Wastewaters are increasingly being viewed as a renewable resource whereby valuable products (e.g., water, nutrients, energy, carbon, other resources) can be recovered and reused. This shift in focus from removal to extractive recovery whereby a chemical product that is distinct from biosolids is recovered, can reduce energy consumption, improve treatment efficiency, reduce nuisance scaling and provide utilities with alternative revenue streams with which to offset operational and capital costs. Within this context, both nitrogen (N) and phosphorus (P) have been identified as ideal candidates for extractive recovery from water resource reclamation facilities (WRRFs). A review of the extractive nutrient recovery concept, and a case study facility that has successfully practiced extractive nutrient recovery are provided here.

Making the Case for Extractive Nutrient Recovery

The nutrient concentration in the influent to municipal WRRFs typically ranges from 10 to 50 mg N/L for N, and from 1 to 10 mg P/L for P (Latimer et al., 2012). Since the efficiency of extractive nutrient recovery technologies is low at these concentrations, N and P must first be concentrated. This can be accomplished using a combination of existing biological and chemical treatment technologies.

For instance, up to 20 percent of the influent N load will be assimilated into biomass in activated sludge systems. Similarly, up to 90 percent of the influent P load can be accumulated into the solids fraction through use of enhanced biological phosphorus removal (EBPR), or chemical precipitation with metal salts.

Once accumulated into the solids phase, a large fraction of these nutrients can be released into a low volume stream via solids stabilization processes like anaerobic digestion. One important exception is the fraction of P that is removed via metal salt addition. Metal associated phosphorus complexes are not solubilized during conventional solids removal processes and require further processing for extractive nutrient recovery.

For plants that do not practice chemical P removal, the P and N load of the nutrient rich sidestream resulting from the solids stabilization process can represent between 10 and 30 percent of the total nutrient load to WRRFs. These nutrient rich loads can compromise the mainstream EBPR performance as well as increase nuisance scaling potential within solids handling processes.

Importantly though, these low flow nutrient rich streams represent an ideal feedstock for extractive nutrient recovery processes like struvite crystallization, which is the most commonly applied technology. In the crystallization process, P can be recovered from sidestream flows as struvite (NH₄MgPO₄•6H₂O) or hydroxyapatite (Ca₅(PO₄)₃(OH)) within designated reactors in which the precipitation potential in the reactor is controlled by sodium hydroxide (NaOH) addition while limiting reagents, typically magnesium (Mg).

Table 1. Overview of Phosphorus Recovery Alternatives

<table>
<thead>
<tr>
<th>Application</th>
<th>Principle Behind Recovery</th>
<th>Chemical Additions Needed</th>
<th>Recovered Element</th>
<th>Examples of Technology</th>
<th>Reuse Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wastewater and Sludge</strong></td>
<td>A concentration step (e.g., EBPR or adsorption onto selective media) acts to remove P from the mainstream flow. P is then released into a smaller stream via anaerobic digestion, VFA stripping or media regeneration. This stream is then subjected to chemical precipitation and crystallization under alkaline conditions.</td>
<td>Mg, Ca, NaOH</td>
<td>P, N, Mg</td>
<td>PearlP™, Multiform Harvest (MH) process, PHOSPAQ™, Crystalactor™, NureSys™</td>
<td>Fertilizer, Replacement for P rock</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ca, NaOH</td>
<td>P, Ca</td>
<td>Crystalactor™</td>
<td>Replacement for P rock</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quartz (sand) NaOH, Ca</td>
<td>P, Ca, trace metals</td>
<td>Crystalactor™</td>
<td>Replacement for P rock</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H₂SO₄, H₂O₂, Na₂S, Mg, NaOH</td>
<td>P, N, Mg</td>
<td>SEABORNE™ E™</td>
<td>Fertilizer</td>
</tr>
<tr>
<td><strong>Sludge Ash</strong></td>
<td>Acid addition to digested sludge re-dissolves nutrients. The sludge is then dewatered to generate a nutrient rich stream which is then subjected to chemical precipitation at alkaline pH.</td>
<td>H₂SO₄, Ca</td>
<td>P, Ca, Al</td>
<td>SEPHOS™</td>
<td>Replacement for P rock; coagulant</td>
</tr>
<tr>
<td></td>
<td>Acid addition to sludge ash re-dissolves nutrients. Selective precipitation of phosphate complexes is performed at pH 3.5. Potassium or magnesium chlorides are added to the ash. This mixture is then heated to &gt; 10000 C to remove heavy metals chlorides. Potassium and magnesium phosphates can then be recovered directly from the residue.</td>
<td>P, K, Mg</td>
<td>P, K, Mg</td>
<td>SUSAN™</td>
<td>Replacement for P rock</td>
</tr>
</tbody>
</table>

