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Integrated approach for nutrient recovery and mitigation of struvite formation in corn processing wastewater treatment plant

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Highlights:

- Identification of struvite formation as a key issue leading to pipe encrustation and manual removal requirement.
- Evaluation of two treatment routes: control, utilizing iron salts for phosphorus removal, and recovery, targeting struvite precipitation.
- Construction and assessment of a crystallizer for struvite recovery, analyzing parameters such as hydraulic retention time, pH, and concentrations of nutrients.
- Demonstrated effectiveness of the recovery route in mitigation struvite formation while producing a valuable fertilizer product.

Keywords: Bioeconomy; Waste valorization; Crystallizer

INTRODUCTION

There are still numerous obstacles related to industrial production and the treatment process of its effluents. One example is the formation of struvite in wastewater treatment plants (WWTP), which poses operational challenges such as pipe blockages and equipment damage. This hinders treatment efficiency and potentially poses hazards to worker safety during struvite removal processes.

Despite the inherent challenges associated with struvite formation in treatment plants, there are opportunities emerging, such as the recovery of this crystal for future use as fertilizer. Struvite, composed of ammonium, phosphate, and magnesium, can be reclaimed and utilized as a slow-release fertilizer, minimizing nutrient leaching and promoting sustainable agricultural practices (Guan et al., 2023). These opportunities signify a shift towards more sustainable practices within wastewater treatment processes. By harnessing technologies like struvite crystallization, what was once regarded merely as a pipe clogging issue now emerges as a valuable resource. This approach not only enhances the efficiency of wastewater treatment but also contributes to closing the loop in nutrient cycles, promoting a more circular and environmentally friendly approach to resource management (Nagarajan et al., 2023).

In this context, the study was conducted through two routes: the first, called control, involves the application of a metallic salt to inhibit the formation of struvite; and the second, called recovery, consists of the crystallization of struvite aiming at future application as fertilizer.

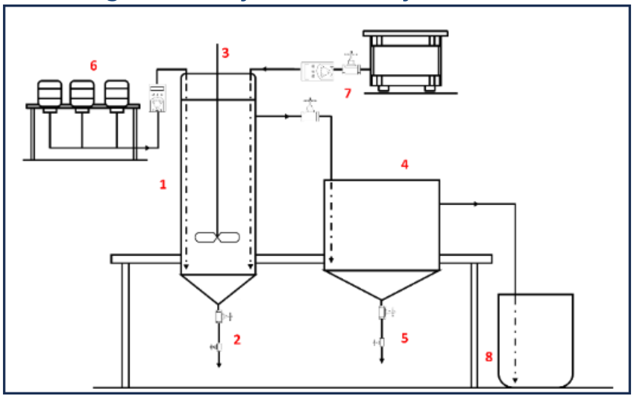
METHODOLOGY

The effluent used in the research is the result of corn processing, after partial treatment in an anaerobic biodigester. Its composition presents a high concentration of organic matter (~5.6 gCOD/L) and moderate concentrations of magnesium (~2.9 mg/L), phosphate (~512 mg/L), and ammonium (~396 mg/L), ideal for the routes evaluated in this study.

For the control route, ferric chloride hexahydrate was applied. Concentrations ranging from 0.02 g/L to 5.1 g/L were evaluated, with and without pH correction prior to its application.

For the recovery route, a crystallization system was built, as shown in Figure 1. It consists of: (1) perfect mixing crystallizer; (2) struvite outlet from the crystallizer; (3) mechanical stirrer; (4) sedimentation tank; (5) struvite outlet from the settler; (6) dosing and supplementation unit; (7) feed tank; (8) effluent outlet free of struvite.

Figure 1 – Crystallization system



Different operating conditions were evaluated for this system, including hydraulic retention time (HRT), pH (it was maintained between 8 and 8.1 in the tests presented), mixing intensity (500-1000 rpm), and nutrient supplementation. The efficiency of the recovery was mainly evaluated in relation to the reduction of magnesium concentration in the effluent.

