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Feasibility of struvite recovery process for fertilizer industry: A study of financial and economic analysis

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ABSTRACT

Struvite precipitation is widely used as an established and promising physicochemical treatment method due to its higher effectiveness for removing and recovering excess nitrogen and phosphorus from wastewater, and production of a beneficial byproduct at the end of the process. However, the majority of the literature focus not on the economic aspects of the process, but rather on the effect of different chemical combinations and changing operating conditions. In order to fulfill this gap, this study aims at a comprehensive feasibility analysis of struvite recovery process for a full-scale fertilizer production industry with a 500 m^3/day capacity. For quantitative assessment, the experimental conditions and chemical combinations that will allow the receiving environment discharge standard for ammonium nitrogen are optimized by taking into account a large number of economic and operating parameters. The effect of change in the struvite sale price on the profit share is examined for the optimum conditions, and the investment and operating costs are calculated by getting the latest up-to-date values from the market. It is determined that when the struvite sale price is raised to 560 €/ton, the facility will obtain a net profit of €445.62/day, and be able to pay for itself in approximately six years. The findings of this study corroborate the economic feasibility of struvite recovery process as a clean and eco-friendly technology at the plant level for a sustainable nutrient management. Clearly, it appears likely that the struvite precipitation method will become more widespread in the future as an effective and non-polluting process.

1. Introduction

With the modern urbanization and rapidly progressing industrialization, which have emerged as a result of modern life, increasing amounts of wastewater production has become an inevitable problem in many parts of the world. One of the biggest environmental concerns due to wastewater production is the adverse effects on the ecosystem and human health of discharging high concentrations of nutrients into rivers, lakes, seas, and soil. Today, anaerobic treatment technologies are widely used for the treatment of domestic and industrial wastewaters, and the number of studies regarding these technologies is rapidly increasing, especially for the last 20 years. In the developed or developing countries, contaminants in wastewaters are not only kept under control by means of anaerobic treatment methods, but also biogas is obtained as a result of these techniques. This results in a considerable economic contribution in the form of green energy production for both the state and the industrial sector (Yetilmezsoy, 2008). However, effluent wastewaters obtained from industrial plants mostly exceed the discharge capacities of receiving environments and therefore, a variety of advanced treatment alternatives are definitely required in the second stage (Safari et al., 2013; Yetilmezsoy et al., 2009a; Yetilmezsoy and Sakar, 2008).

Due to the rapid depletion of natural reserves, research on the recovery of nutrients – a main raw material for many industrial sectors – from wastewater and treatment sludge have gained importance in recent years (Cieślik and Konieczka, 2017). The recovery of nutrients from wastewater ensures significant cost-savings, especially with regards to agricultural resources (Yetilmezsoy et al., 2011). It is known that phosphorus is extensively used in agriculture, and that phosphorus deficiency can result in considerable decreases in agricultural yield. As phosphorus production is insufficient in certain countries, this nutrient

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is often imported from other countries. However, it is likely that these resources will eventually become insufficient as well, and face rapid depletion. In addition, while it is possible to utilize wastewater with high nutrient content as liquid fertilizer in agricultural applications, it is important to control the nitrogen and phosphorus content of these waters, since these two important parameters can especially pollute surface waters and lead to eutrophication. To prevent this while using these water to increase agricultural production yield, it is necessary to ensure the recovery of excess nutrients that can serve as a raw material source for certain industries, and find alternative uses in different sectors. High costs and difficulties in implementation (for example, difficulties in lowering nitrogen and phosphorus to desirable levels through classical biological treatment methods; the operation of these treatment systems, etc.) severely restrict the use of conventional methods for controlling nutrients in wastewater. For this reason, there is a need to develop high-yield and cost-effective technologies that would remove and recover high nitrogen and phosphorus in wastewaters in a reliable and easily implementable way. In this context, the magnesium ammonium phosphate hexahydrate ($MgNH_4PO_4.6H_2O$, MAP) or struvite precipitation is described in the literature as an effective, easily implementable, and high-yield physicochemical treatment method for removing and recovering excess nitrogen and phosphorus from wastewater (Yetilmezsoy and Sapci-Zengin, 2009).

