Startup of the First Commercial Phosphorus Recycling Facility in the US at Durham AWWTP

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Abstract

The Durham Advanced Wastewater Treatment Plant (AWWTP) has to meet a monthly median of 0.10 mg/L effluent total phosphorus (TP) limit during the six month summer season. In April 2009, Durham AWWTP commissioned the first commercial phosphorus recovery facility in the United States. After two months of continuous operation, the P-recovery facility is removing 83% of soluble PO4-P from the sludge dewatering centrate while recovering 20% of the plant influent phosphorus load, an average of 1.1 tons per day. The first shipment of 11 tons of the recovered slow-release product has been sold in June to British Columbia Ministry of Environment.

The reduction of phosphorus in the plant has reduced the phosphorus inventory in the main biological nutrient removal (BNR) system. After only a relatively short time of continuous operation, the dependency of the BNR plant on P-recovery performance has become evident. The biological phosphorus removal process has quickly adapted to the lower BNR influent phosphorus load.
Introduction & background

The Durham AWWTP is a 25 MGD facility first placed into service in 1976 and gradually evolving to a full biological nutrient removal (BNR), tertiary phosphorus removal facility. Figure 1 shows the schematic of the facility. Primary effluent is pumped to four parallel secondary treatment trains, operated independently; each has its own solids retention time (SRT). In A2O mode, return activated sludge (RAS) from each train combines upstream of the anaerobic zone, which consists of two cells and which is followed by two anoxic cells. The aerobic zone is comprised of a complete mixed zone followed by a plug flow cell. Internal recycle from the aerobic zone is returned to the anoxic zone. The secondary treatment trains are followed by three tertiary treatment trains, effluent filtration and disinfection. Primary solids are pumped to the fermentation and thickening process, while waste activated and tertiary sludge are blended in an aerated storage tank before centrifuge thickening. Thickened primary, secondary, and tertiary sludges are blended in a digester feed tank from where they are pumped to the digesters.

Digested sludge is dewatered with centrifuges and the centrate is equalized in centrate storage tanks. Prior to the recycle return to the secondary treatment process, the centrate is sent to the phosphorus recovery process.

Operators can add alum for phosphorus removal to the primary, secondary, and tertiary clarifiers. Under normal operation during the summer permit months, 10 to 20 parts per million (ppm) of alum is added to the tertiary clarifiers, and lime is added to the primary effluent. The lime dose varies and is adjusted to maintain an effluent alkalinity around 75 mg/L.

In 1988, the first Total Maximum Daily Load (TMDL) for phosphorus in the US was applied on the Tualatin River, which receives the effluent from Durham. In 1994, the Durham AWWTP received a new effluent permit of total phosphorus (TP) equal to 0.07 mg/L. This has recently (2005) been increased to 0.1 mg/L (May 1 to October 31, monthly medium) after river modeling showed 0.1 mg/L to be the natural river background level. After several years of solely chemical phosphorus removal, the plant was converted to biological nutrient removal with chemical backup, to save on operational costs. The process was augmented with volatile fatty acids (VFA) from two-stage primary sludge fermenters. Digested primary and waste activated sludge (WAS) is dewatered and the centrate is sent to the phosphorus recovery facility.

Table 1 summarizes the annual chemical use per ton of phosphorus removed between 2001 and 2005, illustrating the process optimization impact on chemical use. Over this five year period, lime addition for alkalinity supplementation was reduced by 78% and aluminum sulfate addition decreased by 45%.

The reduced chemical addition increased the concentration of centrate phosphate from 50 to 100 mg/L: PO₄-P in 2002 to 500 to 600 mg/L PO₄-P in 2008. This highlights one side-effect of biological phosphorus removal optimization. The increase of recycled phosphorus to 60 percent was accompanied by the problem of excessive struvite formation, which occurred in two forms: in centrate pipes and as struvite grit accumulation in digesters. In the digested sludge holding tank, an estimated 70 cy3 of struvite grit has accumulated (Figure 2).
Figure 1: Process Schematic of Durham AWWTP

Table 1: Summary of chemical use at Durham AWWTP in comparison to total Phosphorus removed*, **

