It's always something

Understanding the connections among biological phosphorus removal, anaerobic solids digestion, dewatering, and land application

Gary F. Shimp, James L. Barnard, and Charles B. Bott

Biological phosphorus removal (BPR) is gaining momentum because it offers both chemical-cost savings and struvite-recovery advantages. But increased biological nutrient removal use necessitates a closer look at its effect on such subsequent processes as solids treatment – especially for facilities using anaerobic digestion.

Most BPR facilities report increased struvite formation in digesters, solids pumps and piping, dewatering equipment, and centrate and filtrate return lines. An additional detriment of BPR is lower-than-anticipated cake solids content and higher operating costs for polymer conditioning, downstream processing, and truck hauling. This phenomenon is another reminder of the interrelationships between liquid treatment and solids processing – a change in one unit operation often affects another.

BPR transfer of phosphorus

In the BPR process, magnesium and potassium, in addition to phosphorus, are taken up from the very dilute influent liquid stream and concentrated into the waste activated sludge (WAS) cell mass. The WAS is transferred to a solids processing train that commonly consists of thickening, anaerobic digestion, and mechanical dewatering. At many facilities, the resulting biosolids are applied to cropland.

Another subset of the phosphorus is left behind within the digesters as insoluble struvite, which may exist as sandlike deposits on the floor of digesters or as encrustations on digester walls or in pumps and piping. Conversion from conventional activated sludge treatment to BPR doesn't change biosolids quantities significantly to be managed but doubles or triples biosolids phosphorus content. When biosolids are land-applied at agronomic rates for nitrogen, as is the norm, phosphorus is applied at loading rates greater than crop needs, even from conventional activated sludge facilities. BPR significantly exacerbates this overapplication of biosolids phosphorus.

Dewatering performance can vary widely from one facility to another, depending on feed solids characteristics, type of dewatering equipment, and other factors. Cationic polymers supplement natural bioflocculation to condition solids for mechanical dewatering. Deficiency in natural bioflocculation requires a higher dose of polymer for dewatering. Researchers have shown that cations and exocellular biopolymers produced by the microbes are involved in flocculation, settling, and dewatering solids. The 2002 *Water Research* article by D. Sobeck and M. Higgins, "Examination of Three Theories for Mechanisms of Cation-Induced BioFlocculation," examined three different cation-induced floc models. The authors concluded that divalent cation bridging, in which both calcium and magnesium ions equally bind negatively charged biopolymers, best explains the beneficial role of divalent cations in building strong floc structures.

Digesting WAS from a BPR facility results in more phosphorus than magnesium in solution in the digesters. This leads to depletion of divalent magnesium during the formation of struvite, while leaving an abundance of monovalent potassium. Excessive concentrations of potassium reportedly prevent bridging and result in poor solids settling and dewatering characteristics manifested by a drastic decrease in final cake solids and an increase in polymer requirements for dewatering. This balance can be restored and dewatering ability improved by adding more divalent cations, such as magnesium and calcium. A ratio of divalent to monovalent cations greater than 1.2 ideally improves dewatering.

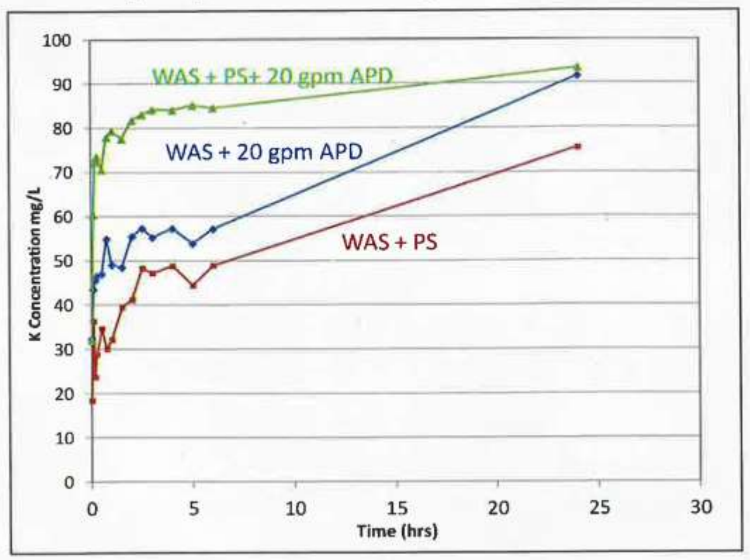
Two major mitigation measures have been explored in Europe and North America: stripping phosphorus, magnesium, and potassium from the WAS before digestion to allow struvite recovery and also divert potassium cations away from the solids processing train; and adding magnesium to digested biosolids to satisfy the twofold demand for magnesium in struvite formation and bioflocculation.

