Stable Attraction: How to Cheat the Activated Sludge Process for Additional Capacity Using the Magnetite-Ballasted Mixed Liquor Process

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Utilities are often faced with addressing improvements at their wastewater treatment facilities due to a number of issues, including increased growth and more stringent effluent limits. The land available for implementing facility upgrades and/or expansions may not be available, leaving the utility in a challenging situation. There are a number of technologies that have gained traction to address this concern, including moving bed bioreactors (MBBRs), integrated fixed-film activated sludge (IFAS), membrane bioreactors (MBRs), and biological aerated filters (BAFs). An emerging technology is the BioMag™ treatment system.

A full-scale demonstration of the process was completed from September 2009 through January 2010 at the Mystic Water Pollution Control Facility (WPCF), which is owned by the Town of Stonington, Conn., to verify achievement of required process performance and to test the impacts of magnetite-impregnated mixed liquor on settling, resuspension, and other mechanical aspects of successful treatment. The primary goal of the demonstration was to evaluate the potential of the treatment process to adequately meet the facility's nitrogen removal performance goals in regards to effluent quality, mixed liquor inventory, and settleability. The ability of the system to meet this primary goal was achieved and previously documented (McConnell et al, 2010).

A second important goal of the process demonstration was to evaluate certain mechanical and process impacts on other treatment plant systems, e.g., aeration tank mixing, secondary clarifier capacity, and pipeline solids deposition/resuspension, such that a final installation could be designed to address these impacts. The ability of the system to meet this secondary goal was achieved and also previously documented (Moody et al, 2011).

Several full-scale facilities are nearing completion or are presently in the start-up phase of the treatment process. This article will summarize the results of the full-scale demonstration testing, preliminary results from the facility after start-up of the BioMag™ operation, and lessons learned during the start-up and early stages of full-scale, permanent operation.

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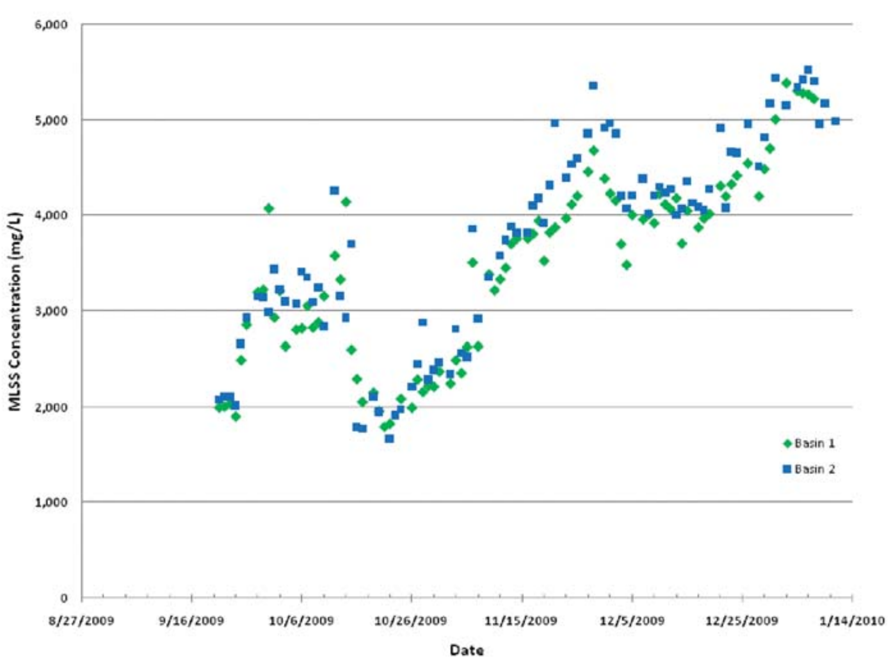

Figure 1. Mixed Liquor Suspended Solids Concentration Variation (not including magnetite; McConnell et al, 2010)

Background

The WPCF is rated at a permitted design capacity of 0.80 mil gal per day (mgd). A facilities plan in 2007 identified improvements needed to upgrade the aging facility, as well as to meet an annual effluent total nitrogen (TN) limit mass load equivalent to 5.2 mg/L. At the time, the WPCF was not configured for biological nutrient removal (BNR).

