Getting More Out of Activated Sludge Plants by Using a BioMag Process

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As nutrient requirements are tightening in the United States, one of the biggest challenges in wastewater treatment has become to reliably meet effluent limits in a sustainable manner. The reliability requirement is driven by the need to meet strict effluent daily or weekly limits set in permits to protect the designated uses of the receiving water. Hence, facilities facing more strict nutrient requirements have to consider a wide, and possibly confounding, array of treatment technologies. In order to address this issue, The U.S. Environmental Protection Agency (EPA) has recently published a technical document that includes process descriptions and operating factors for over 40 different treatment technologies for removing nitrogen, phosphorus, or both, from municipal wastewater streams (EPA, 2009).

Nutrient removal processes, however, come at a cost to municipal wastewater treatment facilities and their ratepayers. Although funding from various sources might be available, they are not generally sufficient to address all aspects of the necessary improvements for nutrient removal. Another important factor affecting the cost of nutrient removal at wastewater facilities is site limitations on physical expansion of their treatment facilities. Some plants are located in urban areas and do not have any way to obtain the physical space necessary to expand. Space limitations can severely limit the type of processes that can be used to reduce nutrients (Naik and Strenstrom, 2011). Therefore, the BioMag process is a recently developed, emerging technology that aims to increase the capacity of treatment plants and to enhance nutrient removal in facilities that have limited spaces.

Objectives

The main objective of this article is to introduce the BioMag process as an alternative to enhance the capacity and effluent quality of existing treatment plants. Objectives that are more specific are:

- To present the BioMag process and to provide the advantages and disadvantages of this emerging technology.
- To investigate nutrient removal capacity of this technology by providing several examples from existing pilot scale projects.
- To discuss the design considerations of the BioMag process.
- To provide a case study to compare the footprint of the BioMag process with other alternatives.

BioMag Process

The BioMag process is a ballasted flocculation-aid wastewater treatment process that uses magnetite to increase the specific gravity of biological floc. It was developed and patented by Cambridge Water Technology (CWT) in 2010 (Woodard et al., 2010),

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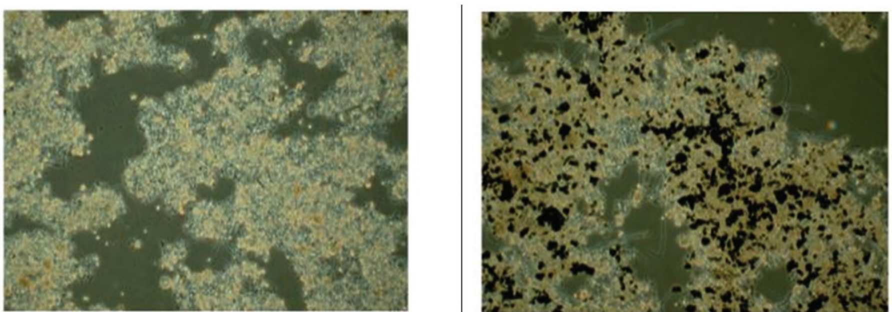
which is currently owned by Siemens. Magnetite (Fe_3O_4) is an inert iron ore, with a specific gravity of 5.2 and a strong affinity for biological solids. In this process, magnetite integrates with the biological floc, substantially increases the settling rate of the biomass, and improves overall solids removal. Figure 1 depicts the magnetite-introduced floc (right side) and compares it with normal floc. The dark spots appear on the right image are magnetite added into the process.

The BioMag process provides the ability to operate the reactors at three to four times above traditional activated sludge process mixed liquor suspended solids (MLSS) concentrations, while still maintaining adequate settling and thickening in the secondary clarifiers. This allows existing activated sludge systems to treat two to three times the original design flows and loadings at food-to-microorganism ratios (F/M), which are similar to conventional activated sludge systems, thereby increasing plant capacity within the same footprint. The process also facilitates nitrogen and phosphorus removal by allowing plants to increase the sludge retention time (SRT) and free up existing aeration tankage for use as anoxic and/or anaerobic zone(s). It provides enhanced and reliable removal of suspended solids, nitrogen, and phosphorus.

