Innovative nutrient recovery from digestate through integrated crystallization and stripping technologies

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Introduction

In recent years, the agricultural industry has witnessed a growing interest in sustainable waste management practices, particularly concerning the utilization of digestate, a byproduct of anaerobic digestion processes (Czekała *et al*, 2022). This organic-rich material has become a focal point for researchers and innovators seeking effective ways to recover valuable nutrients and transform waste into a resource. The quest for sustainable solutions has led to the exploration of various technologies for agronomic valorization of digestate, each with its unique set of challenges and opportunities. Traditionally, technologies such as solid-liquid separation, ammonia stripping, ion exchange, membrane processes, and evaporation have been employed to address nutrient recovery from digestate (Kovačić *et al*, 2022.). While these methods offer certain benefits, they often fall short in delivering high-value end-products (Razzioli *et al*, 2023). For instance, solid-liquid separation methods may result in low-value byproducts, and ammonia stripping tends to focus solely on nitrogen recovery, neglecting other essential nutrients. Moreover, membrane technologies face challenges related to fouling, necessitating chemical cleaning processes that drive up operational costs. The evaporation process, although effective, demands substantial energy inputs and poses environmental concerns. As a result, there exists a need for innovative technologies that not only overcome these limitations but also integrate seamlessly into the broader context of sustainable agriculture.

The landscape of nutrient recovery technologies has seen advancements, with membrane purification being a prominent method in some European countries. However, these processes often lack cost-effectiveness and fail to achieve comprehensive nutrient recovery. Additionally, the utilization of heat-dependent technologies like evaporation has gained traction, especially in Germany, driven by incentives for residual heat utilization in biogas cogeneration plants. In the realm of nutrient recovery from struvite precipitation, several industrial-scale technologies have emerged, primarily focusing on wastewater treatment plants. However, a notable gap exists in adapting these processes for digestate from anaerobic digestion facilities (Chojnacka and Moustakas, 2024). This presents a distinctive opportunity for innovation, where the integration of struvite crystallization and stripping technologies could revolutionize the landscape of nutrient recovery from organic waste, specifically digestate.

ECOVITA project (Figure 1) aims to bridge these gaps by proposing a novel and comprehensive solution that combines the strengths of struvite crystallization and ammonia stripping. By doing so, the project not only addresses the challenges associated with existing technologies but also presents a groundbreaking approach to nutrient recovery from digestate, contributing to the advancement of sustainable agriculture practices.