Utilizing Extractive Nutrient Recovery to Effectively Manage Nutrient Rich Sidestreams

by Wendell O. Khunjar, Katya Bilyk, Ron Latimer, Laurissa Cabbage, Paul Piit, Bill Balzer, Rick Baumler and Charles Bot

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and calcium (Ca), are added to the nutrient rich stream. Effluent from this recovery process can then be recycled within the crystallization reactor or directly returned to the head of the plant. During this crystallization process, between 80 and 90 percent of the soluble phosphorus and 20 and 30 percent of the nitrogen from the sidestream flow can be recovered as products that can then be reused as slow release fertilizers (struvite) or feedstock (hydroxyapatite) for other industries. A general overview of technologies that are available for extractive nutrient recovery is provided in Table 1.

Implementation and Successful Operation of an Extractive Nutrient Recovery Facility

The Nansemond Treatment Plant (NTP) in Suffolk, Virginia, is operated by the Hampton Roads Sanitation District (HRSD) and discharges treated effluent into the Chesapeake Bay (Figure 1). The 30 mgd NTP uses a modified 5-stage biological nutrient removal (BNR) secondary process to achieve annual average total phosphorus and total nitrogen effluent limits of 2.0 mg/L and 8.0 mg/L, respectively (Figure 2). The facility’s influent contains high nitrogen (45 mg/L) and phosphorus (8.2 mg/L) concentrations due to industrial contributions.

Solids handling consists of anaerobic digestion of separately thickened primary and waste activated sludge followed by centrifuge dewatering. Prior to the most recent upgrade, dewatering centrate contributed an abnormally high phosphorus loading on the mainstream process (30 percent of total load), resulting in frequent process upsets to the EBPR process. Process modeling performed by Hazen and Sawyer indicated that side stream treatment of the P rich centrate would increase the reliability of EBPR (Cubbage et al., 2011). Two options were considered for controlling P recycle loads:

1. Ferric chloride precipitation
2. Extractive nutrient recovery from the centrate via OSTARA Pearl® Process

A cost evaluation was performed to compare the cost of P recovery with that of side-stream ferric chloride removal. For the ferric alternative, it was assumed that the precipitate would ultimately be processed through centrifuges and disposed of through incineration. For the P recovery option, two different scenarios were evaluated. In the first, the equipment would be purchased from the manufacturer, and operation and maintenance of the facility would be the responsibility of the utility (capital option). In the second option, the utility would provide a monthly fee in exchange for the manufacturer providing the facility and equipment (fee option). In both options, recovered product would be purchased by the manufacturer to offset the operation costs borne by the utility (electricity, chemicals, etc.).

Present worth analysis indicated that both extractive nutrient recovery options would be less expensive than using ferric for P removal. A comparison between capital and treatment fee recovery options indicated that the capital purchase option was superior to the fee option. As a consequence, the HRSD chose to construct the nutrient recovery facility using this option.

Construction of the nutrient recovery facility began on November 11, 2009, and the project was completed by the end of May 2010 (Figure 3). The system was started up soon thereafter, and has resulted in an average 84 percent reduction in soluble phosphorus content in the centrate. Nitrogen content of the centrate also has dropped by an average of 24 percent. As of August 2014, approximately 835 US tons of Crystal Green® product (specialty struvite blend fertilizer (Figure 4) have been produced to date at the facility. Since startup, ferric addition at the facility has been limited to one three-week event, due to an EBPR upset event.

Results from this work represent a unique scenario where extractive nutrient recovery was shown to be the lower cost alternative for reducing sidestream phosphorus loading versus conventional ferric addition. Factors that were determined to positively contribute to a favorable outcome for nutrient recovery included the amount of nutrient that

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must be removed or recovered; the degree to which infrastructure could be repurposed; the business model employed by the struvite recovery technology provider; and, the offset in chemical and energy costs associated with nutrient removal and reduced sludge production.

Figure 3: Nansemond Treatment Plant Nutrient Recovery Facility

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References