

Phosphorous removal during sludge dewatering to prevent struvite formation in sludge digesters by full scale evaluation



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ABSTRACT

One of the challenges faced by sludge handling systems is the clogging of pipes at the anaerobic digesters and sludge dewatering units due to struvite ($\text{NH}_4\text{MgPO}_4 \cdot 6\text{H}_2\text{O}$) deposition. Struvite also forms on the digester walls eventually reducing the available digester volume. At the South District Waste Water Treatment Plant (SDWWTP) in Miami-Dade County, Florida, struvite formation has increased the plant maintenance costs due to the frequent need for replacement of plugged pipes. The purpose of this study was to control struvite formation by reducing phosphate availability in the digesters. Full scale and bench scale tests were performed at the SDWWTP to control struvite formation by limiting the available phosphate. Phosphate availability was limited by ferric chloride addition prior to sludge dewatering by centrifugation. The ferric ion binds the available phosphorous forming ferric phosphate which is captured in the sludge cake due to its low solubility. The results of this study showed that reducing the total phosphorous available in the digested sludge prevented struvite formation in the sludge handling lines and anaerobic digesters. Economic analyses showed that the amount of available phosphorous can be reduced by about 35% without additional costs.

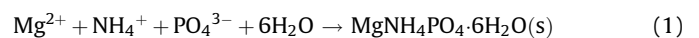
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1. Introduction

Nutrient removal from municipal wastewater is an increasing challenge for water utilities as regulatory authorities tighten discharge standards to avoid eutrophication problems in receiving waters. At the same time, phosphorus accumulation in wastewater sludge can result in the formation of undesirable precipitates such as struvite that hinder sludge handling efforts. The South District Waste Water Treatment Plant (SDWWTP) is one of three wastewater treatment plants owned and operated by the Miami-Dade Water and Sewer Department (MDWASD) in Miami, Florida. The SDWWTP treats about 90 MGD ($3.94 \text{ m}^3/\text{s}$) wastewater and is currently permitted to treat an average flow of 112.5 MGD ($4.93 \text{ m}^3/\text{s}$). The facility uses pure oxygen activated sludge system; followed by secondary clarifiers, gravity concentrators, anaerobic digesters, and centrifugation for sludge treatment and handling. The plant also receives leachate from an adjoining municipal solid waste landfill in addition to the incoming

raw sewage. Leachate is mixed in the sewer lines outside the plant. The annual average incoming carbonaceous BOD (cBOD) for the wastewater entering the SDWWTP is about 170 ppm while the effluent cBOD is less than 10 ppm, indicating about 95% cBOD removal.

One of the challenges faced by the plant is the clogging of pipes at the anaerobic digesters and centrate lines due to struvite ($\text{NH}_4\text{MgPO}_4 \cdot 6\text{H}_2\text{O}$) deposition. This has led to increased maintenance costs due to the required replacement of the plugged pipes as well as upsetting the plant performance. Struvite has also been observed to accumulate inside the digester, eventually reducing the available digester volume. Fig. 1 presents the pictures of struvite crystals and the struvite deposits formed in the pipes at the plant. Struvite is a white orthorhombic crystal which forms when ammonium, magnesium, and phosphorous react in equal molar amounts according to the chemical reaction below:



The solubility of struvite is lowest at pH levels between 10 and 11, and increases with decreasing pH. Struvite precipitation is a recognized problem in anaerobic sludge digesters especially at locations where pressure is reduced, allowing dissolved carbon

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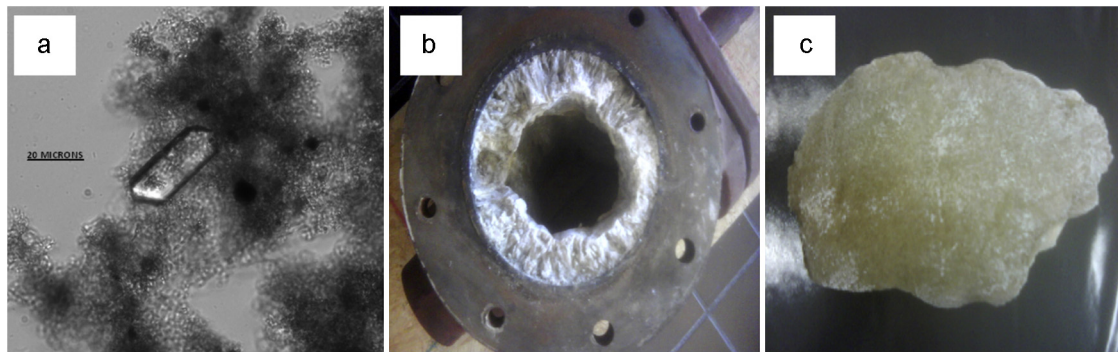


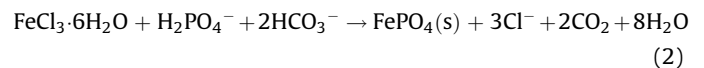
Fig. 1. Struvite crystals: (a) crystals forming in sludge (magnification given by bar representing 20 μm), (b) crystals deposited inside an 8-in. sludge line, (c) a large crystal formed inside the anaerobic digester.

dioxide to be released from the solution, thereby increasing the pH levels [1–3]. Methods for controlling struvite include lowering the pH and/or reducing the concentration of one of the ions necessary for struvite formation (i.e., magnesium, ammonium or phosphate). However, struvite formation has also been observed in anaerobic digesters where typical pH values are between 4 and 6 due to microbial activity suggesting that pH reduction may not always be effective in its control [2,4,5]. Struvite crystals can be harvested to produce commercial fertilizers. Several methods for struvite recovery and its use as a slow release fertilizer have been studied in recent years [6–9].