North American experience with dewatering at BPR plants

Clean Water Services (CWS; Hillsboro, Ore.). At the 75,700-m³/d (20-mgd) Durham advanced wastewater treatment facility, CWS has a summer limit on phosphorus of less than 0.1 mg/L but strives to achieve 0.07 mg/L. The utility uses BPR to remove orthophosphates and chemicals to polish in a tertiary facility to ensure compliance with summer phosphorus limits.

According to P. Schauer and his coauthors on "Increasing Revenue While Reducing Nuisance Struvite Precipitation: Pilot Scale Testing of the WASSTRIP Process" from the 2011 WEFTEC proceedings, CWS has reported a decrease in solids content after dewatering and an increase in polymer use after converting to BPR. CWS subsequently installed a system to recover struvite from centrate after dewatering digested sludge and, more recently, the utility has endeavored to increase recovery of struvite by using the WASSTRIP (Waste Activated Sludge Stripping To Remove Internal Phosphorus) process to strip phosphorus, magnesium, and potassium from the WAS prior to digestion. This shunts more magnesium and phosphorus around the digesters to the recovery process and simultaneously reduces the amount of potassium entering the digester. Studies are under way to determine whether the reduced phosphorus will bind up less magnesium and if the reduced potassium to the digesters will improve dewatering.

Figure 1. Release rate measurements for potassium in trials with a temporary WASSTRIP arrangement at Atlantic facility



Hampton Roads Sanitation District (HRSD; Virginia Beach, Va.). The Atlantic water resource recovery facility (WRRF) is the largest of HRSD's treatment facilities. It handles approximately 1.3 m³/s (30 mgd) for discharge to the Atlantic Ocean without nitrogen or phosphorus removal requirements.

The facility recently was upgraded to include a high-rate (1.5- to 3-day solids retention time) plug-flow Phoredox process with anaerobic selector to improve settleability. Chemically enhanced primary treatment was eliminated with this upgrade as well. The digestion process was converted to mesophilic acid/gas digestion. The upgraded facility has exhibited considerable BPR activity, as indicated by high centrate orthophosphate concentrations in the range of 550 to 650 mg/L. Sludge volume index findings are good, but dewatering typically achieves only 16% to 17% total solids, with some prolonged periods as low as 15%. Struvite accumulation in solids handling has increased dramatically.

In mid-2012, HRSD began to evaluate WASSTRIP without struvite recovery as a means to reduce struvite precipitation in the digesters and improve dewaterability. The evaluation began with a series of batch release rate measurements during testing with a temporary WASSTRIP arrangement. The significant release rate measurements for potassium (see Figure 1, p. 44) particularly prompted HRSD to initiate a new research project, jointly funded with CWS, to assess the benefits of applying the WASSTRIP process.

Metropolitan Council Environmental Services (MCES; Minneapolis-St. Paul). The Blue Lake facility – MCES's second largest facility – treats approximately 1.15 m³/s (26 mgd). Centrifuge dewatering and heat drying were added for solids processing in 2000, with dewatered cake concentrations of 27% to 28%. The facility was upgraded to achieve BPR in 2008, and anaerobic digestion was incorporated in 2012. To control the effect of BPR on the downstream solids handling piping and equipment, iron is fed directly into digesters to limit soluble orthophosphate in the digested biosolids to the range of 50 to 100 mg/L. Although MCES expected some dewaterability problems, the centrifuge dewatering of the digested BPR solids initially yielded cake at only 18% to 19% total solids (see Figure 2, above).

