Enhanced Dewatering with Struvite Recovery: Pilot Testing of AirPrex® Technology at Miami’s South District WWTP

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ABSTRACT

Magnesium ammonium phosphate (MAP) also known as struvite is a common problem in wastewater treatment plants which can foul piping and equipment. Struvite accumulation and fouling has historically been one of the major maintenance issues for the South District Wastewater Treatment Plant (SDWWTP) operations, consuming resources for continuous pipe cleaning to maintain steady, un-interrupted operation of the existing digestion and dewatering processes. Struvite formation results from high soluble orthophosphate (PO₄-P) concentration in the digested biosolids and the potential is expected to increase in the future with improved thickening prior to digestion. Moreover, biosolids with high soluble PO₄-P appears to result in poor dewatering performance in terms of lower cake solids and higher polymer dosing requirements. One method to deal with high orthophosphate concentrations is to precipitate out the struvite. In the AirPrex® process, marketed in North America by CNP Corporation, struvite is crystallized directly from the biosolids stream from an anaerobic digester prior to dewatering. AirPrex piloting was conducted at Miami Dade’s SDWWTP in April 2016 and the AirPrex treated biosolids was dewatered using a pilot dewatering centrifuge. The feed to the pilot centrifuge was set up to allow the pilot to test both the AirPrex and non AirPrex treated digested biosolids in the same day. The results showed that the AirPrex process consistently achieved 91% removal of soluble orthophosphate and 14 to 16% removal of ammonia (NH₃-N). From a dewatering perspective, the AirPrex pretreatment provided a 2-4 points increase in the cake solids from the pilot centrifuge, in comparison to non AirPrex treated sludges with similar polymer dosages.

KEYWORDS

Biosolids, Struvite, Dewatering, Phosphorus, Anaerobic Digestion, Resource Recovery

INTRODUCTION

Struvite accumulation and fouling has historically been one of the major maintenance issues for the South District Wastewater Treatment Plant (SDWWTP) operations, consuming resources for continuous pipe cleaning to maintain steady, un-interrupted operation of the existing digestion and dewatering process. Struvite is magnesium ammonium phosphate (MgNH₄PO₄(s)) and results from high soluble orthophosphate (PO₄-P) concentrations in the digested biosolids when adequate ammonia and magnesium are present. The potential for struvite formation is expected to increase in the future with improved thickening prior to anaerobic digestion. Moreover, increasing the PO₄-P concentration in the biosolids has been reported to reduce dewatering
Goss et al (2017) presented the results from centrifuge thickening piloting, digestion high rate piloting and centrifuge dewatering piloting at the SDWWTP. SDWWTP (Digester 9) was isolated to receive mechanically thickened sludge (from a pilot thickening centrifuge) to simulate future high rate anaerobic digestion. The digester was operated in this manner to allow the digester to reach a steady state with mechanically thickened sludge. The solids content in Digester 9 was increased from 2 to 2.5% total solids (TS) to approximately 3.4 to 3.5% TS. Once three digester solids retention time turnovers were achieved in Digester 9, pilot centrifuge dewatering testing was conducted, but the results showed that only 18% TS could be achieved with active dry polymer dosages of 20 to 30 pounds per dry ton (lb/DT) or 10 to 15 grams per dry kilogram (g/kg). The initial goal was to achieve greater than 20%TS with greater than 95% solids recovery using an active dry polymer dose of less than 25 lb/DT (12.5 g/kg).

Since it was desired to improve dewatering and mitigate the maintenance issues associated with struvite fouling, SDWWTP staff evaluated methods for struvite control which could also enhance dewatering. In the AirPrex® process, marketed in North America by CNP Corporation, struvite is crystallized directly from the biosolids stream from an anaerobic digester prior to dewatering. The precipitation of struvite prior to dewatering is one potential method to achieve both improved dewatering and reduced maintenance costs. The objective of the pilot study presented herein was to demonstrate the technology at SDWWTP and document the struvite precipitation and centrifuge dewatering performance results. The AirPrex® pilot testing was conducted after a series of thickening, digestion and dewatering pilot testing were completed at SDWWTP (Goss et al., 2017).