The treatment system was eventually selected due to its attractive life cycle cost. Other technologies that were evaluated included expanding the facility with conventional suspended growth technology, IFAS, and MBRs.

The process provides a magnetite ballast to bioreactors for dramatically enhanced settling of biological and chemical flocs. Magnetite is an iron oxide powder with a high specific gravity that adsorbs to solids to enhance secondary clarification. This allows for the secondary treatment process to operate at mixed liquor suspended solids (MLSS) concentrations much higher than conventional activated sludge systems due to the enhanced setting rate of the magnetite-impregnated mixed liquor. Magnetite is recycled from the clarifiers back to the suspended growth process in the return activated sludge (RAS). The waste activated sludge (WAS) is processed for magnetite recovery using an in-line shearing mechanism to separate the sludge from the magnetite, followed by a magnetic drum. Recovered magnetite from the WAS is returned to the bioreactors for reuse.

Summary of Full-Scale Pilot Demonstration

The goals of the full-scale testing were to evaluate the following:

- Operations and performance of the facility to meet target performance goals of less than 10 mg/L of biochemical oxygen demand (BOD_5), 10 mg/L of total suspended solids (TSS), less than 5 mg/L of TN, and less than 1 mg/L of ammonia nitrogen in the effluent.
- Impacts of the magnetite on facility equipment and piping, namely, effectiveness of basin mixing, impacts on the power draw to the chain-and-flight clarifier drives, and solids deposition in piping.

Both process trains were used for the testing due to the inability to isolate an aeration basin and a coupled clarifier to only run one train. In addition, mechanical mixers were installed in the aeration basins to keep MLSS in suspension when air was turned off to provide anoxic conditions at the facility.

Operation and Performance Goals

Figure 1 shows the increase in MLSS and solids loading rate to the secondary clarifiers during the pilot testing. The MLSS values (biomass only) increased from an initial value of 2,000 mg/L up to over 5,000 mg/L. A large amount of foaming was experienced in October of 2009. Plant operations staff were required to waste a large amount of solids from the system and interim foam removal measures were taken.

Figure 2 and Figure 3 show the solid loading rate to the secondary clarifiers and the sludge volume index (SVI) of the mixed liquor. The secondary clarifiers averaged 150 kg/m2-d (30 lb/d/ft2) during the snow melt periods with peak days reaching over 250 kg/m2-d (50 lb/d/ft2). The higher-than-normal solids loading rates can be attributed to the SVI values of below 100 mL/g observed during the test period (with the exception of the October 2009 foaming event).

The MLSS, with the magnetite engrained in the floc, caused the solids–liquid interface in the standard SVI test to be achieved rapidly at about the five-minute mark. Approximations for the Vesilind initial settling velocity (Vo) and hindered zone settling parameter (K) were 109 m/hr (359 ft/hr) and 0.4 L/g, respectively. The initial settling velocity results in much higher settling capacity than typical mixed liquor, about 10 times greater, resulting in additional clarifier capacity.

Figure 4 shows the ammonia-N, nitrate-N, and TN concentration for the test period.