Figure 2. Timeline for dewatering at the Blue Lake facility

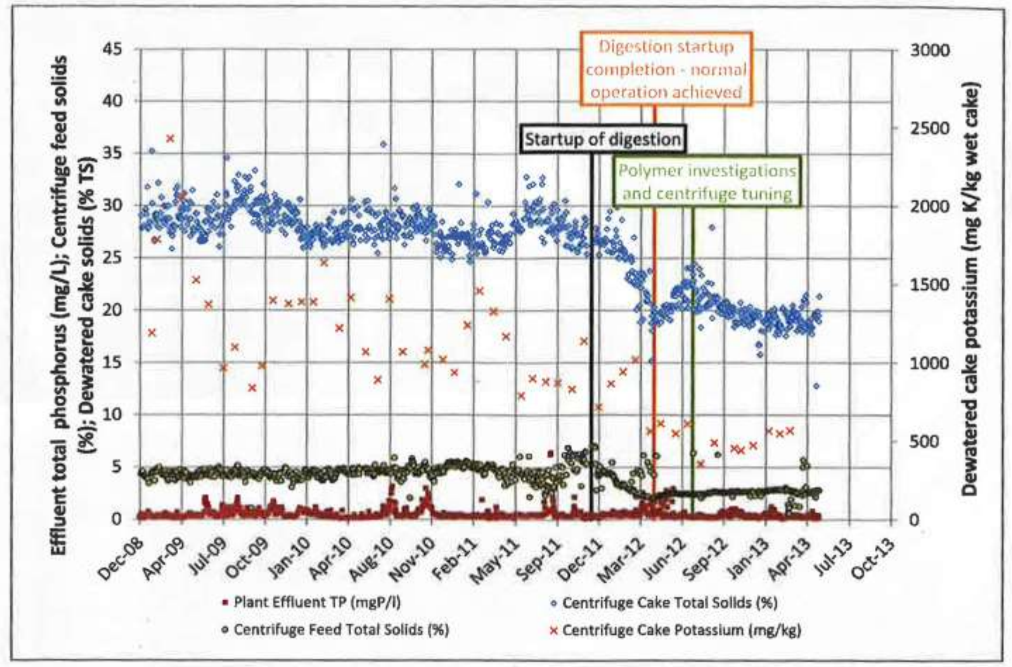


Figure from Sprouse, G. (2013). "Biosolids dewatering at the Empire WWTP following conversion to bio-P and influent wastewater changes," Central States Water Environment Association 18th Annual Education Seminar, Biosolids: Resource or Refuse? (April 2, 2013).

With a high dose of an expensive polymer and optimization assistance from the centrifuge manufacturer, Blue Lake achieved cake solids up to 26% to 27% total solids. But based on solids characteristics, operators have since opted to operate with lower-cost polymer and reach 19% to 20% cake for feed to the downstream heat drying process.

Also plotted on Figure 2 is the potassium content of the BPR cake solids (mg K/kg wet cake) before and after the startup of digestion. The data show the effect of potassium release from the cell mass during digestion, with more of the potassium in the feed stream to dewatering being in the bulk liquid and less in the solids. G. Sprouse presented this information in April 2013 at the Central States Water Environment Association 18th Annual Education Seminar, "Biosolids: Resource or Refuse?"

Encina Wastewater Authority (EWA; Carlsbad, Calif.). The Encina Water Pollution Control Facility currently treats about 1 m³/s (23 mgd) for discharge to the Pacific Ocean. In 2003, an anoxic zone (selector) was incorporated into the aeration basins for improved filament control and settleability. Primary solids and dissolved air flotation-thickened WAS are combined for anaerobic digestion and dewatering on belt filter presses (BFPs). Cake solids from the BFPs gradually declined to less than 17% total solids in 2006.

When the new centrifuges were started up, they required a higher-than-anticipated polymer dose and produced cake solids at 22.5% to 23%, much lower than the specified 26%. In 2011, EWA found that significant phosphorus uptake was occurring in the secondary process with the use of the anoxic selector. Struvite crystals were visible in the dewatered cake, and heavy struvite precipitation rendered the centrate drain nearly inoperable. The authority commissioned a pilot study of a crystallizer process to reduce the recycle phosphorus load in the centrate but concluded that installation of a phosphorus recovery system would not likely be economically viable without a significant driver such as a large avoided cost.

Metro Wastewater Reclamation District (Denver). The Metro Wastewater Reclamation District's Robert W. Hite Treatment Facility in Denver currently treats about 7 m³/s (160 mgd). The solids processing train includes acid/gas anaerobic digestion and high-solids centrifuge dewatering for land application of biosolids. Cake solids content varies seasonally from 21% to 26%, with an average of 23%. Anticipating future effluent phosphorus limits, the district undertook a 6-month demonstration study of BPR at 70% of full-plant scale by using one of the existing return activated sludge (RAS) reaeration basins as an anaerobic zone where about 30% of the RAS was contacted with overflows from the gravity thickeners that were operated with high sludge blankets to promote fermentation of the primary sludge. The innovative experiment was highly successful, achieving orthopohosphate concentrations approaching 0.1 mg/L, according

to L. Cavanaugh *et al.* in the 2012 WEFTEC paper, "A Small Footprint Approach for Enhanced Biological Phosphorus Removal: Results from a 95 MGD Full-Scale Demonstration." However, the dewatering characteristics of the facility's digested solids began to deteriorate within days of beginning the demonstration, resulting in lower cake solids (See Figure 3, right) and higher doses for polymer conditioning, Cavanaugh said. While the success of the unconventional mode of operation has the potential to save millions in the cost of converting the plant to BPR, the district is concerned with its effect on solids dewatering given the large scale of the Hite facility.

Madison Metropolitan Sewerage District (MMSD; Madison, Wis.). MMSD modified its 151,400-m^3/d (40-mgd) Nine Springs WRRF to operate in BPR mode in the late 1990s. For more than 10 years, MMSD produced effluent total phosphorus concentrations that averaged 0.35 mg/L without filtration or chemicals. When the district upgraded in 2006 to temperature-phased anaerobic digestion (TPAD) and added a dewatering centrifuge to produce a Class A product, significant increases in struvite precipitation greatly affected heat recovery. Upon startup of the high-solids centrifuge in early 2007, MMSD was able to achieve a cake of only 21% to 22% total solids, despite running the centrifuge at lower throughput (60% of design) and with high polymer doses. Performance fell short of the 23% total solids specified.