<table>
<thead>
<tr>
<th>Year</th>
<th>kg Alum / kg P Removed</th>
<th>kg Lime / kg P Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>6.75</td>
<td>8.83</td>
</tr>
<tr>
<td>2002</td>
<td>6.77</td>
<td>2.54</td>
</tr>
<tr>
<td>2003</td>
<td>4.48</td>
<td>3.91</td>
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<tr>
<td>2004</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>2005</td>
<td>3.72</td>
<td>1.94</td>
</tr>
</tbody>
</table>

* during phosphorus removal season from May 1 to October 31 of any year
** 2006 – 2008 are not representative due to construction and maintenance related shutdowns of major unit processes
The AWWTP facility decided to recover phosphorus, which was supposed to reduce the amount of ortho-phosphorus in the centrate by 80% and result in an overall 20% reduction of the total phosphorus inventory. The reduced phosphorus load was to reduce the demand for VFA and increase the biological phosphorus removal reliability. A private-public partnership was developed with the manufacturer of the fluidized bed struvite recovery technology with the hope of generating enough revenue from the sale of the product to repay the capital investment over a six year period, after which it is expected to generate a net income for CWS. This paper will discuss the first months of the operation of the full scale facility.

**Phosphorus recovery process at Durham AWWTP**

The phosphorus recovery system at Durham AWWTP consists of three fluidized bed reactors with a recovery capacity of approximately 150 lb/h of phosphorus, thus yielding up to 3600 lb/d of magnesium ammonia phosphate (MAP, or struvite) product at 100 percent reactor utilization.

The centrate from the dewatering centrifuges is discharged into two 1,100 m³ storage tanks for equalization. The centrate previously received ferric chloride as an acid to suppress the pH rise from CO₂ off-gassing. After startup of the phosphorus recovery facility, a Nalco struvite prevention polyphosphate was applied to protect the pipe leading to the recovery facility. The centrate composition varies depending on dewatering operation. The phosphorus recovery process received equalized dewatering centrate at a rate of approximately 100,000 gal/d with a PO₄-P load in the range of 400 to 500 lb/d.

From the equalization tanks, the centrate is fed to reactors entering the process in the recirculation loop. The recirculation is necessary to fluidize the reactor bed. Magnesium chloride is dosed to provide sufficient magnesium concentration to maximize the phosphorus capture rate.
The reactors were each seeded with one ton of 1 mm prills (a granular form of MAP) from the Edmonton AB full scale pilot plant. The crystal pellets grow over a period of two to four weeks to reach the desired size. Depending on the receiving customer preferences, the operator can control the crystal size, the growth rate, and the crystal density. Once the recovery product pellets have reached the desired size they are flushed out of the reactor through a harvesting mechanism.

The product slurry is sent to a vibrating screen where water is removed. The harvested pellets then travel through a product dryer (fluidized bed). The dried product exits the dryer onto a vibrating screen classifier where product is sorted into size groups and bagged up separately (Figure 3 and Figure 5). The treated centrate is sent to the plant drain system and is ultimately returned to the plant influent.

Figure 2: Schematic of the phosphorus recovery process
P-recovery process startup and performance

The process startup occurred over a six week period, beginning with reactor seeding using seeds harvested from the Edmonton facility. All three reactors were started up at the same time; initially, while testing was under way, they were only operated during the day shift with the startup team present. The rest of the time the reactors remained in idle mode where their liquid content was recirculated to keep the bed fluidized. Following the initial seeding, operators began feeding dewatering centrate to the reactors, as well as a reduced dose of magnesium chloride to control the rate of crystal growth. The first product was harvested after two weeks and then the facility went into 24/7 operation during week four.