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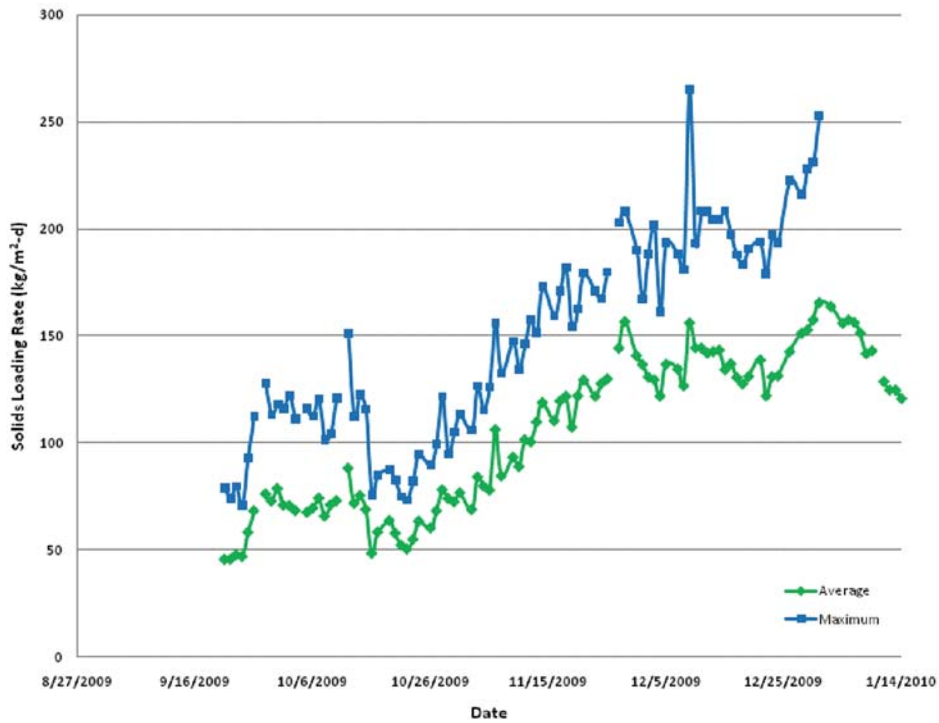

Figure 2. Secondary Clarifier Solids Loading Rate Variation (not including magnetite; from McConnell et al, 2010)

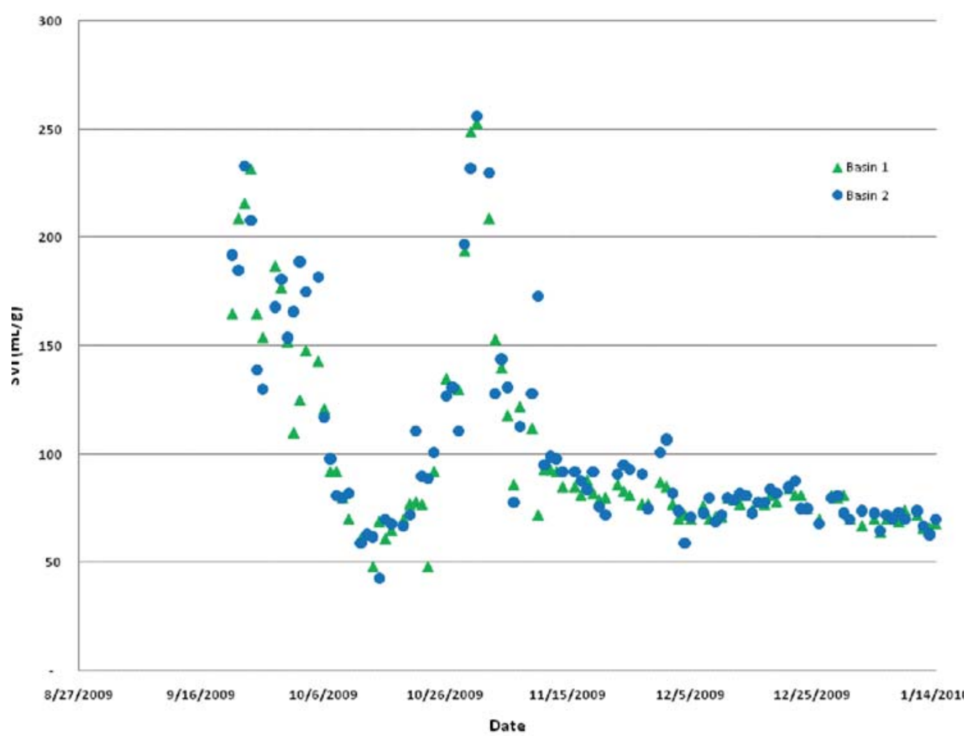

Figure 3. Sludge Volume Index Variation (not including magnetite; from McConnell et al, 2010)