BACKGROUND ON STRUVITE FORMATION

Magnesium ammonium phosphate (which is sometimes referred to as MAP) precipitation is a common problem in wastewater treatment plants which can foul piping and equipment. Struvite typically forms in plants that contain anaerobic digesters with upstream biological phosphorous removal. Struvite precipitation occurs when the release of orthophosphate and ammonia from cell hydrolysis during anaerobic digestion reacts with magnesium ions at pH conditions conducive for struvite formation (pH of 7.5 to 10). Struvite accumulation tends to occur at locations where pressure is low and CO₂ is released from solution thus increasing the pH. Unwanted struvite fouling has traditionally been solved by manual cleaning, dilution, dosing an iron salt to precipitate the phosphorous or using an anti-scaling agent to lower the pH.

The following chemical equation dictates struvite formation (Snoeyink, et al).

\[ \text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O} \leftrightarrow \text{Mg}^2+ + \text{NH}_4^+ + \text{PO}_4^{3-} + 6\text{H}_2\text{O} \]

\[ \text{pK}_{SO} = 12.6 \]

Under these conditions, the activities \{Mg^{2+}\} \{NH_4^+\} \{PO_4^{3-}\} can increase above the solubility product or solubility equilibrium, defined at \text{K}_{SO}, causing struvite precipitation. The common places for struvite accumulation are locations where pressure is low and CO₂ is released from the solution thus increasing the pH (Snoeyink, et al).
For every kilogram of phosphorus recovered, 7.9 kilograms of dry struvite is produced. Typically, magnesium concentration in the wastewater or in the anaerobic digester is at a lower molar ratio than the phosphorous so magnesium is generally the limiting reagent for unintended struvite formation. Therefore, the addition of a magnesium salt is required and a common feature of most controlled struvite precipitation and removal processes.

AIRPREX PROCESS

The AirPrex process, was developed and patented by Berliner Wasserbetriebe (Germany) in collaboration with the Berlin Institute of Technology and is marketed in North America by CNP Corporation. In this process, struvite is crystallized directly from the biosolids stream out of an anaerobic digester, rather than from centrate, as is the case with more developed struvite crystallization processes such as the Ostara Pearl process. A general process flow diagram for the AirPrex process is provided in Figure 1. Figure 2 provides a more detailed process diagram of the AirPrex reactor.

AIRPREX PILOTING AT SDWWTP

The AirPrex piloting was conducted in April 2016 and the AirPrex treated biosolids was dewatered using a pilot dewatering centrifuge. The reactor was equipped with aerators that strip out carbon dioxide to increase the pH to between 7.9 and 8.2. The aeration also provides circulation of the struvite crystals inside the reactor (Figure 2), which grow until they reach a sedimentation point and settle to the bottom of the cone shaped reactor. Magnesium chloride was also dosed to the reactor as a 30% liquid solution and the dosing was set to be proportional to the orthophosphate concentrations and biosolids flow. For the pilot operation, the magnesium...
chloride dosing rate was set at 1.8 liters per cubic meter of digested biosolids (or 1.8 gallons per 1,000 gallons of digested biosolids).

During the pilot period, the AirPrex unit operated continuously with a digested biosolids flow that ranged from 30 to 45 liters per min (L/min) or 8 to 12 gallons per minute (gpm) and the treated sludge was stored in a mobile frac tank equipped with mechanical mixers that provided a buffer and storage between the AirPrex system and pilot centrifuge. The frac tank was filled continuously during operation but since the dewatering pilot throughput was up to four to ten times the flowrate of the AirPrex pilot, the pilot dewatering unit needed about 2 to 4 hours of operation time to empty the frac tank. Photos of the pilot unit reactor and frac tank are provided in Figure 3.

The feed to the dewatering pilot was set up to allow testing of both the AirPrex and non AirPrex treated digested biosolids in the same day, which allowed for consecutive testing to be conducted to determine impact of the technology on the dewaterability of the digested biosolids. The objective of the demonstration was to verify the performance of the technology in terms of:

- Percent of orthophosphate (PO₄-P) removal from the digested biosolids,
- Change in dry cake solids against the baseline,
- Change in polymer consumption compared to the baseline, and
• Ability to generate MAP (Struvite) that can be recovered.