Figure 3 shows the phosphorus reduction performance of the recovery process from the beginning of continuous operation. The phosphorus capture ranged from 65 to 90 percent with an average of 83 percent and was primarily a function of magnesium chloride dosing. Reactor effluent phosphate concentration ranged from 40 mg/L to 170 mg/L and ammonia ranged from 1,010 to 1,220 mg/L. The ammonia reduction follows the phosphorus recovery nearly at the expected stoichiometric ratio of 0.45:1.0 (N/P w/w), resulting in an average removal rate of 10% of the ammonia. To date, the reactors yielded on average 1.1 ton/d of product, while capturing 20% of the plant influent phosphorus. At 1.1 ton/d, only 55% of the theoretical reactor recovery capacity is utilized. It is expected that the ongoing fine tuning and optimization of the recovery operation will increase the reactor utilization to 85%. Due to the necessary routine, maintenance shutdowns, and some loss of crystallized struvite to the reactor drain, only about 80% of the theoretical reactor capacity can be realized.
At the beginning, magnesium was dosed at a rate below the stoichiometric ratio of phosphorus to grow the seed into larger prills and build inventory in the reactors. Once the reactors were filled to harvest level, the normal magnesium dose was used to optimize the P-recovery and maximize the reactor capacities.

Because the sale of the recovered product at a maximum price is essential to the overall economic success of the P-recovery facility, high product quality is imperative. High quality for the crystalline recovery product means the minimal inclusion of inorganic or organic matter (less than 1 ppm), consistent size and quality, high crystal prill density and hardness, and a low content of heavy metals. With no pretreatment of centrate, the variability of the centrate composition was a great concern.

On average, the centrate contains 1,500 mg/L TSS, 600 mg/L BOD, 1,200 mg/L ammonia nitrogen, and 300 to 500 mg PO₄-P/L. The centrate is not pretreated prior to entering the phosphorus recovery reactors but the centrate storage tanks are mixed, which prevents the dewatering centrifuge startup slurry from entering the reactors. The plant uses a cationic liquid polymer in the dewatering process and the centrate contains, at times, a visible polymer residue.

Operators inadvertently performed a system solids handling stress test with respect to the impact of centrate quality on the phosphorus recovery product quality. The centrate storage tank mixers were turned off to minimize the transfer of floating, scum-like material since the recovery reactors were not equipped to handle scum. Because this created a conflict with the operations of the main plant, the mixers had to be turned back on after several days resulting in a slug load of centrate with a TSS content of over 10,000 mg/L. While such solids load was never anticipated and was highly undesirable, no impact on product quality was observed. Clean, white prills were produced without any organic inclusions, as shown in Figure 4. Table 2 summarizes the product composition and the results from the heavy metal analysis.

Figure 3: Performance of the process of P-Recovery from centrate in 2009.
Figure 4: Macro images of the phosphorus recovery product

Table 2: Struvite Product Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Measured</th>
<th>Regulatory limit*</th>
</tr>
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<tbody>
<tr>
<td>Nitrogen</td>
<td>% N</td>
<td>5.00-5.75</td>
<td></td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>% P2O5</td>
<td>27.55-28.5</td>
<td></td>
</tr>
<tr>
<td>Potash</td>
<td>% K2O</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>Arsenic</td>
<td>mg/kg</td>
<td>BDL (0.5)</td>
<td>364</td>
</tr>
<tr>
<td>Cadmium</td>
<td>mg/kg</td>
<td>BDL (0.1)</td>
<td>280</td>
</tr>
<tr>
<td>Cobalt</td>
<td>mg/kg</td>
<td>BDL (0.1)</td>
<td>86800</td>
</tr>
<tr>
<td>Lead</td>
<td>mg/kg</td>
<td>BDL (1.2)</td>
<td>1708</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>mg/kg</td>
<td>BDL (1.0)</td>
<td>1176</td>
</tr>
<tr>
<td>Nickel</td>
<td>mg/kg</td>
<td>0.3</td>
<td>7000</td>
</tr>
<tr>
<td>Selenium</td>
<td>mg/kg</td>
<td>BDL (5.5)</td>
<td>728</td>
</tr>
<tr>
<td>Zinc</td>
<td>mg/kg</td>
<td>3.3</td>
<td>11760</td>
</tr>
<tr>
<td>Mercury</td>
<td>mg/kg</td>
<td>BDL (0.05)</td>
<td>28</td>
</tr>
<tr>
<td>Copper</td>
<td>mg/kg</td>
<td>0.9</td>
<td>N/A</td>
</tr>
<tr>
<td>Total Coliform</td>
<td>MPN/1g</td>
<td>BDL (&lt;2)</td>
<td>N/A</td>
</tr>
<tr>
<td>Fecal Coliform</td>
<td>MPN/1g</td>
<td>BDL (&lt;2)</td>
<td>N/A</td>
</tr>
<tr>
<td>Salmonella</td>
<td>/4g</td>
<td>Negative</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* (AAPFCO @28%P2O5)

