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Research article

Sludge management modeling to enhance P-recovery as struvite in wastewater treatment plants

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A B S T R A C T

Interest in phosphorus (P) recovery and reuse has increased in recent years as supplies of P are declining. After use, most of the P remains in wastewater, making Wastewater Treatment Plants (WWTPs) a vital part of P recycling. In this work, a new sludge management operation was studied by modeling in order to recover P in the form of struvite and minimize operating problems due to uncontrolled P precipitation in WWTPs. During the study, intensive analytical campaigns were carried out on the water and sludge lines. The results identified the anaerobic digester as a “hot spot” of uncontrolled P precipitation (9.5 gP/kg sludge) and highlighted possible operating problems due to the accumulation of precipitates. A new sludge line management strategy was simulated therefore using DESASS© software, consisting of the elutriation of the mixed sludge in the mixing chamber, to reduce uncontrolled P precipitation and to obtain a P-rich stream (primary thickener supernatant) to be used in a crystallization process. The key operating parameters were found to be: the elutriation flow from the mixing chamber to the primary thickener, the digestion flow and the sludge blanket height of the primary thickener, with optimized values between 70 and 80 m^3/d, 90–100 m^3/d and 1.4–1.5 m, respectively. Under these operating conditions, the preliminary results showed that P concentration in the primary thickener overflow significantly increased (from 38 to 100 mg PO_4-P/L), which shows that this stream is suitable for use in a subsequent crystallization reactor to recover P in the form of struvite.

1. Introduction

The demand for Phosphorus (P), a non-renewable material essential to life, is on the increase and recent studies have shown that the production rate of economically available phosphate reserves will peak between 2030 and 2040, after which demand will exceed supply (Cordell et al., 2009). In addition, phosphate discharges into the environment will have to be controlled, due to problems such as eutrophication. Wastewater Treatment Plants (WWTPs) thus play an important role, as they are one of the main routes of non-diffuse P losses. Moreover, P recovery from municipal wastewater now presents an opportunity to generate local supplies of P fertilizers (Bradford-Hartke et al., 2015). Sustainable P management should therefore focus on its final recovery from wastewater. In this regard, the Swiss government recently approved (01.01.2016) a new regulation which imposed obligatory P recovery and recycling in the form of inorganic products from all sewage sludge and slaughterhouse waste, which should serve as an example to other countries.

In WWTPs with Enhanced Biological Phosphorus Removal (EBPR), phosphates and other ions (i.e. magnesium and potassium) are removed from wastewater and accumulated inside the polyphosphate accumulating bacteria (PAO) as internal granules of polyphosphate (Poly-P). The fate of the phosphate in EBPR processes is thus to be transferred from the water line to the sludge line. Sludge stabilization in large WWTPs is usually carried out by anaerobic digestion, during which Poly-P is released into the liquid phase, which notably raises P, magnesium and potassium concentrations. Ammonium and other metal cation concentrations also increase significantly, due to the organic matter degradation that takes place inside the digester. The increased concentrations of dissolved components and the high pH achieved during anaerobic digestion raise the P precipitation potential in this stage of the treatment system (Ohlinger et al., 1998).

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The uncontrolled precipitation of struvite ($MgNH_4PO_4 \cdot 6H_2O$) onto pipe walls and equipment surfaces of anaerobic digestion and post-digestion processes has been frequently reported (Parsons and Doyle, 2004; Barat et al., 2009a). Precipitation problems lead to higher sludge management costs (Neethling and Benisch, 2004) and reduce the potential P that can be recovered in the WWTPs. These precipitation problems, along with struvite's potential as a fertilizer, have led wastewater companies and research groups to study P recovery from wastewater as struvite.

P recovery technologies from flows with dissolved P (e.g., WWPT effluents, digester supernatants) via precipitation or crystallization as struvite or calcium phosphates produces more clean and crop-available materials than technologies that recover P from sewage sludge ash (SSA). However, the P recovery rates (<25% relative to the WWTP input) are relatively low compared with those obtained in the SSA processes (~40–50% relative to the WWTP input) (Egle et al., 2016).

The product thus obtained from dissolved P streams can be used as an effective slow-release fertilizer in agriculture (de-Bashan et al., 2004; Egle et al., 2016) and can be sold at a profit. Using struvite as a fertilizer not only involves its recovery, but also the reuse of nutrients, thereby promoting sustainable WWTP management. However, although struvite crystallization has been widely studied on the laboratory scale (Battistoni et al., 2000; Pastor et al., 2008; Martí et al., 2010; Lahav et al., 2013), its full-scale application is still limited in Europe, and only a few WWTPs in Germany, Denmark, The United Kingdom and The Netherlands have as yet put this technology into practice (Desmidt et al., 2015). These full-scale applications are mainly focused on P recovery in the dewatering stream after anaerobic digestion, which reduces the potential P recovery, since an important amount of P is lost inside the anaerobic digesters and post-digestion systems due to uncontrolled precipitation.