Specified dewatering requirements were to achieve greater than 20% TS with greater than 95% solids recovery at an active polymer dose of 25 lb/DT (12.5 g/kg) or less (MWH, January 2016).

The AirPrex reactor was first fed digested biosolids from Digester 9 on April 4, 2016 and the dewatering centrifuge first started processing AirPrex treated biosolids on April 5, 2016. Digester 9 was chosen since it was being operated as a pilot digester which was receiving mechanically thickened sludge for four months prior to the start of testing. The first week of dewatering operation was performed to optimize the dewatering centrifuge for the AirPrex treated biosolids. After a few days of operation, however, it was noted that the feed solids to the centrifuge from Digester 9 were decreasing rapidly. It was found that a flush valve was left open for several days that allowed water to fill Digester 9, diluting the digester. Based on the trend shown in Figure 4, it appears that dilution started at the end of March 2016, reducing the concentration in Digester 9 from 3.3 to 3.5% TS down to 2% TS. Because of the dilution, the feed to the AirPrex reactor was switched from Digester 9 to Digester 10 on April 12, 2016. Digester 10 was acting as a secondary digester that was receiving only mechanically thickened digested sludge from Digester 9 and the concentration in the digester was steady at approximately 2.5% TS.
AIRPREX PERFORMANCE DATA

Daily sampling was conducted from the AirPrex reactors to monitor the orthophosphate and ammonia concentrations, as well as the pH of the inflow feeding the AirPrex unit and the outflow, which fed the frac tank (and was the feed for AirPrex treated biosolids dewatering testing). Centrate samples from the dewatering unit were also collected for a period to monitor both ammonia and orthophosphate concentrations, as well as pH. Figure 5 summarizes the data monitored during the AirPrex testing and a vertical red line was added to the figures to depict the point where the feed to the AirPrex unit was switched from Digester 9 to Digester 10. The data did not show a large difference in the orthophosphate concentrations when switched from Digester 9 to Digester 10. However, the ammonia concentration in Digester 9 decreased over time as the digester was diluted. When switching to Digester 10, both the ammonia concentration and the pH of the inflow biosolids increased. When operating with feed biosolids from Digester 9, the pH averaged 7.6 but when switched to Digester 10, the pH averaged 7.8. The results from Figure 5 also show that the centrate orthophosphate and ammonia concentrations, as well as pH, measured similar values and followed the trends of the AirPrex outflow biosolids.

After the first day of AirPrex operation, the process was optimized and approximately 91% orthophosphate reduction was maintained throughout the pilot reactor (ranging from 89 to 93%), reducing the concentration from approximately 200 milligrams per liter (mg/L) down to less than 20 mg/L. In addition, the AirPrex process also provided a 14 to 16% reduction in ammonia concentration. Table 1 provides the average orthophosphate and ammonia concentrations in and out of the AirPrex pilot reactor throughout the test. The data broken down for the period when testing was conducted from Digester 9 and Digester 10 is also presented in Table 1.
Figure 5: Summary of AirPrex Monitoring
Table 1: Summary of AirPrex Performance Data

<table>
<thead>
<tr>
<th></th>
<th>Inflow (mg/L)</th>
<th>Outflow (mg/L)</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Orthophosphate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average for entire test</td>
<td>202.3</td>
<td>18.7</td>
<td>90.7%</td>
</tr>
<tr>
<td>Digester 9</td>
<td>197.9</td>
<td>18.2</td>
<td>90.8%</td>
</tr>
<tr>
<td>Digester 10</td>
<td>206.1</td>
<td>19.0</td>
<td>90.8%</td>
</tr>
<tr>
<td><strong>Ammonia</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average for entire test</td>
<td>1,862</td>
<td>1,597</td>
<td>14.2%</td>
</tr>
<tr>
<td>Digester 9</td>
<td>1,648</td>
<td>1,408</td>
<td>14.6%</td>
</tr>
<tr>
<td>Digester 10</td>
<td>2,049</td>
<td>1,716</td>
<td>16.3%</td>
</tr>
</tbody>
</table>

