Scaling Up Nutrient Recovery: The Demonstrative Filtration plant (TRL7) of LIFE DIMITRA project

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The Department of Biotechnology of the University of Verona (UNIVR) is participating in the LIFE project titled "*Valorising anaerobic digestates into bio-fertilisers for climate-friendly agriculture*", also known by its acronym, LIFE DIMITRA. This initiative is funded under the "LIFE-2022-SAP-CLIMA" call of the "LIFE 2027" program. The project aims to valorize anaerobic digestate into bio-based fertilizers by the realization of two demonstrative plants in Greece and Italy.

UNIVR is in charge of the realization of DEMO 2, which will treat agricultural digestate through a combination of mechanical and pressure driven membranes filtrations. DEMO 2 has been installed at Cooperativa Agricola Zootecnica "La Torre" (LATORRE), an Italian farming company located in Isola Della Scala (Verona, Italy), which is a project partner. The company specializes in cattle farming, managing approximately 7,000 beef cattle annually. The livestock is a central focus of the farm, and the manure and slurry produced are utilized in its biogas plant to generate renewable energy. In addition to livestock farming, La Torre cultivates silage corn on its farmland, producing approximately 8,500 tons annually. This silage corn, alongside 35,000 m³ of slurry and 18,000 tons of manure, is used to feed the biogas plant. The plant produces biogas containing 53-54% methane, which is converted into around 8,600 MWh of electricity each year. The recovered thermal energy is used to heat the fermentation process.

DEMO 2 system will focus on the separation and recovery of key macronutrients (nitrogen, ammonia, phosphorus, and potassium) from agricultural digestate through sequential pressure-driven filtration processes.

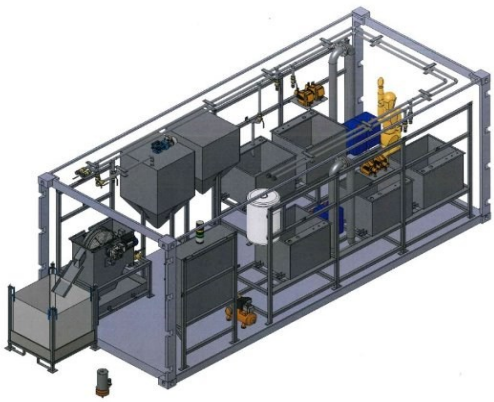
The process involves three-unit operations:

1. Initial Separation: Splitting the digestate into a solid fraction (SF), rich in particles and fibers, and a liquid fraction (LF), containing organic and inorganic compounds smaller than 100-60 µm.
2. Ultrafiltration: Processing the LF to produce a permeate rich in salts (ammonium and potassium) and a concentrate containing microorganisms, phosphorus, and organic nitrogen.
3. Reverse Osmosis: Treating the ultrafiltration permeate to yield pure water and a concentrate enriched with ammonium and potassium salts.

The present work aims to provide detailed information on the process which lead to the design, construction and implementation of DEMO 2 in the framework of the WP2 of LIFE DIMITRA project.

The three processes are integrated into a compact, modular container measuring about 2.4 x 3.0 x 5.8 meters, as illustrated in Figure 1. The design allows individual units to be activated or deactivated as needed, depending on the type of waste stream being treated. This modularity enhances the system's flexibility, enabling it to be relocated to other anaerobic digestion facilities and adapted for use with various types of wastewaters, ensuring its transferability and replicability in diverse contexts.

Figure 1. Tridimensional vision of the three-unit operations in the container.



Preliminary Solid Liquid Separation of the AGRD

The PSLS of the AGRD has the aim to remove fibers, the colloids and the biggest solid particles in order to protect the membrane of the UF stage. Moreover, it will allow a first fractioning of the main nutrients. Specifically, the phosphorus compounds will be mainly recovered along this step together with the main solids. The PSLS separation will be provided by a commercial machine, realized by "Nuove Energie" company, named PRIMESCREEN®. This fully self-cleaning, conical disc filtration system ensures an immediate improvement in biological treatment performance by reducing particle size and Volatile Suspended Solids (VSS).