RESULTS AND CONCLUSIONS

The following results were obtained:

- The struvite formed, both in the clogging of the corn processing plant's wastewater treatment plant pipes and through the recovery route, is the classic one with the chemical formula $NH_4MgPO_4 \cdot 6H_2O$ (Guan et al., 2023).
- The results presented in the control route demonstrate to be an interesting localized alternative for reducing struvite formation in the WWTP. However, it is worth noting the large volume of phosphate sludge that are formed when applying the metallic salt, which can impact the efficiency of the biological treatment. Table 1 presents the results related to different operating conditions for the control route.

- In control route, the maximum reduction in phosphate concentration in the effluent was observed at a ferric chloride dosage of 1.12 g/L, with a resulting efficiency of 94.8%. Under this condition, significant sludge flotation was observed (in fact, sludge flotation was noted from a dosage of 2.81 g/L), giving the effluent an undesirable appearance. However, high efficiency was already achieved at a dosage of 1.12 g/L, reaching 87.1%, without sludge flotation
- A pH above 8 has proven to be essential for the recovery of struvite by the crystallization system (Shaddel et al., 2020). Furthermore, increasing the agitation intensity of the crystallizer from 500 rpm to 1000 rpm did not result in a significant increase in struvite recovery.
- Supplementation of both nutrients, magnesium and phosphate, was essential to intensify and optimize the production of struvite, as observed by Shaddel et al., (2020). A magnesium concentration reduction efficiency of 91% was observed. All test results for the recovery route are presented in Table 2.
- The observed efficiency, with pH correction and without nutrient supplementation, was 26.7%

Therefore, while struvite formation presents obstacles, it also presents a pathway towards more sustainable and resource-efficient wastewater treatment practices.

Table 1 - Bench tests for the control route

Sample	$FeCl_3.6H_20$ (g/L)	Fe (mg/L)	PO_4 (mg/L)	pH	V_{sed} (mL/L)	t_{dec} (min)	E_{Fe} (%)	E_{PO4} (%)	E_{PT} (%)
CR-01	1.12	232.0	610.2	7.05	-	180 (2h e 40 min)	96.0	87.1	84.9
CR-02	1.68	348.0	610.2	6.62	267	420 (7h)	91.4	74.4	96.1
CR-03	2.25	464.0	610.2	6.45	333	420 (7h)	89.4	80.3	95.4
CR-04	2.81	580.0	610.2	6.04	333	420 (7h) *	86.9	89.9	96.7
CR-05	3.93	812.0	610.2	5.82	-	180 (2h e 40 min) *	91.8	94.8	92.9
CR-06	5.05	1044.0	610.2	5.07	-	180 (2h e 40 min) *	90.8	95.3	93.2

*Samples where sludge flotation was observed; CR – Control route

Table 2 - Bench tests for the recovery route

	Crystallizer inlet								**Crystallizer outlet**			
Sample	**Mg**	**PO_4**	**NH_4**	**Mg**	**PO_4**	**NH_4**	**PO_4 / Mg**	**NH4 / PO_4**	**Mg**	**PO_4**	**E_{Mg}**	**E_{PO4}**
	mg/L.min	**mg/L.min**	**mg/L.min**	**mg/L**	**mg/L**	**mg/L**	**molar**	**molar**	**mg/L**	**mg/L**	**(%)**	**(%)**
RR-01	0.07	12.8	9.9	2.89	512.2	396.3	45.4	4.1	2.12	313.8	26.7	38.7
RR-02	0.07	17.3	21.2	2.89	692.2	846.3	61.3	6.4	1.65	459.8	43.1	33.6
RR-03	0.07	17.8	22.4	2.89	712.2	198.2	63.1	1.5	1.49	441.4	48.5	38.0
RR-04	0.69	18.9	4.9	27.51	754.3	252.1	7.0	1.8	2.28	503.0	91.7	33.3
RR-05	0.72	25.3	9.9	28.95	1010.4	752.1	8.9	3.9	3.10	467.3	89.2	59.7

RR – Recovery route.

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