Impact of P-recovery on plant nutrient removal performance

Overall, the recovery process captured an average of 83% of recycled phosphorus and 10% of recycled ammonia nitrogen. Overall, 20% of the plant influent phosphorus was recovered, as well as 1.5 percent of the influent nitrogen. When comparing the dewatering centrate contribution to the secondary treatment phosphate load before and after phosphorus recovery, the recycle load was reduced from 55% to 9%. The ammonia nitrogen recycle load was reduced from 13% to 11%. The mixed liquor phosphorus content decreased from 4.9 percent (the average of the past four years) to 4.1 percent. Figure 5 shows the comparison of the mixed liquor suspended solids (MLSS) phosphorus content during the month of May, illustrating the phosphorus content reduction. Due to the short run time to date, it is not expected that the plant phosphorus mass balance has fully...
stabilized and that further reductions of both MLSS and the subsequently dewatered biosolids total phosphorus content are expected.

After only a relatively short time of continuous operation, the dependency of the main stream BNR plant on the performance of the P-recovery system has become apparent. The biological phosphorus removal process has quickly adapted to the lower BNR influent phosphorus load. This development has elevated the P-recovery process operation from a beneficial process to a necessary process to perform for permit compliance.

This represents a new challenge to the overall plant operation. The BNR phosphorus removal performance now depends on the P-recovery process and its recycle load reduction. Without the recycle load reduction, secondary effluent PO₄₃⁻-P increases, which requires the introduction of the secondary clarifier influent alum dose in addition to a higher tertiary alum dose to ensure permit compliance. The more tertiary alum operators have to add the less phosphorus can be recovered because more is being tied up chemically by alum during tertiary treatment and in the digester. In addition, higher alum doses also require higher lime doses to compensate for the additional alkalinity consumption from the alum addition. The calcium added with the lime also precipitates phosphorus. Thus, operational problems in the phosphorus recovery process not only impact the secondary treatment, but also the revenue stream. In other words, the amount of product yield depends on the amount of recoverable phosphorus in the dewatering centrate. Higher chemical doses in the liquid stream reduce the amount of recoverable phosphorus.

The seasonal nutrient removal requirement at the Durham AWWTP complicates the evaluation of the P recovery impact on plant performance. Phosphorus removal is only required from May 1 through October 30 and nitrification only from May 1 to October 31. Therefore, the startup of the P recovery process overlapped with the startup of the nutrient removal season. During the winter, no metal salts or lime are added and the plant does not nitrify. This results in reduced competition from denitrifiers over volatile fatty acids. In the past, biological phosphorus removal, which remains in
service year around, performs very well during the winter. It is expected to recover more phosphorus during the winter when no more alum and lime is added to the main process.

Before the beginning of the summer nutrient permit season, the plant shifts into nitrification, which requires alkalinity supplementation in the form of lime. The lime also provides a significant amount of calcium, which subsequently precipitates some amount of phosphate in the anaerobic zone and anaerobic digester.

The low effluent phosphorus limit and overall effluent quality standards for reuse require some alum dose to the tertiary treatment stage. Even if very little soluble phosphorus is left in the secondary effluent, a tertiary dose generates alum sludge, which is collected and transferred to the digester where it contributes to soluble phosphate precipitation. As a result, prior to the introduction of phosphorus recovery at Durham WWTP, the dewatering centrate soluble phosphate concentration was typically lower in the summer compared to the winter months because significantly less free metal ions are available in the digester to precipitate the released phosphate. Furthermore, shortly after the phosphorus recovery startup the effluent filtration facility was malfunctioning and had to be bypassed, which forced operators to temporarily dose alum at a rate 10 times higher than normal, immediately resulting in a drop in centrate soluble phosphate, skewing the overall results of the P inventory reduction impact.