A schematic diagram of the BioMag process is illustrated in Figure 2. Mixed liquor is introduced with both recovered and virgin magnetite in a continuously mixed tank before entering into activated sludge. Then, mixed liquor, including magnetite, is fed into the reactor where it is held in suspension through a combination of aeration and supplemental mechanical mixing. After clarifiers, the return activated sludge (RAS) is conveyed from the clarifier to the reactor. Activated sludge is wasted from the RAS line and sent to a magnetite/waste activated



(a) Floc without magnetite | (b) Magnetite introduced floc

Figure 1. Comparison of Flocs With and Without Magnetite Addition
(from Andryszak et al., 2011)

sludge (WAS) separation system for removal of the magnetite prior to the sludge processing. The magnetite removed from the WAS line is recovered and sent into the mixing tank. The magnetite separation and recovery process starts with shear mills that apply high-shear forces to break up the floc. It is then followed by a rotating magnetic drum to separate the magnetite from the WAS. Once separated, the WAS is sent to solids processing facilities.

The BioMag magnetite recovery process has an efficiency rate of 85 to 95 percent. Makeup magnetite is added to maintain the design MLSS-to-magnetite weight ratio of 0.8 to 1.5 (optimum 1), depending on the application. Approximately 100 lbs of makeup magnetite are needed for mil gal (MG) of wastewater treated, based on an approximation of the total sludge yield being 1 dry ton/MG of wastewater treated. Average cost for magnetite has been around $0.25/lb, which would be at $25 of magnetite cost for 1 MG wastewater treated.

The main advantage of the BioMag process is that it can easily be applied to the conventional activated sludge process in confined spaces, with the advantage of eliminating the need of any additional enhanced nutrient removal (ENR) reactor and/or clarification capacity. It can notably enhance the capacity of the facility, improve secondary effluent quality, and increase the nutrient removal capacity of the plant. The BioMag process also offers significant capital cost/benefits compared to traditional biological processes.

On the other hand, there are some disadvantages of this technology not identified until recently. The process is still in the infant phase, where there are some unknowns. The facility that decides to implement this technology would need to make some assumptions and would involve some risks associated with the technology. Conducting a pilot-scale project before implementation of the full-scale process would lower the risk; however, the process does not have much established information like other traditional processes. Other than that, the BioMag process is not suited for intermittent operation. The life of shear mills necessary for the separation of magnetite from biological flocs has been questionable. If the facility does not have an influent fine screen or primary clarifiers, a fine screen should be incorporated into the WAS line to protect the shear mill from becoming clogged or damaged. The process can also be energy intensive due to high mixing requirements and the amount of shear necessary to break the flocs in magnetite separation step. Major challenges of the BioMag process are addressed in the process design considerations section.

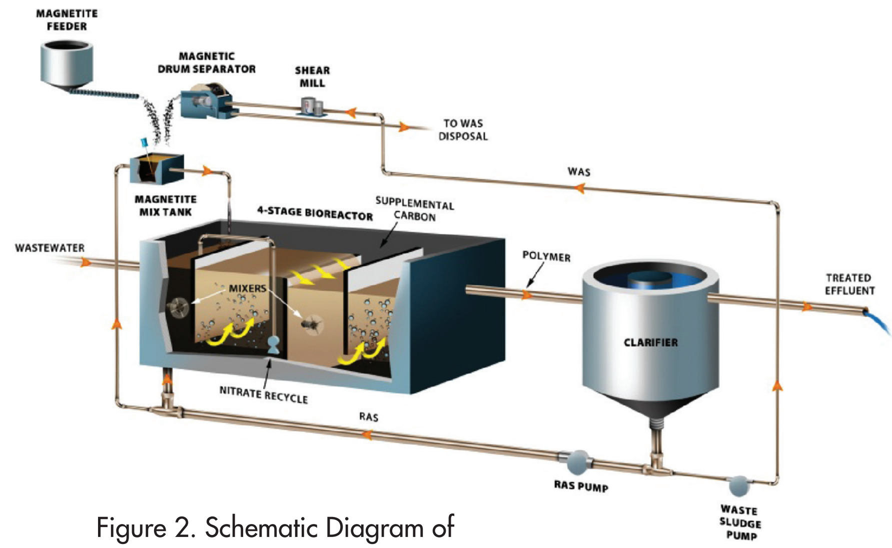


Figure 2. Schematic Diagram of BioMag Process (from Siemens)