Recently, great efforts have been done by researchers for the removal and recovery of ammonium nitrogen (NH_4^+-N) and/or phosphate phosphorus (PO_4^{3-}-P) as struvite from various types of wastewaters such as landfill leachate (Huang et al., 2014; Li and Zhao, 2003), supernatant of anaerobically digested sludge (Yoshino et al., 2003; Celen and Turker, 2001; Battistoni et al., 2001), semiconductor wastewater (Ryu et al., 2008), swine wastewater (Huang et al., 2016; Ryu and Lee, 2010; Quan et al., 2010; Song et al., 2007; Suzuki et al., 2007; Nelson et al., 2003), source-separated human urine (Mbaya et al., 2017; Antonini et al., 2011; Etter et al., 2011; Latifian et al., 2014), poultry manure wastewater (Yetilmezsoy and Sapci-Zengin, 2009; Yetilmezsoy et al., 2009b, 2013), poultry slaughterhouse wastewater (Yetilmezsoy et al., 2011), anaerobically digested dairy manure (Tao et al., 2016), wasted sludge (Jaffer et al., 2002), effluent from anaerobically digested sewage sludge (Uysal et al., 2010), effluent of the potato processing industry (Uysal and Kuru, 2013), baker's yeast wastewater (Uysal et al., 2014), and synthetic wastewater (Kozik et al., 2013, 2016; Guadie et al., 2014; Hutnik et al., 2013; Capdevielle et al., 2013; Lee et al., 2013; Adnan et al., 2003). Previous studies indicate that MAP precipitation is an effective method for treating/recovering both nitrogen and phosphorus, and that it provides different results depending on the pH value, ambient temperature, Mg^{2+}:NH_4^+-N:PO_4^{3-}-P molar ratios, and the sources of magnesium and phosphate that are used. As MAP is formed from the combination of magnesium, ammonium, and phosphate at a stoichiometric molar ratio of Mg^{2+}:NH_4^+-N:PO_4^{3-}-P = 1:1:1 (and based on the processes used for nitrogen and phosphorus removal), it has been observed that the presence of magnesium and phosphate at certain ratio increases nutrient removal. In addition, it has also been determined that the presence of magnesium at levels below the stoichiometric ratio significantly reduces the removal efficiency of both nitrogen and phosphorus. All previous studies have reported different results depending on the materials and methods used, the type of wastewater used, and the ambient conditions. It was especially observed that the combinations of certain chemicals had notable effect on yield. A general review of the literature reveals that the majority of the treatability studies on MAP precipitation focus not on the economic aspects of the process, but rather on the effect of different chemical combinations and changing operating conditions (e.g., pH values, ambient temperature, M:N:P molar ratios, etc.) on the removal or recovery of nutrients in wastewater.

To the best of the authors' knowledge, in spite of a number of experimental studies and laboratory tests carried out in recent years regarding the elimination and recovery of nutrients such as NH_4^+ or PO_4^{3-} as struvite, there is still a significant gap in the relevant literature with reference to the investigation of the economics of this process, particularly for full-scale applications. Although the studies mentioned above (as well as other similar studies) have provided important scientific findings, there is still an important gap in the literature concerning the most crucial aspect of struvite process, namely its financial and economic aspects. Filling this gap is a prerequisite for the effective planning of project infrastructure for large-scale applications, and for developing an up-to-date database on this subject.

The overall aim of this study was to perform a financial and economic feasibility analysis of struvite recovery process for a full-scale fertilizer industry. The specific objectives of this study were as follows: (1) to assess the efficiency of ammonium nitrogen (NH_4^+-N) recovery from the synthetic wastewater (representing effluent from a fertilizer industry) by a series of batch-scale physicochemical studies; (2) to study the effects of pH, magnesium source, phosphorus source, and Mg^{2+}:NH_4^+-N:PO_4^{3-}-P ratio on the efficiency of NH_4^+-N recovery using struvite precipitation process; (3) to investigate the optimal experimental conditions for NH_4^+-N recovery based on both the water quality regulations for receiving water (Turkish Water Pollution Control Regulation, TWPCR) and various operating cost items; and (4) to appraise the feasibility of struvite crystallization and recycling process for the optimal conditions by means of a detailed financial and economic feasibility analysis.

2. Materials and methods

2.1. Preparation of synthetic wastewater used in MAP precipitation tests

In the present study, synthetic wastewater containing the constituent ions of struvite was prepared as influent for the experiments conducted at the batch level. In the MAP precipitation process, a stock solution of 1 g/L of NH_4^+-N was prepared by dissolving the predetermined amount (3.819 g) of NH_4Cl powder (Merck Chemical Corp., Ammonium Chloride Gr for Analysis Iso, product code: 1.01145.1000) in 1 L deionised water supplied from a TKA GenPure water purification system (TKA Water purification systems GmbH, Niederelbert, Germany). It should be noted that the synthetic composition of NH_4^+-N (C_0 = 1000 mg/L) was studied with no presence of urea, and dissolved solids (Chandravathanam and Murthy, 2001). Therefore, the prepared aqueous solution was considered as a representative composition of actual fertilizer wastewater on a nitrogen basis as defined in Table 14.7.b of TWPCR (2004). Preparation of the required amount of the stock aqueous NH_4Cl solution was performed 5 min before the beginning of each experiment (not for a long run) to minimize the possible volatilization of NH_3 (Capdevielle et al., 2013). The addition of NH_4Cl powder was performed at a fixed stirring speed of 120 rpm ($\approx$12.57 rad/s). The initial pH of NH_4Cl solution was 6.84 ± 0.08, without the addition of any source of magnesium or phosphate. The weights of chemicals to be added to synthetic media were quantified with an electronic precision analytical balance (Kern PCB 350-3, reading precision: 0.001 g, maximum measuring range: 350 g, reproducibility: 0.002 g, linearity: ±0.005 g; temperature range: +5 °C to +35 °C). Stability of the physicochemical process and components of synthetic wastewater samples were monitored