Operation and maintenance

During the startup period, the facility was operated by engineers and scientists with an intimate knowledge of the system. Issues encountered during that period were primarily related to specific pieces of equipment and were not atypical for the commissioning of a facility of similar scale and complexity. The primary operational tasks after start-up include:

- Process monitoring
- Filling magnesium chloride day tank via transfer pumping
- Removal of bagged product and replacement of bags

Process monitoring tasks are no different from any other unit process at a wastewater treatment plant, and include observation via SCADA, responding to alarms, and regular walkthroughs. Camera surveillance was installed to minimize the need for operators to walk the facility.

The magnesium chloride is delivered as a solution by tanker and is stored in two 19 m³ (5,000 gallon) tanks from where it is transferred to the day tank. At maximum capacity, the facility will produce one to two 900 kg (2,000 lb) bags of product per day. Typically, at least one bag has to be removed per day and two every other day. The fluidized bed reactors have the ability to store several tons of products such that harvesting during the weekend is not necessary, eliminating weekend staffing issues. In addition, the product storage silo can hold up to four tons of dried product.

Post-startup, the maintenance requirements are expected to be low since all equipment is new. The equipment that requires maintenance are primarily pumps, analytical equipment, valves, etc., which are familiar to plant maintenance staff. Their maintenance requirements are typical to their counterparts used around the plant. Only three pieces of equipment are new to the wastewater treatment environment: the product dryer, the bagging assembly, and the classifier.
Some struvite buildup has been observed initially in the recycle pipe near the injection quill and at the injection quill itself (Figure 6). These have since been replaced with Polyvinylidene Fluoride (PVDF) lined counterparts, which have surface characteristics that prevent surface struvite deposits.

Significant struvite formation was also discovered in the drain pipe. Several alternatives are presently being evaluated to prevent the buildup in the future; including submerging the drain pipe to prevent surface turbulence from the reactor overflow cascading into the drain pipe, replacing the affected pipes with PVFD lined pipe, and adding dilution water. Unless prevented in the future, the struvite build-up would have to be removed on a regular basis. The latter would require shutting down the reactor and manually cleaning the scaled sections of pipe. No scale accumulation was found inside the reactor.

So far, operators have spent an average of five man-hours per week dedicated to the P-recovery facility operation and harvesting; however, this may not be representative of an annual average labor requirement.

![Figure 6: Struvite deposits in Reactor Drain Pipe](image)

**Economics of P recovery**

The total cost of the P-recovery facility was $US 2.5 million. As the first full-scale facility, the vendor provided significant financial incentives to lower the payback period. The cost for a building is not included in the total cost due to the use of a preexisting building. It does include, however, the building remodeling cost and the installation of transfer lines (500 m) for centrate and magnesium chloride through a utility tunnel from the centrate storage facility. In order to reach the desired six year return of investment (ROI), the combination of savings and income from the sales revenue (SR) have to total $US 40,000/month assuming an annual interest rate of 5 %. To date, 45 t of product have been recovered, which amounts to 35 t/month. At 35 t/month, the required SR for the six year ROI amounts to $US 1,150 without operation cost, overhead and profit. Operation and maintenance costs include energy ($US 0.08/kWh) for operation of the plant (~ $US 50/t of product), labor hours ($US 45/h), and magnesium chloride ($US 240/t).
Because of the confidential nature of the public/private partnership, the exact information about the revenue generated from the sale of the product is not available. At the time of publication, data on savings realized from reduced chemical use and sludge hauling was limited because of the brief period of operation. The P-recovery facility has also not been fully utilized with respect to its true P-recovery capacity. As centrate phosphorus dropped from the initial 500+ mg/l soluble PO$_4$-P to the low 300+ mg/L due to a reduction in phosphorus recycle and due to alum addition, 100% of the centrate flow can be handled by just two of the three reactors by feeding them at higher-than-designed rates. Optimization and determining the operating range parameters will be ongoing. Importing waste phosphoric acid from industry is being investigated. Enough phosphoric acid has been located to generate one reactor’s worth of struvite, which would significantly reduce the ROI period or the amount of revenue per ton or product required.