Table 1. List of BioMag Process Applications

Full-Scale Plants and Demonstrations	Pilot- and Full-Scale Projects
• Long Tail Brewing Company, VT –operating since 2008, capacity enhancement and ENR upgrade • Allenstown, NH – 1.3 mgd ENR upgrade • Upper Gwynedd WWTP, PA – 3 mgd ENR & 13 mgd Wet weather flow treatment • Winebrenner WWTP, MD – 0.6 mgd ENR • Sturbridge WWTP, MA – 1.3 mgd ENR	• Mystic WPCF, CT –0.88 mgd, increase capacity by 2.5 times, TN removal • Taneytown WWTP, MD– 1.1 mgd ENR upgrade • Connocochegue WWTP, MD– 4.1 mgd ENR upgrade • Opequon Hedgesville WWTP, WV – 1.3 mgd ENR upgrade • East Norriton-Plymouth WWTP, PA – 8.7 mgd ENR upgrade • Marlay Taylor WWTP, St. Mary's County, MD - 6.0 MGD ENR upgrade

Nutrient Removal Capability

Due to the fact that the BioMag process is still being developed, there is limited data available on nutrient removal capacity of the process. Table 1 provides the list of BioMag projects.

As indicated in Table 1, almost all BioMag applications aim to enhance nutrient removal. Although the data from some facilities have been published in various conference proceedings, some facilities are in the construction or design phase where no data are available.

The Sturbridge Wastewater Treatment Plant (WWTP) in Massachusetts has completed successful full-scale demonstration that doubled the capacity of the plant's activated sludge system, resulting in BioMag process selection for application. This facility has a 1.3-mgd treatment capacity and includes an ENR upgrade, utilizing existing tankage. After the successful pilot project, construction activities were initiated in February 2010 and the project was completed in the summer of 2012. There were many challenges in the startup of the project; however, data collected to date clearly show that effluent total nitrogen (TN) and total phosphorus (TP) values of 3.0 mg/l and 0.05 mg/l are achievable (Catlow & Woodard, 2012).

Another successful full-scale demonstration was conducted at Upper Gwynedd WWTP in Pennsylvania. This facility includes a 3-mgd enhanced nutrient removal upgrade and a 13-mgd wet weather flow treatment, utilizing existing tankage. This facility had to demonstrate TP < 0.2 mg/l while maintaining effluent total suspended solids (TSS) < 10 mg/l monthly average, TSS< 30 mg/l during a wet weather event, and effluent cBOD<5 mg/L. The results indicated that the facility could meet effluent requirements by implementing the BioMag process.

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The Mystic WWTP located in Connecticut was in need of a process upgrade to meet future requirements for effluent total nitrogen. A full-scale demonstration of the BioMag process was completed from September 2009 through January 2010 to verify achievement of required process performance (Moody et al., 2011). Based on the results from the demonstration project, the facility could meet effluent TN<5 mg/L and effluent ammonia <1 mg/L. The sludge volume index (SVI) was around 80 mL/g.

A pilot-scale project was conducted at the Winebrenner WWTP, located in Maryland. This four-stage Bardenpho facility is required to have a 0.6-mgd capacity, with an ENR upgrade utilizing existing tankage. The process has to achieve effluent TN <3.0 mg/L and TP < 0.3 mg/L. A full-scale four-month demonstration financed by the Maryland Department of Environment (MDE) met all success criteria. The BioMag process was operated for varying influent loading conditions at a MLSS concentration of 10,000 mg/L between 6-11°C, achieving TN < 3 mg/L, TP < 0.2 mg/L, and TSS < 5 mg/L without the use of effluent filters (Andryszak et al., 2011).

