly by animal manure and crop residues (maize triticale, rice and wheat straw, energy crops). In particular, the agricultural waste is sent to an Anaerobic Digestion (AD) process to produce biogas as the main product, and digestate as by-product.

With a production of $3.7 * 10^8$ tons per year, the agricultural digestate is primally composed by recalcitrant lignocellulosic residues which cannot be easily convertible into biogas during AD. Digestate is attracting the attention because its high content of nutrients compounds, especially nitrogen (N), phosphorus (P) and potassium (K), as stated in Table 1. These compounds represent main macro-nutrients for plants growth, and fertilization, making the agricultural digestate a potential source for bio-fertilizers' production. However, the direct usage of the digestate in the soil is strictly regulated by the European Nitrate's Directive of 1991 (91/676/EEC), issued to prevent soil and water pollution by nitrates. This directive identified Nitrate Vulnerable Zones (NVZ) that are often coincident with European plains, flat areas and rivers' drainage basins. Consequently, a majority of livestock production sites and farms are concentrated in NVZ in Europe, leading to an excess of digestate that cannot be directly applied on farmland. This digestate overproduction needs to be stabilized in order to avoid water and soil pollution.

Table 1. Mean nutrients concentration in digestate

Nutrient	Average nutrients concentrations in agricultural digestate (kg/m^3)
Nitrogen (TN)	5.1
Phosphorus (P_2O_5)	2.3
Potassium (K_2O)	5.5

The digestate stabilization is achieved with two different approaches: (i) a wastewater-like approach, where the nutrients of the digestate are consumed by a denitrification process to convert nitrates to molecular nitrogen; (ii) a conditioning of digestate to recover nutrients for bio-fertilizer production. This recovery approach allows the digestate valorization into soil improvers and bio-fertilizers productions to be applied on nutrient deficiency soils. This approach is also promoted by the European Union (EU) with the new Directive on Fertilization Product Regulation (EU Directive 1008/2019), which granted the access to the EU fertilizer market of recycled organic fertilizer, so at fertilized derived from compost and digestate.

This review paper will provide an overview on of N and P recovery from digestate, focusing the attention on the processes that are already implemented at Technology Readiness Level (TRL). In particular, TRL from 6 to 9 will be investigated, which means from pilot/demonstrative scales to industrial one.

In order to recover nutrients, various processes can be applied at the digestate. The first step is common for all the methods and concerns solid-liquid separation, usually by a screw-presses, vibrating screens, decanter centrifuges and belt filters. The solid part, composed principally of lignocellulosic residue with Total Solid (TS) concentration of 20 – 30 % w/w, can be used directly as soil conditioner or undergo a further stabilization phase with drying or composting processes. The liquid part has a concentration of roughly 2 % TS w/w and contains more nutrients, such as nitrogen and phosphorus.

Nitrogen is usually recovered by ammonia stripping. In this process, the liquid part of digestate is treated with NaOH for CO_2 removal and ammonium volatilization, the latter is collected in a scrubber, mainly H_2SO_4 or HNO_3, to produce ammonium sulphate or ammonium nitrate, respectively, for commercialization. A recent work of Brienza et al. (2021) evaluated the techno-economic performance of a full-scale (TRL 9) digestate processing plant with ammonia stripping process. This process generated ammonium sulphate (22% solution) by gypsum scrubber without direct H_2SO_4 application. This nitrogen stripping system obtained the recovery of 57% of NH_4-N present in the digestate. Fouling problems of the stripping tower, due to calcium carbonate formation, and ammonia release risk are the major drawbacks of stripping process. Thus, the ammonia stripping plant needs frequently maintenance controls.

Regarding the phosphorus recovery, the two main processes used at high TRL are struvite precipitation and Hydrothermal Carbonization (HTC).