**Comparing full scale performance with simulated performance**

Prior to the full scale installation, modeling of the entire Durham treatment process with and without the phosphorous recovery process was conducted. The objectives of the modeling were to:

- Estimate the product yield.
- Simulate how the P-recovery process would impact the plant phosphorus mass balance.
- Determine the models ability to predict the process changes and product yield.
- Investigate options to increase the product yield

As part of this effort, a whole plant BioWin model for Durham AWWTP was developed and calibrated for the month of May 2008 (Figure 7). The calibrated model was then modified to include P-recovery from the dewatering centrate and magnesium chloride addition. Figure 6 shows the phosphorus mass balance for the plant without phosphorus recovery, comparing actual data with results from the calibrated model. Figure 7 shows actual results from the phosphorus recovery operation in May 2009 in comparison to the simulation.

The primary parameter for calibrating the phosphorus mass balance was the surrogate alum feed to the digester. The plant does not actually feed Alum to the digester but is needed in the model to account for the various phosphate metal precipitations that are not included in the model (i.e. K, Fe$^1$). In Table 3, key parameters from the whole plant simulation with P-recovery are compared with the actual data from May 2009.

Without available data at the time, some assumptions had to be made regarding operation changes after the P-recovery startup. In May 2008, a 30 mg/L alum dose was added to the primary clarifiers at the startup of the P removal season. This alum dose was turned off and the surrogate alum dose used to calibrate the digester PO$_4$-P content was reduced by 60% to account for the eliminated ferric chloride feed to the centrate storage tanks.

Despite the limited run time of the plant with phosphorus recovery, the results are remarkably close to the model considering the complexity of the model and the fact that it was not specifically calibrated to the new conditions. The biological phosphorus removal appears to perform better in reality than in the model. It remains unclear whether the difference is due to PAO kinetics, calcium phosphate precipitation in the anaerobic zone or higher cell growth related phosphorus removal.

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1 BioWin only allows either alum phosphorus chemistry or iron phosphorus chemistry at one time
The simulated product yield was about 10% higher compared to the actual removed product even though the amount of phosphorus removed from the centrate is compatible to the actual data. This difference can be explained with an imperfect capture rate. Some of the smaller struvite crystals are lost to drain. After taking into account the 90% product capture rate the total recovered influent phosphorus is almost identical.

Additional simulations and a more detailed sensitivity analysis will be required in order to determine whether the fairly good simulation results were due to the models capability, luck, or coincidence.

It appears however, that the model predicts the whole nutrient removal performance, mass balance, and P-recovery well enough that after calibration to the new conditions, it could be used to identify ways to optimize the recovery product yield.

Different model configuration and conditions are simulated to estimate their impact on the product yield:

**Condition 1:** Summer Operation: at higher temperatures (22°C), 100% higher fermenter VFS yield and 100% higher influent VFA

**Condition 2:** Winter Operation: Without nitrification and tertiary alum addition, anoxic zones become anaerobic

**Condition 3:** WASSTRI½: WAS storage tank is converted to ANR tank with VFA feed from fermenters to release stored phosphorus prior to digestion.

Table 4 summarizes the product yield, MLSS P, and biosolids TP for the three conditions and the condition before P recovery. The summer operation condition did not increase the product yield and showed little change in the phosphorus mass balance. During the winter however, with no chemical addition that ties up phosphate, the yield increases significantly from 2380 lb/d to 3700 lb/d. It is to be expected that the actual amount would be smaller since the model did not take into account the short retention times in the BNR system due to high wet weather flows.

The WASSTRI½ process increases the product yield by forcing the release of stored phosphorus prior to anaerobic digestion. The effluent from the WAS stripping tank is sent directly to the phosphorus recovery system where it merges with the dewatering centrate. The yield increases significantly to 5200 lb/d, but so does the magnesium dose. By mixing the two streams, the ammonia and phosphate concentrations decrease, which requires overdosing magnesium.

Because the phosphorus recovery facility at Durham only has a capacity of approximately 3500 – 4000 lb/d, the WASSTRI½ process would have to be controlled such that the P-recovery capacity is fully utilized without increasing the recycle phosphorus load back to the secondary treatment.