From the reactor, the struvite collected in the cone was sent to a grit washer but limitations in the pilot setup showed that the struvite recovered was in a crude form and present with sludge and other debris. Pictures of the struvite product are provided in Figure 6. Furthermore, the grit washer was located in the test trailer beside the reactor and the struvite had a tendency to accumulate in the interconnecting hose. The grit washer was also oversized for the application so some seed sand had to be added to provide enough pressure for the auger’s pressure sensor to be activated. For a full-scale application, the grit washer would be placed directly underneath the reactor and more time would be available to seed the system with struvite.

![Figure 6: Pictures of Struvite Product](image)

DEWATERING RESULTS

The majority of the dewatering testing with Airprex was conducted with the same dry polymer used in the plants existing dewatering centrifuges and previously used in the dewatering tests (Polydyne C-3283) at a targeted concentration of 0.4% TS. However, some additional testing was also conducted with Polydyne emulsion polymer, based on recommendations from onsite jar testing.

The first week of dewatering operation, using sludge from Digester 9, was performed to optimize the machine for the AirPrex treated biosolids but because of the dilution issue, the results could not be directly compared to the previous pilot dewatering testing conducted without AirPrex pretreatment. Optimization included adjusting pool depths, bowl speeds, differential speed, and
polymer dosing. The initial dewatering results were, however, promising and results of greater than 21% TS were being achieved compared to 18% TS prior to starting the AirPrex Pilot.

Because of the dilution in Digester 9, it was decided to conduct sequential testing with and without AirPrex treated digested biosolids to gauge the impact of the technology on dewaterability of SDWWTP’s digested biosolids. Since the concentration in Digester 9 was diluted, the feed to the AirPrex unit and to the pilot centrifuge was switched from Digester 9 to Digester 10 on April 12, 2016 and the remainder of the AirPrex and Centrifuge pilot dewatering tests were conducted using the digested biosolids from Digester 10.

**Dry Polymer Curve Testing**

In order to better gauge the impact that the AirPrex treatment had on the dewaterability of the digested biosolids from Digester 10, several dry polymer curve tests were conducted at 45, 60 and 80 gpm (170, 227, and 303 L/min) with and without AirPrex pretreatment. The flowrate, feed concentrations, dry polymer concentration and dates for these tests is summarized in **Table 2**. For all of the tests the bowl speed was maintained at 93% which is equal to 3,100 revolutions per minute (RPM).

**Table 2: Summary of Dry Polymer Curve Tests from Digester 10**

<table>
<thead>
<tr>
<th>Flow (gpm)</th>
<th>Test with AirPrex</th>
<th>Test without AirPrex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feed (% TS)</td>
<td>Polymer (% TS)</td>
</tr>
<tr>
<td>45</td>
<td>2.40% TS</td>
<td>0.44% TS</td>
</tr>
<tr>
<td>60</td>
<td>2.48% TS</td>
<td>0.43% TS</td>
</tr>
<tr>
<td>80</td>
<td>2.54% TS</td>
<td>0.43% TS</td>
</tr>
</tbody>
</table>

All of the dry polymer curves conducted with and without AirPrex on the digested biosolids from Digester 10 is summarized in **Figure 7**. The data for all three polymer curves show that with AirPrex pretreatment, the sludge dewatering was improved, allowing close to a 3% point increase in the dry solids content at the same polymer dosing rate. The data also shows that the driest cake achievable without AirPrex pretreatment can be achieved with AirPrex pretreatment at a lower polymer dose. When comparing the trends with and without AirPrex, however, it can be seen that without AirPrex, the optimal polymer dose, meaning the point where additional polymer dose does not improve cake solids, is lower without AirPrex than with AirPrex. **Table 3** summarizes the optimal point based on the polymer curves with and without AirPrex treatment.