The 1.1-mgd-capacity Taneytown WWTP located in Maryland has two sequencing batch reactors (SBRs). A full-scale trial of the BioMag process was conducted in 2010, representing its first application to an SBR. The full-scale project demonstrated effluent TN and TP concentrations averaging 1.2 mg/L and 0.11 mg/L, respectively. The facility could successfully meet all performance requirements (TN < 3.0 mg/L and TP < 0.3 mg/L) by adopting the BioMag process (Lubenow et.al., 2011).

Although, BioMag is an emerging technology, it presents promising results for ENR in pilot- and full-scale demonstration projects. Still, application of this technology in full-scale projects is needed to be able to establish the capabilities in nutrient removal.

Process Design Considerations

As indicated previously, there are many areas that are not clearly identified in this process. The first issue is the conveyance of solids, which includes magnetite. The transportation of dense solids in RAS and WAS lines might require higher energy pump capacity; however, settling in these lines must be eliminated.

The impact of magnetite on the life of pipes, pumps, and valves is not well defined. The data available do not show major wear of equipment; however, since the process only developed several years ago, there is no sufficient time to monitor this aspect of the process.

Another major area that requires further research and assessment is the mixing and aeration requirements of the BioMag process. Mixing is a crucial part of the process, not only to contact solids with magnetite, but also to prevent the mixed liquor stratification. The high-dense flocs can easily settle down in aeration tanks; hence, additional mixers would be necessary to keep the flocs in suspension all the time. Mixing can be very energy intensive and could notably increase the operating cost. Other than mixing, the impact of magnetite addition on alpha value (ratio of process-to-clean-water mass transfer) has to be clearly identified. The issue has been addressed in several projects; however, further research is essential to determine this value, which has a major impact on aeration requirement of the process.

Addition of magnetite into biological flocs would vary the coagulation and flocculation kinetics, and the role and dose of coagulants in a magnetite-introduced process needs to be evaluated. The facility might need to change the chemical conditioner and/or dose, and to conduct optimization studies. The pH and alkalinity response would also have to be monitored.

Foaming was a major problem of the BioMag process that was identified at the Sturbridge WWTP (Figure 3). Following startup of the facility's new BioMag system, foaming was observed in each of the package treatment units. Microscopic examination of the facility's mixed liquor indicated that much of this foaming is attributable to *microthrix parvicella* and *nocardia bacteria*. The abundance of filaments observed at startup was believed to be due to the prevalence of these bacteria during temporary treatment system operation (Catlow & Woodard, 2012); however, this issue has to be investigated comprehensively. The facility tried various methods to resolve foaming issues, such as RAS chlorination, defoamers, and surface wasting. Surface wasting was identified as the most effective method to address the foaming issue; however, it was labor intensive.

Figure 3. Foaming Observed at Sturbridge Wastewater Treatment Plant
(from Catlow & Woodard, 2012)

Fate of residual magnetite that is wasted through WAS (the capture rate is around 95 percent) is also not known at this stage. Accumulation of magnetite in solids processes (such as digesters) could be problematic. Furthermore, the impact of magnetite in dewatering processes has not yet been reported.

Another important consideration is continuous facility operation while retrofitting the BioMag process into the existing facility. During retrofitting, when several process units were offline, the facility still has to meet the permit requirements; temporary units, flow diversion, and various modifications might be necessary, especially in wet weather events.

A Case Study: Comparison of the Biomag Process With Conventional Technologies

The Marlay Taylor Water Reclamation Facility (WRF) in Maryland has a new permit to reduce the effluent nitrogen and phosphorus loads from the facility to ENR levels and to achieve 3mg/L TN and 0.3 mg/L TP; the WRF has explored cost- and energy-effective solutions to upgrade the facility to meet these ENR requirements. Three process alternatives were compared for required footprint and initial capital cost, along with a 15-year present-worth analysis. The four-stage Bardenpho process was selected for the conventional alternative, and integrated fixed-film activated sludge (IFAS) was also used for comparison. In this facility, the footprint of the BioMag process was found to be significantly smaller than other options, since this process eliminates the need for adding a secondary clarifier and effluent filters (Figure 4).