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The process basins were operated in a three-hour intermittent aeration cycle, with two hours being aerobic and the third hour being anoxic. The ammonia-N concentration averaged 0.86 mg/L during the test period, while the nitrate-N concentration averaged 1.35 mg/L.

Impacts on Equipment and Piping

As mentioned previously, the full-scale testing included use of floating mixers, which were operated during the anoxic cycles. Two 5-horsepower (hp) mixers were installed in each aeration basin. The mixers were installed on the upstream and downstream ends of the basin. The TSS measurements were taken during anoxic cycles to assess the variability of the MLSS in the tanks during the anoxic cycles.

Measurements were taken with both mixers in operation, and with only the upstream mixer in operation. The MLSS concentrations for the two-mixer operation, with a power input of 0.69 hp/1,000 cu ft of volume, varied within 5 percent from top to bottom of the tank, which was deemed to provide adequate mixing. One mixer operation, with a power input of .34 hp/1,000 cu ft, showed stratification at the downstream end of the basin, with concentrations 100 percent different between the upper and lower portions of the tank (6,000 mg/L at the top to 13,000 mg/L at the bottom).

Measurements were taken at the clarifiers to determine if the higher concentration of solids in the secondary clarifier affected the amp draw on the motors operating the chain-and-flight clarifiers. It was determined that there was negligible impact due to the magnetite use in the secondary clarifiers.

Testing was also done to access settling concerns in magnetite-ballasted mixed liquor in process piping. Clear polyvinyl chloride (PVC) piping was connected to a submersible pump. The RAS, at concentrations of 0.9 to 1.1 percent solids (without magnetite), were pumped into the clear PVC piping. The submersible pump was shut off and the solids were allowed to settle in the pipe. After settlement, clear water was pumped through the pipe to determine the resuspension velocity needed. Testing indicated that resuspension occurred at velocities of one ft per second at a MLSS-to-magnetite ratio of 1 to 1. Tests were run at velocities below this value and did not show resuspension of solids in the pipeline.

Based on the results of the successful process demonstration, the WPCF was recently upgraded to a full-scale, permanent treatment system installation, configured in a four-stage BNR configuration. Initial start-up of the plant occurred in late fall 2014.