**Table 3: Optimal Settings for Flow based on the Polymer Curves from Digester 10**

<table>
<thead>
<tr>
<th>Flow (gpm)</th>
<th>AirPrex</th>
<th>No AirPrex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cake (% TS)</td>
<td>Solids Recovery (%)</td>
</tr>
<tr>
<td>45</td>
<td>23.0%</td>
<td>93.9%</td>
</tr>
<tr>
<td>60</td>
<td>21.5%</td>
<td>93.8%</td>
</tr>
<tr>
<td>80</td>
<td>20.8%</td>
<td>95.6%</td>
</tr>
</tbody>
</table>
Figure 7: Summary of All Digester 10 Dry Polymer Curves with and without AirPrex
The data shows that with lower throughputs, lower differential speeds can be maintained and dryer cake can be produced with AirPrex treatment compared to operation without AirPrex treatment. The results also indicated that with AirPrex treatment, up to 21 to 23% TS cake could be achieved with recoveries at or above 93% when a 30 to 32 lb/DT (15 to 16 g/kg) active polymer dosage rate was used. This is compared to operation without AirPrex that shows 18 to 20% TS cake can be achieved with recoveries at or above 95% when a 29 to 30 lb/DT (14.5 to 15 g/kg) active polymer dosage rate was used.

Extended Operation Testing

In order to test the stability of dewatering operation for the AirPrex treated digested biosolids, several extended operation tests were conducted at 45, 60 and 80 gpm (170, 227, and 303 L/min) using digested biosolids from Digester 10. For all of the tests, the bowl speed was maintained at 93% (3,100 RPM) and polymer concentrations were approximately 0.4% TS. With the tests conducted at 60 and 80 gpm (227 and 303 L/min), the testing started with an extended run on non AirPrex treated biosolids based on the optimal settings and then switched to AirPrex treated biosolids to see the impact over the course of the run.

On April 14, 2016, an extended operation test was conducted at 60 gpm (227 L/min), targeting the optimal setting from Table 3, and the results are summarized in Figure 8. When running on the non AirPrex treated biosolids with a differential speed of 3.3 RPM and a polymer dose of 27.6 lb/DT (13.8 g/kg) active, the centrifuge dewatered the biosolids from approximately 2.4% TS to 18.9% TS with a solids recovery of 97.7%. When the centrifuge feed was switched to AirPrex treated biosolids at the same polymer dose (27.6 lb/DT or 13.8 g/kg active) but with a lower differential speed of 2.5 RPM, the dewatered cake solids increased to 20.1% TS (starting with a 2.5% TS feed) and recoveries were maintained at 98.2%. Further increasing the polymer dose to 31 lb/DT (15.5 g/kg) active improved the dewatered cake solids to 21.3% TS and recoveries were near 100%. Because of the high recovery, the differential was further reduced to 2.3 RPM but this did not show improvement in dewatering and recoveries were still at 98.5%. During the run on April 14, 2016, the non AirPrex treated feed averaged 2.4% TS and the AirPrex treated feed averaged 2.5% TS. The polymer concentration averaged 0.42% TS. The results, based on the optimal setting, matched the results indicated by the previously conducted polymer curve shown in Figure 7.

On April 15, 2016, an extended operation test was conducted at 80 gpm (303 L/min) and the results are summarized in Figure 9. The test again targeted the optimized setting outlined in Table 3 but the testing was further expanded to gauge the impacts on the differential speed and polymer dose on dewaterability. The test started with non AirPrex treated biosolids using the optimized differential speed settings (3.1 RPM) and polymer dose settings (31.4 lb/DT or 15.7 g/kg) for the AirPrex treated biosolids. At these settings, up to 19.3% TS cake was produced but recovery was only 83.6%. When the differential was increased to 4.2 RPM and the polymer dose was reduced to 28.4 lb/DT (14.2 g/kg), the dewatering was reduced to 18.3% TS but recoveries improved to 93%. When switching to the AirPrex treated biosolids without adjusting any of the centrifuge parameters, the dewatered cake solids improved to 19.9% TS and recoveries improved to 98.1%. Lowering the differential to 3.2 RPM with the same polymer dose increased the dewatered cake solids to 20.7% TS and recoveries were still high at 97.1%.
Figure 8: 60 gpm Operation – Dry Polymer (4/14/16)
Figure 9: 80 gpm Operation – Dry Polymer (4/15/16)
Finally, when adjusting the differential speed and polymer to the optimized AirPrex setting outlined in Table 3 (3.1 RPM and 31.2 lb/DT [15.6 g/kg] active), the dewatered cake solids improved to 21.3% TS with recoveries of 97.3% showing slightly better results than indicated by the previously conducted polymer curve (Figure 7). Throughout the testing, the feed biosolids concentration (both with and without AirPrex treatment) averaged 2.5% TS and the polymer concentration averaged 0.43% TS.