Since the BioMag process eliminates the need for building additional units, this alternative would require notably lower initial capital costs compared to the conventional four-stage Bardenpho and hybrid IFAS processes. For a 6-mgd annual average flow, the capital cost of BioMag was around 34 percent less than the four-stage Bardenpho and 25 percent lower than the IFAS process (Dursun et al., 2012).

On the other hand, the BioMag process was shown to be energy intensive due to the high mixing requirements and additional energy consumption of the process-related equipment (Figure 5). Additional mixing, compressors, and shear mills to separate the magnetite from flocs, separators, and pumps would significantly increase the energy demand of the conventional process.

As a basis for comparing the various options, a present-worth analysis was also conducted for the WRF. The capital costs were inflated to 2011 dollars, which represent the present worth. Energy and maintenance costs were multiplied by the annual present-worth factors that provide the present worth for a series of values for a 15-year period. An interest rate of 4.67 percent was used in the analysis. Figure 6 exhibits the 15-year present-worth value of each alternative (Dursun et al., 2012).

Based on this analysis, the present-worth value of the three alternatives were quite similar to each other. The conventional four-stage Bardenpho process showed slightly higher value compared to the other two alternatives.

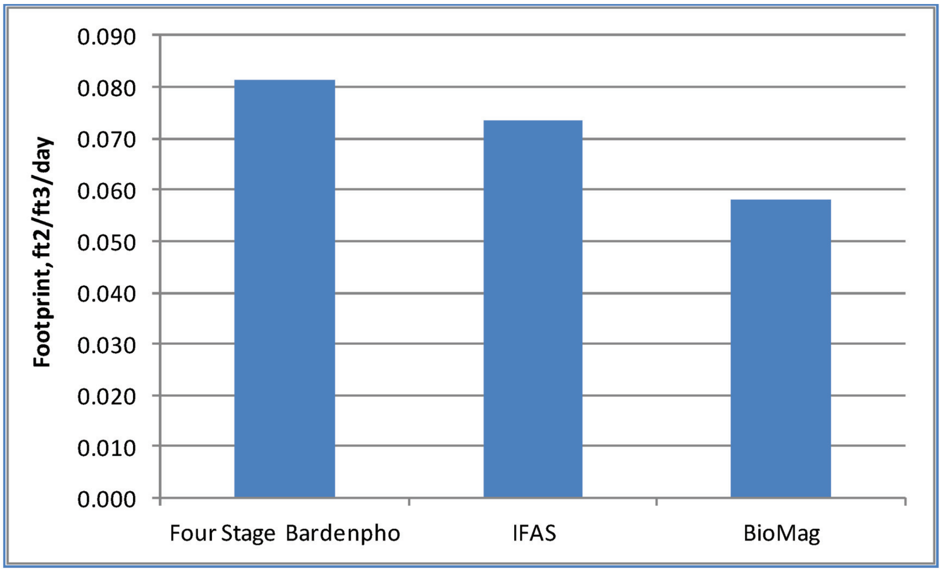

Figure 4. Comparison of Process Footprint (Required Area/Flow to be Treated)