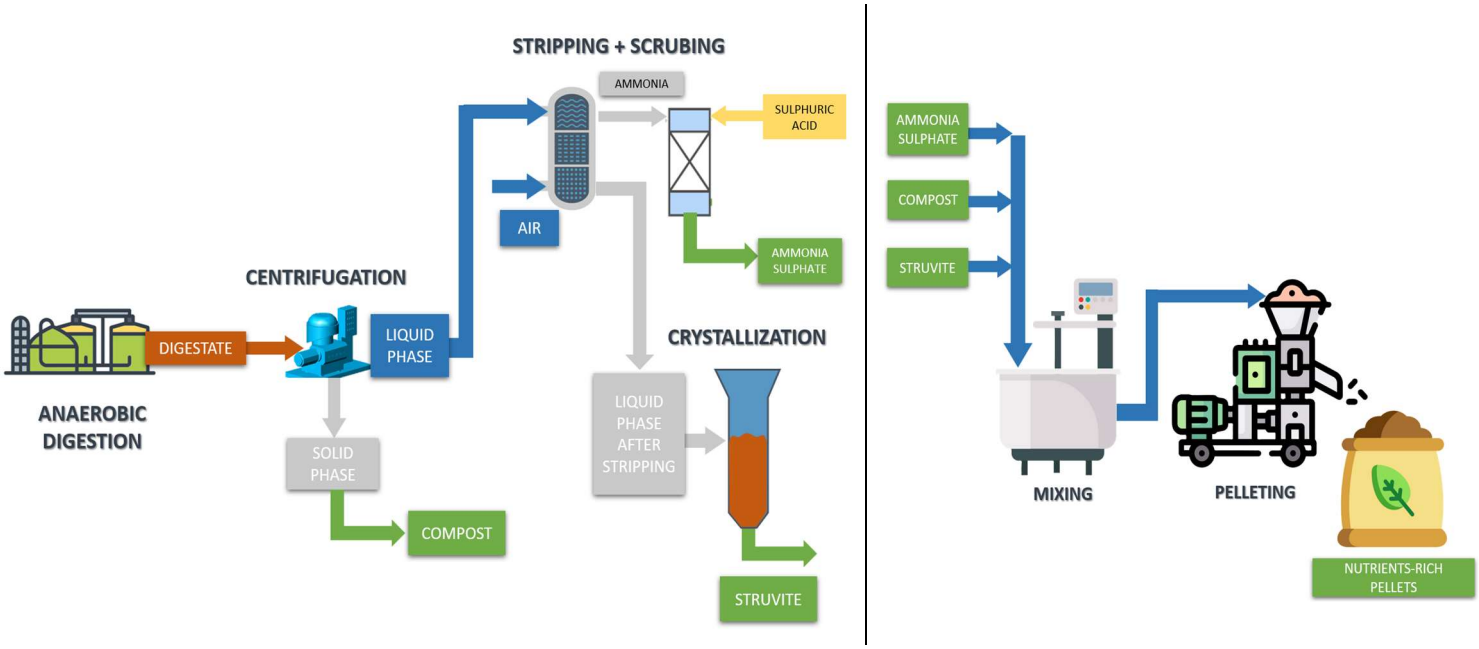

Figure 1. ECOVITA concept.

ECOVITA technology: Overcoming challenges and setting new paradigms

ECOVITA project introduces a paradigm shift in nutrient recovery from digestate by addressing key challenges associated with existing technologies.

- Crystallization reactors, striking the balance between chemistry and fluid dynamics: ECOVITA places a significant focus on crystallization reactors for struvite production. By combining chemical reactions with fluid dynamics, the project aims to design reactors that ensure optimal performance. The challenge lies in achieving a delicate equilibrium that guarantees technical, economic, and environmental viability. The selection of a fluidized bed reactor introduces complexities in control but promises high-quality struvite granules, setting ECOVITA apart from conventional stirred reactors.

- Integrating crystallization and stripping technologies: The integration of two distinct technologies, crystallization, and stripping, presents a unique challenge. ECOVITA tackles this by harmonizing the two processes to ensure synchronization. The strategic use of effluents from the struvite crystallization process for the stripping phase minimizes fouling issues, offering a streamlined and efficient nutrient recovery pipeline.

- Upscaling struvite recovery for industrial applications: Many existing struvite recovery plants are integrated into wastewater treatment facilities. ECOVITA seeks to transcend this limitation by applying its innovative process to large-scale agricultural operations. By doing so, the project aims to establish the feasibility of its approach in diverse settings, contributing to the broader adoption of sustainable waste management practices in the agriculture sector.

- Novel fertilizer synthesis through pelletization: ECOVITA goes beyond traditional nutrient recovery methods by pioneering the synthesis of new fertilizers through the synergistic pelleting of compost, struvite, and ammonium salts. This innovative approach allows for the creation of custom formulations tailored to specific agricultural needs. By combining the organic richness of compost, the phosphorus potential of struvite, and the nitrogen content of ammonium salts, ECOVITA aims to produce high-quality pellets that provide a comprehensive nutrient profile for diverse crops.

- Environmental sustainability: ECOVITA aligns with the principles of the circular economy. The integration of nutrient recovery technologies into anaerobic digestion plants not only offers a holistic approach to organic waste treatment but also synergizes with other processes like biogas upgrading. This multifaceted integration enhances the overall value proposition of anaerobic digestion plants, presenting them as environmentally sustainable hubs for organic waste management.

In navigating these challenges and pushing the boundaries of conventional nutrient recovery, ECOVITA establishes itself as a trailblazer in the quest for sustainable and innovative solutions in the agricultural waste valorization landscape.

Future perspectives

The ECOVITA project sets the stage for future advancements in nutrient recovery and sustainable agricultural practices. The knowledge gained from this research can potentially impact fertilizer producers and marketers, offering the opportunity to obtain two substitute products (struvite and ammonium sulfate) for traditional mineral fertilizers. Moreover, the project's outcomes may enhance the agronomic potential of these products while employing environmentally more sustainable processes. As the experimentation phase unfolds, technical feasibility and environmental sustainability will be evaluated, contributing valuable insights to the state-of-the-art in nutrient recovery from organic waste. The adaptability of the process to different digestate compositions and its potential economic viability will be critical factors influencing its broader applicability in the agricultural sector. The project's adherence to the principles of the Circular Economy adds another dimension, emphasizing the holistic use of outputs and minimizing waste. In conclusion, ECOVITA not only addresses the immediate challenge of nutrient recovery but also paves the way for a more circular and sustainable approach to agricultural waste management and fertilizer production.

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