During wastewater treatment at the SDWWTP, phosphorus removal is relatively small since most of the phosphorus remains in soluble form. Table 1 summarizes the average monthly biosolids data analyses for the digested dewatered sludge at the SDWWTP over a five-year period. The average phosphorus concentration was 0.91% indicating that less than 700 lbs/d (320 kg/d) of phosphorus are removed in sludge. This value is a little less than the mean phosphorus content of typical wastewater sludges listed in the literature (at 2.5%) [10]. Following sludge dewatering, the supernatant is continuously recycled back to the head of the plant, resulting in an accumulation of phosphorus within the system.

The purpose of this study was to evaluate the effectiveness of phosphorus removal by ferric chloride ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) addition during the sludge dewatering process to control struvite formation in the anaerobic sludge digester and sludge lines. This study provides analysis of full scale test results for using ferric chloride to control struvite formation in pipes and anaerobic digesters and comparison and suitability of jar test results with the full scale test

results. Dewatering at the SDWWTP is achieved through centrifugation. Full scale and bench scale experiments were conducted at the plant that reduced the amount of available phosphate through the addition of ferric chloride just before centrifugation, as represented by the following reaction:



Ferric phosphate has very low solubility; hence, it is captured in the sludge cake during the sludge dewatering step. Phosphorus removal with sludge cake and the consequent reduction in available phosphorus in the centrate (which is returned to the plant head) were evaluated. Economic analyses were performed to assess the feasibility of phosphorus removal to control struvite formation in the anaerobic digesters and sludge transport pipes.

2. Materials and methods

Full scale and bench experiments were conducted to investigate the effectiveness of phosphorus removal with sludge cake and the resulting reduction in available phosphorus in the centrate by the addition of ferric chloride prior to centrifugation. Preliminary experiments were conducted with both ferric chloride ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) and ferric sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) additions. Tests with ferric sulfate did not yield practical results; hence, the study was continued with ferric chloride only. Ferric chloride is widely used in wastewater treatment plants for phosphorus removal [2]. The ferric chloride solution was obtained from Gulbrandsen Technologies (Phillipsburg, NJ), and used as received. The ferric chloride content of the solution was between 37% and 41% with specific gravity between 1.39 and 1.43 at 20 °C.

2.1. Bench scale tests

The metering pump for the full-scale tests could deliver a maximum ferric dose of 275 mg/L as Fe. Therefore, it was necessary to use laboratory batch experiments to examine the effects of higher ferric dosages. The supernatant in the laboratory jar tests simulates the centrate from the dewatering process in the full-scale tests. The jar tests were conducted using a constant polymer dosage corresponding to 32.4 lbs/DT (16.2 g/kg dry sludge) which was achieved by adding 80 mL polymer/L sludge. Results from the bench scale tests are presented in Table 4. The phosphorus removal efficiencies were calculated by comparing supernatant total phosphorus (TP) concentrations in the presence and absence of ferric chloride, and indicate continued TP reduction with increasing ferric dosage. Ferric chloride doses in excess of 500 mg/L as Fe resulted in the removal of more than 85% of the TP from the settled water. Increasing the ferric chloride dosage further resulted in near

Table 1
SDWWTP class B biosolids analysis: average data for 2003–2008.

Parameter	Unit	Method	Average	Minimum	Maximum
Solids	%	2540G	54.4	20.2	90.5
Volatile	%	2540E	58.8	21.4	88
Nitrogen	%	351.2	1.14	0.04	10.4
Phosphorus	%	365.1	0.91	0.0002	6.28
Potassium	%	7610	0.15	0.003	0.437
Arsenic	mg/kg	7061A	5.0	0.7	42.7
Cadmium	mg/kg	7130	3.8	1.24	11.6
Chromium	mg/kg	7190	34	1.4	100
Copper	mg/kg	7210	457	3	1120
Lead	mg/kg	7420	96	3.4	281.5
Mercury	mg/kg	7471A	1.75	0	13
Molybdenum	mg/kg	7480	22.7	2.3	59.3
Nickel	mg/kg	7520	16.9	2.7	39
Selenium	mg/kg	7741A	10.46	2	27.6
Zinc	mg/kg	7950	1338	617	3380
pH		9045	6.8	1.06	8.34
Fecal Coliform	MPN/g	9221E	1,557,653	12	45,481,294

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