Struvite precipitation recovers principally P from the digestate, by the addition of magnesium and phosphoric acid, to precipitate the nutrients in form of magnesium ammonia phosphate (MAP). Then, the precipitated MAP is separated by centrifugation and collected for commercialization. Saerens et al. (2021) investigated a full-scale (TRL 9) struvite precipitation plant operated by Aquafin, at Leuven (Belgium). In this plant, the digestate was firstly minced in order to remove the biggest fibers and then crystallized with $MgCl_2$ addition (Mg/P ratio 2), forming struvite. Then, the MAP precipitate was separated from the remaining sludge by a hydrocyclone. The weekly production of struvite was 500 kg and the overall P-recovery was 5%. Besides the low P-recovery, another drawback of struvite precipitation was the high operational costs due to the large quantity of chemical used.

The HTC solubilizes almost all the P and N content, from the solid part of the digestate, in water, with a high pressure (5 – 45 bar) and temperature (180 – 250 °C) treatment. The products of HTC treatment are dried coal as solid part, and a liquid part enriched of P and N. The nutrients in the liquid phase are then precipitated to form struvite. Although HTC is equal to the classic struvite precipitation regarding the final product, the HTC treatment enhances the solubilization of P in the liquid phase, consequently, the final P recover yield was higher. Lucian et al. (2021) found a final P-recovery yield of 91% on an industrial-scale HTC plant treating agro-industrial digested sludge. This process is currently applied at full scale in the city of Jining (China) by TerraNova Company, treating 14,000 tons per year of sewage sludge. As for classic struvite precipitation, HTC requires large amount of chemicals.

Alongside these methods, a new approach started to be studied in lower TRL level: the membrane separation for digestate nutrient's recovery. In this process, the liquid part of the digestate undergoes sequential filtration steps, passing through a porous membrane under a driving force that can be electrical (electro-dialysis), or pressure driven. The latter usually consist by a step of ultra-filtration (UF) to remove all the TS content, followed by one or more steps of Reverse Osmosis (RO). The final product is the RO concentrate, rich in nutrients that can be stored, and purified water in the permeate, that could be released in the land. Membrane separation do not require chemical compounds to be implemented, thus representing a greener solution than the classic methods mentioned above. The fouling of the membranes is the major problem of membrane processes. For this reason, membrane processes are often coupled with an enhanced solid removal operation from digestate, for example, by a precipitation/flocculation step or adding more filtration steps. The main drawback of this combination is the increasing of the economic cost of the process.

This review will provide useful data to better understand the advanced processes in digestate nutrient recovery. With the start of the EU Fertilization Product Regulation, due for 16 June 2022, the nutrient recovery process could be a new investment front for numerous AD plants.

References

Brienza, C., Sigurnjak, I., Meier, T., Michels, E., Adani, F., Schoumans, O., Vaneeckhaute, C., Meers, E., 2021. Techno-economic assessment at full scale of a biogas refinery plant receiving nitrogen rich feedstock and producing renewable energy and biobased fertilisers. J. Clean. Prod. 308, 127408. https://doi.org/10.1016/j.jclepro.2021.127408

European Commission, 2019. Regulation of the european parliament and of the council laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003. Off. J. Eur. Union 2019, 114.

European Commission, 1991. Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. Off. J. Eur. Union 34, 1–8.

Lucian, M., Merzari, F., Gubert, M., Messineo, A., Volpe, M., 2021. Industrial-Scale Hydrothermal Carbonization of Agro-Industrial Digested Sludge: Filterability Enhancement and Phosphorus Recovery. https://doi.org/10.3390/su13169343

Project Jining - Sludge Drying by TerraNova Energy [WWW Document], 2022. URL https://terranova-energy.com/en/project/project-compiegne/ (accessed 2.11.22).

Saerens, B., Geerts, S., Weemaes, M., 2021. Phosphorus recovery as struvite from digested sludge – experience from the full scale. J. Environ. Manage. 280, 111743. https://doi.org/10.1016/j.jenvman.2020.111743