Ultrafiltration step

The Liquid Fraction of the AGRD from the PSLS step, is then pumped in the Ultrafiltration (UF) section having the aim to remove the finest solids, the microorganisms and the organic nitrogen compounds. They will recover in the retentate flux of the UF, while the ammonium, phosphate and potassium compounds and the other salts are able to pass through the membrane and to constitute the permeate flux. The ultrafiltration module, realized by TAML – INSIDECERAM, represents an advanced system designed for applications requiring high filtration performance. This device utilizes tubular ceramic membrane technology, ensuring durability, efficiency, and reliability.

Reverse Osmosis

The UF permeate, purified from microorganisms and bigger cellular residues entered the RO step in order to concentrate most of the nutrients in the RO retentate and remove water, which will be collected in the permeate RO fractio. The RO modules consist of two tubular columns of polymeric membranes, having a weigh of about 4 kg for column. Specifically, the product employed for the construction of the DEMO 2 plant is the MWG SERIES 1000 E-4, with code H4E4G1. The housing body is made of epoxy resin reinforced with glass fibers, and the external finish is UV-resistant polyurethane resin.

Estimation of the mass balances for DEMO 2 plant

DEMO 2 can treat about 20 ton/d of AGRD. Each separation step will produce two outputs. PSLS will separate AGRD into a LF and SF accounting for 80 and 20% w/w of the initial total AGRD mass flow, respectively. The LF will be further treated in an UF step, which will produce a permeate and a concentrate accounting for the 80 and 20% w/w, respectively. The permeate from the UF (UF-PER) will be sent to the final RO step, which can produce a RO-PER accounting for about the 78% w/w of the UF-PER and a RO-RET, which has been estimated at the 22% w/w of the UF-PER.

It is very important to remark that the RO-PER flux, essentially represented by water, will be of about 10 tons/d, which means around the 50% w/w of the initial mass flow of the AGRD. It means that DEMO 2 will respect the correspondent Key Performance Indicator (KPI) of minimal water recovery of 50% w/w of the initial water mass in the AGRD.

The parameters TS and COD follow similar separation trends in the outputs of the DEMO 2 plant. In the AGDR step, over 50% of TS and COD from the PSLS is recovered, while vegetable fibers and solid particles are retained. The PSLS-LF allows smaller particles and soluble molecules to pass through. The next step, UF, separates microorganisms, proteins, and other organic molecules, recovering an additional 20% of TS and COD. Inert salts and lower organic compounds like volatile fatty acids are blocked in the RO-RET, resulting in low remaining TS and COD contents in the RO-PER, around 1.5% and 0.5% respectively.

The initial TKN and ammonium concentrations in the AGRD are about 5 and 3.5 g/kg, respectively, resulting in an ammonium-TKN ratio of around 70%. The PSLS step blocks nitrogen compounds attached to solid particles and vegetable fibers, with over 80% of these compounds flowing to the UF step. This step separates organic and mineral nitrogen compounds. Most organic matter is retained in the UF-RET, while soluble and ammonium ions pass through to the RO step. This reduces the ammonium-TKN ratio in the UF-RET to below 55%. Finally, the remaining nitrogen compounds, mainly ammonium, are recovered in the RO-RET, leaving TKN and ammonium concentrations in the RO-PER close to zero.

TP (total phosphorus) and potassium compounds have different distribution trends. The distribution of TP is similar to TS, with 60% of phosphorus compounds separated in the PSLS step. An additional 17% is recovered as proteins in the UF-RET, and the remaining parts in the RO-RET. In contrast, potassium compounds, being primarily in ionic form, have a distribution trend similar to ammonium. Therefore, the PSLS step recovers only a small percentage of potassium compounds, while around 50% are blocked in the RO-RET.