In this context, the LIFE + PHORWater project proposes the first WWTP integral management model to enhance P recovery. A significant novelty of this study compared to others is that the methodology proposed tries to boost the relatively low P recovery rates in technologies using flows with dissolved P and to reduce the uncontrolled P precipitation in anaerobic digestion and post-digestion processes.

The study project was carried out in the Calahorra WWTP (La Rioja, Spain) and involved simulation of a novel sludge management operation designed to enhance P-recovery in the form of struvite and to minimize operating problems from uncontrolled P precipitation. Intensive analytical campaigns were carried out on the water and sludge lines of the Calahorra WWTP to calibrate the BNMR2 model (Barat et al., 2013) implemented with DESASS© software (Ferrer et al., 2008) to simulate a new sludge line management strategy and determine the optimal operating conditions.

2. Materials and methods

2.1. Calahorra WWTP

Calahorra WWTP has a treatment capacity of 23000 m^3/d. The water line operates for biological nitrogen and phosphorous removal (A2/O configuration) following preliminary treatment and primary settling. The total reactor volume is 15255 m^3 divided into anaerobic, anoxic and aerobic zones. Primary sludge and waste activated sludge (WAS) are concentrated in a gravity thickener and two rotary dynamic thickeners, respectively. Once thickened, both sludges are mixed before being anaerobically digested in a thermophilic digester with SCABA agitator. The digested sludge is stored in a secondary digester and finally dewatered by centrifugation. The effluents from centrifuges and sludge thickeners are recycled to the water line. The layout of the WWTP is sketched in Fig. 1, in which the sampling points are numbered.

2.2. Analytical methods

Total solids (TS), total volatile solids (TVS), suspended solids (SS), volatile suspended solids (VSS), total and soluble Chemical

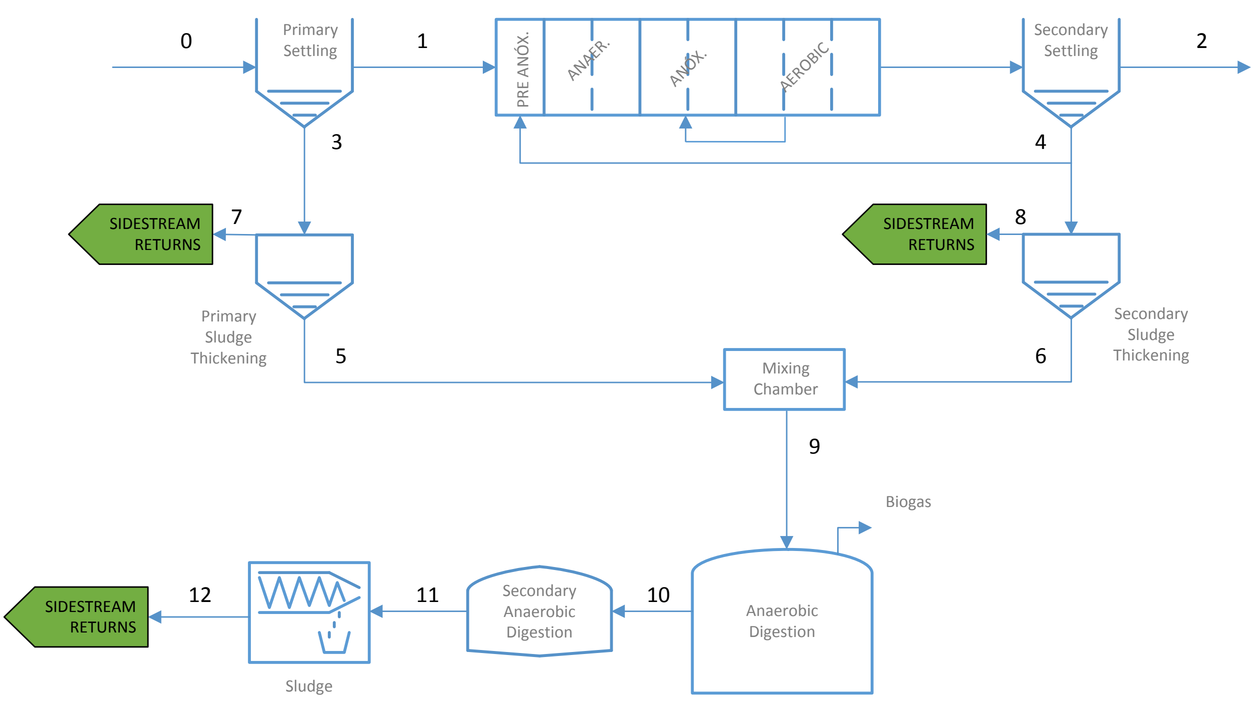

Fig. 1. Layout of Calahorra WWTP (sample points numbered).