More full scale data will be required to fully understand the impact of phosphorus recovery on the whole plant phosphorus mass balance. The simulations however, can be used to anticipate the changes and to aid with the product yield optimization.

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2 Patent Pending, Clean Water Services
Table 3: Comparison of simulated and actual changes in the plant phosphorus mass balance, product yield and effluent quality

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Simulated</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Produce Yield</td>
<td>kg/d</td>
<td>2400</td>
<td>2200</td>
</tr>
<tr>
<td>Secondary Effluent PO4-P</td>
<td>mg/L</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Reduction in MLSS P</td>
<td>%</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Reduction in Recycle P Load</td>
<td>%</td>
<td>97</td>
<td>83</td>
</tr>
<tr>
<td>Dewatering Centrate PO4-P</td>
<td>mg/L</td>
<td>452</td>
<td>430</td>
</tr>
<tr>
<td>Ostara Effluent PO4-P</td>
<td>mg/L</td>
<td>16</td>
<td>76</td>
</tr>
<tr>
<td>P-Recovery (product)</td>
<td>% Influent P</td>
<td>21%</td>
<td>17%</td>
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Table 4: Comparison of P-Recovery Product Yield Potential and MLSS and biosolids Phosphorus content

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Product Yield [lb/d]</th>
<th>MLSSP [%]</th>
<th>Biosolids P [%]</th>
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<tbody>
<tr>
<td>Base P recovery</td>
<td>2380</td>
<td>5.6</td>
<td>3.8</td>
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<tr>
<td>Condition 1</td>
<td>2230</td>
<td>5.7</td>
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<tr>
<td>Condition 2</td>
<td>3700</td>
<td>6.1</td>
<td>3.3</td>
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<tr>
<td>Condition 3</td>
<td>5200</td>
<td>5.4</td>
<td>3.5</td>
</tr>
</tbody>
</table>

*assuming 100% capture
Figure 8: Simulated* and Measured Phosphorus Mass Balance Comparison Pre P-Recovery Installation (May 2008 and 2009)

* simulated values in blue italic font
Figure 9: Simulated* and Measured Phosphorus Mass Balance Comparison Post P-Recovery Installation (May 2008 and 2009),

* simulated values in blue italic font
Conclusions

The phosphorus recovery process was proven to perform as expected both with regard to phosphorus removal and recovery performance, as well as with regard to product quality. On average, the facility removed 83% of the dewatering recycle phosphate and produced 1.1 ton/day of dried fertilizer product.

During the first three months of start up and operation, only about 60% of the theoretical reactor capacity was utilized. It is expected that this will eventually increase to 85% once the process is fully optimized. Full (100%) utilization is not possible because of necessary reactor shutdowns for inspection and maintenance.

The product quality has been exceptional despite the low centrate quality, which at times contained solids concentrations in excess of 10,000 mg/L.

Because of the short operation experience to date, the impact of the recovery process on the secondary treatment BNR system cannot be fully evaluated. However, the dewatering recycle phosphate load was reduced from 55% to 9% by the addition of phosphorus recovery. As a result the mixed liquor phosphorus inventory has already dropped from 4.9% to 4.4%. As the process slowly adapts to the lower recycle load, the performance of the recovery process becomes an integral part of the secondary treatment phosphorus removal process. This means that a sudden loss of the recovery process would directly result in higher secondary effluent phosphorus concentrations.

A thoroughly calibrated whole plant model can be used to simulate the impact of the P-recovery process, including potential product yield, recovery rates, and changes in the plant phosphorus mass balance.

The long-term economic validity of the recovery process will depend entirely on the attainable market value of the slow-release fertilizer product. At the Durham AWWTP, the anticipated return of investment period is six years. The payback of the capital investment is made up of direct revenue from the fertilizer sale cost savings from reduced chemical use in the secondary treatment process and subsequent chemical sludge handling. The payback period can be reduced by maximizing the reactor utilization, which increases the product yield.

After the successful startup of the first US phosphorus recovery facility, Clean Water Services (CWS) is considering the installation of the second facility at their Rock Creek AAWTP.
References


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