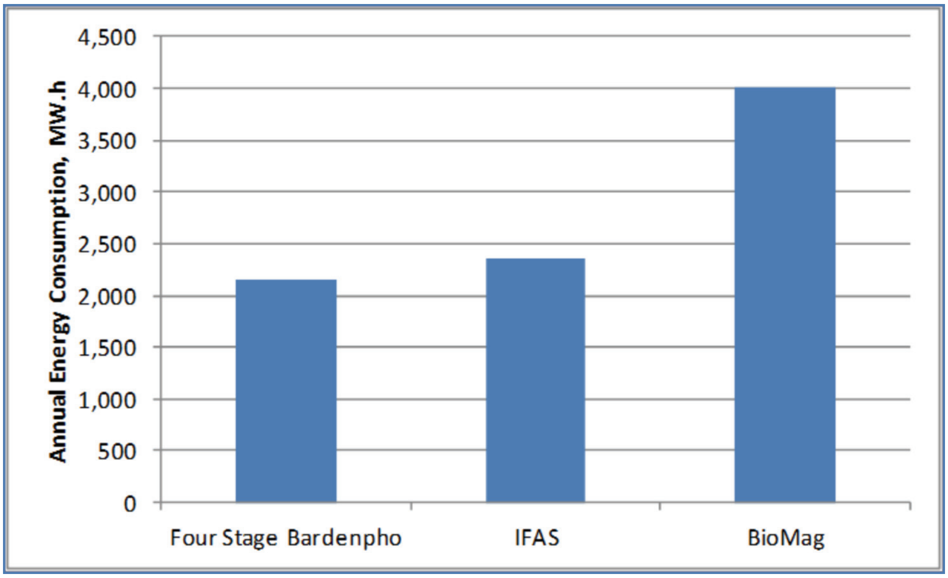

Figure 5. Comparison of Energy Requirement

Conclusions

The BioMag process is a promising emerging technology that might provide potential solutions for WWTPs that have to meet strict ENR requirements in limited spaces:

- Based on demonstration and pilot-scale projects, the process demonstrated its ability to handle high MLSS concentrations and to achieve settling at a very high solids loading rate.
- The process was proven to be successful in achieving ENR levels when adopted in different process configurations and used to treat a wide variation of flows and loads.
- The BioMag process would provide more capacity without building additional unit(s) in treatment plants, while meeting tighter ENR requirements.

However, the process has to be implemented full scale to establish more details of the process that are not clearly identified at this point. Besides many advantages, the process has some challenges, such as conveyance of solids, air and mixing requirements, equipment wear, foaming, the role of coagulants/chemicals, and the fate of residual magnetite in biosolid processes. These areas require more research and investigation. The initial capital costs for the implementation of the process are relatively low compared to conventional processes. On the other hand, the process might be energy intensive compared to other options.

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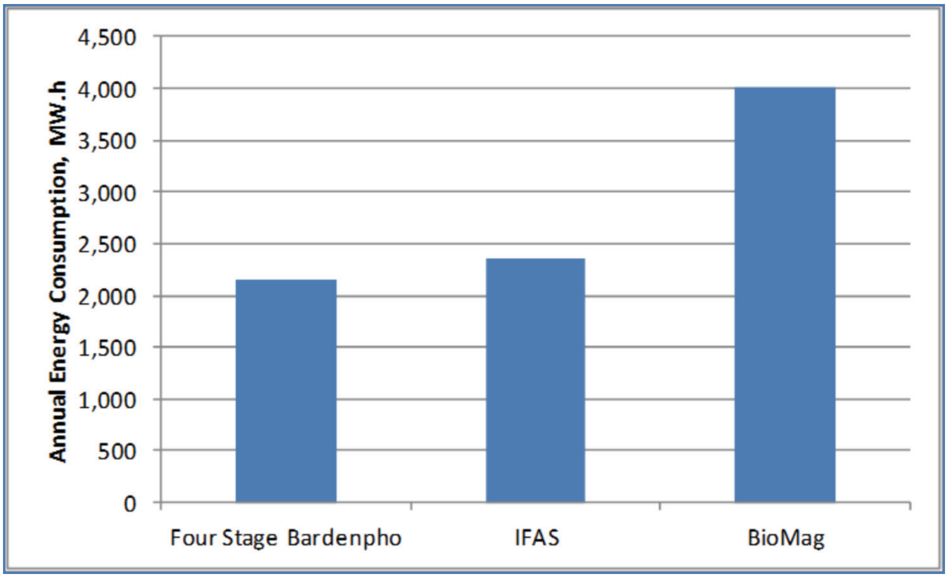

Figure 6. Present-Worth Analysis for Marlay Taylor Water Reclamation Facility