On April 16, 2016 an extended operation test was conducted at 45 gpm (170 L/min) right after conducting the 45 gpm (170 L/min) polymer dose test with AirPrex treated sludge. The testing showed that when operating at a 1.5 RPM differential speed and an active polymer dose of 31.1 lb/DT (15.6 g/kg) that dewatering up to 23.0% TS with recoveries at 95% were possible. The marginal increase in differential speed allowed the recoveries to improve to 95% compared to operation at 1.4 RPM differential speed. The feed solids concentration during this run averaged 2.4% TS and the polymer concentration averaged 0.44% TS.

**EMULSION POLYMER CURVE TESTING**

To provide a comparison to the dry polymer, testing was also conducted using emulsion polymer to determine the impacts on dewatering biosolids from Digester 10. Based on jar testing conducted by Polydyne, three different high molecular weight cationic emulsion polymers were tested on April 18, 2016 at 60 gpm or 227 L/min (C-6272, C-06292, and C-6275). Both the C-6272 and C-6275 polymers had average activities of 52.5% (ranging from 49 to 56%) and the C-6292 polymer had average activities of 51.5% (ranging from 48 to 55%). The results did not show a significant difference in performance between the three polymers but the C-6272 polymer shows slightly better performance in terms of solid recovery when compared to the other polymers. With AirPrex pretreatment and emulsion polymer, over 26% TS was possible but polymer dosage requirements were over 50 lb/DT (25 g/kg) active which is more than 40% more polymer than what was required when using dry polymer.

The data collected on April 18, 2016 allowed a C-6272 emulsion polymer curve to be generated at 60 gpm (227 L/min) and additional testing was conducted on April 19 and April 20, 2016 to generate a C-6272 emulsion polymer curve at 45 gpm (170 L/min). The feed concentration of the AirPrex treated sludge averaged 2.1 to 2.2% TS and the feed concentration of the non AirPrex treated sludge averaged 2.3 to 2.5% TS.

The data for both polymer curves show that with AirPrex pretreatment, the biosolids dewatering was improved allowing for a 2 to 4% point increase in the dry solids content at the same polymer dose. The data also shows that the best performance seen without AirPrex pretreatment can be achieved with AirPrex treatment at a lower polymer dose. The dewatered cake solids continued to increase at higher polymer dosages in the range tested and up to 26 to 27% TS was possible with recoveries near 95% with polymer dosages above 52 lb/DT (26 g/kg) active. This is compared to operation without AirPrex that shows 22 to 23% TS cake can be achieved but recoveries were below 93% when the polymer dosage rate is approximately 50 lb/DT (25 g/kg) active. All of the emulsion polymer curves conducted with and without AirPrex on the biosolids in Digester 10 is summarized in Figure 10.
Figure 10: Summary of Emulsion Polymer Curves with and without AirPrex
CONCLUSIONS

The Results showed that the AirPrex process consistently achieved 91% removal of orthophosphate and 14 to 16% removal of ammonia (NH₃-N) from the digestion process and recovered struvite from the cone of the reactor. From a dewatering perspective, the AirPrex pretreatment provided a 2 to 4 points increase in the cake solids from the pilot centrifuge compared to operation without AirPrex pretreatment and similar active polymer dosages. With dry polymer, up to up to 22% cake solids was achieved with AirPrex pretreatment as compared to 19% without pretreatment using 25 to 35 lb/DT (12.5 to 17.5 g/kg) active polymer dosages. In the case of the emulsion polymer, up to 27% cake solids could be achieved with the AirPrex pretreatment as compared to the 23% without pretreatment but required polymer dosages in excess of 50 lb/DT (25 g/kg).

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