Figure 3. Deterioration of cake total solids at the Robert W. Hite facility coincident with biological phosphorus removal startup

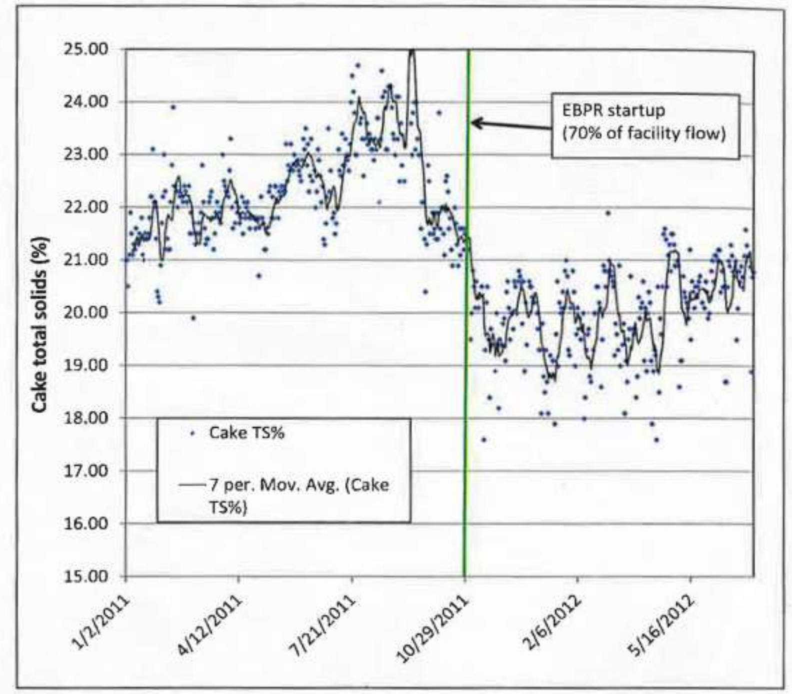


Figure from Cavanaugh, L., K. Carson, C. Lynch, H. Phillips, J. Barnard, and J. McQuarrie (2012). "A Small Footprint Approach for Enhanced Biological Phosphorus: Removal: Results from a 95 MGD Full-Scale Demonstration," WEFTEC 2012 Proceedings (October 2012).

MMSD currently is making additional improvements to its solids processing train, including upstream acid-phase digesters and a phosphorus harvesting process to mitigate the problems with struvite precipitation and reduce the phosphorus in the biosolids to be land applied. The acid-phase digesters will provide needed volatile fatty acids via a small slip-stream to promote phosphorus, magnesium, and potassium release prior to digestion as part of the harvesting process.

This project is the culmination of more than 10 years of research, in conjunction with the University of Wisconsin–Madison, to investigate methods for triggering controlled phosphorus release from WAS and permit reduction and recovery of phosphorus prior to anaerobic digestion, according to A. Grooms in the 2012 paper, "Reducing Biosolids Phosphorus by Efficient Release and Harvesting of Phosphorus." The paper appears in the *Proceedings of WEF Residuals & Biosolids Conference*. From lab testing and modeling, the district expects to reduce both phosphorus concentrations in its biosolids product and struvite formation by approximately 50%.

Global perspective on effects and mitigation

European as well as North American experience to date indicates that dewatering effects from BPR reduce cake solids between 2% and 5%. Utilities contemplating conversion to BPR should be cautious in setting expectations for solids dewatering performance. As noted in the examples, it often is difficult to isolate dewatering effects solely attributable to BPR. A promising development that could mitigate this problem is stripping of magnesium, phosphates, and potassium from WAS before digestion.

Berlin Water and Waternet (Amsterdam) have been able partially to remedy dewatering effects of BPR by aeration of digested solids and magnesium addition in the AirPrex process, according to 2011 graduate research by B. Bergmans at the Delft University of Technology in the Netherlands. The overall cost of BPR with AirPrex and solids dewatering was less than using chemicals for phosphorus removal in the main stream process. This seems to support the importance of magnesium to bioflocculation and dewatering, as potassium largely is unaffected by the controlled struvite precipitation schemes being developed by these two European utilities.

The European experience suggests that a higher magnesium dose ratio (1.5 to 2.2 magnesium:phosphorus molar) may be required to maximize dewatering benefits compared to the ~1.1 ratio typically suggested for economic harvesting of phosphorus from biosolids liquors using crystallizer or other struvite recovery systems.

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