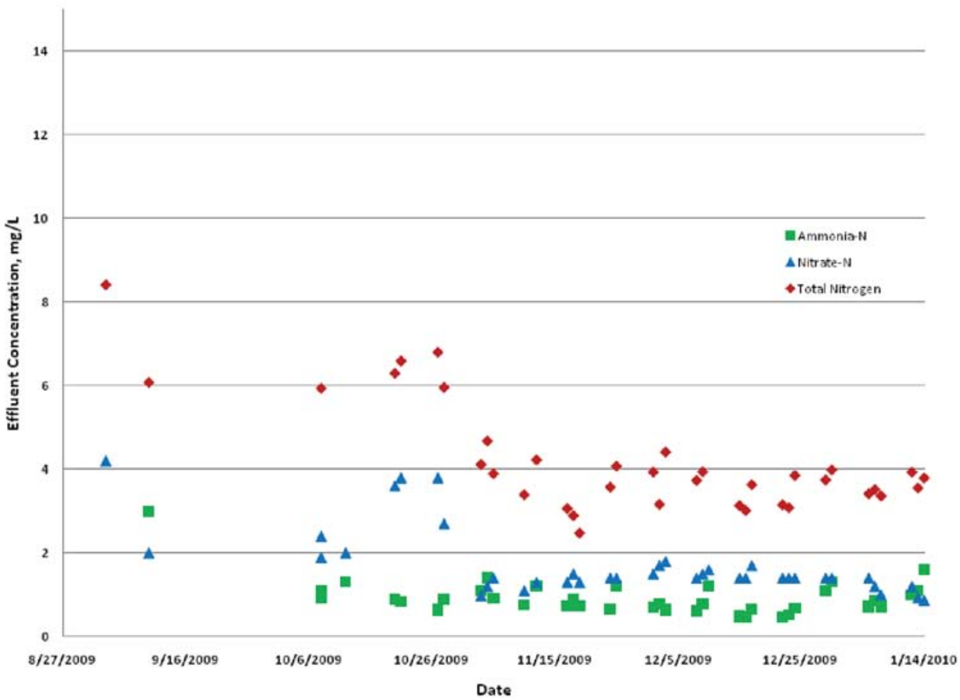

Figure 4. Effluent Nitrogen Values (McConnell et al, 2010)

Table 1: Operational and Effluent Performance Parameters Pretreatment and Post-Treatment System Start-Up

Parameter	Unit	Pre-BioMag	Post-BioMag
Flow	mgd	0.27	0.43
MLSS	mg/L	1136	4526
SVI	mL/g	275	104
Effluent TSS	mg/L	13	8
Effluent Turbidity	NTU	7	2
Effluent Ammonia	mg/L	8.9	0.5
Effluent Nitrate	mg/L	4.5	1.2
UV Dose	mW-s/cm2	50	149
UV Transmittance	%	49	76

Preliminary Results After Start-Up of Treatment System Process

An analysis of the WPCF's operational control parameters and effluent performance was done looking at data from December 2013 through February 2014 (pretreatment system start-up) and compared to data from 2015 (post-treatment system start-up). Table 1 summarizes the findings. Note that the pretreatment system data encompass a period when construction was occurring on-site, and indicates a stressed process condition.

Prior to the facility upgrades, flow was diverted from the WPCF to a neighboring facility. The increase in flow after start-up was a result of ending the flow diversion. The MLSS concentration increased roughly 400 percent after implementation of the treatment process, which allowed for more biomass inventory and increased removals of ammonia and nitrate in the effluent. The increased flow and solids loading to the secondary clarifiers did not cause a deterioration in effluent TSS and turbidity due to the low SVI (even though the full-scale pilot had SVIs even lower). Ultraviolet (UV) transmittance increased due to the lower turbidity in the effluent; however, the UV dose increased due to intermittent difficulty in achieving the plant's disinfection limits for *Enterococci*.

The magnetite recovery system appears to be working well. The system is recovering roughly 95 percent of the magnetite in the system. Full-scale pilot testing indicated a recovery rate of 97 to 98 percent, which compares favorably to the results after the process was started.

Lessons Learned During Start-Up

The following items are lessons learned during the recent start-up process that were not anticipated:

- Foaming has been an ongoing issue during start-up. The facility is equipped with the ability to surface waste and for mechanical foam removal, and operation of these systems are required to avoid significantly excessive foam. Foam was microscopically analyzed and determined to not have an excessive count of *Nocardia* filaments.
- The WAS (the biomass portion) capture percentage at the rotary drum thickener is much lower than anticipated. A 65 to 75 percent solids capture rate has been experienced, causing a thinner sludge-to-solids handling than anticipated, resulting in increased operational time for the thickener. It is suspected that the increased solids recycle back to the suspended growth process may be a factor in seeding the process with the foam-causing bacteria, instead of wasting them out of the plant.
- As noted previously, the UV dose has increased significantly since the treatment process was started up to address intermittent problems with providing satisfactory disinfection; testing is presently underway to determine the cause(s) of this unexpected issue. One theory is that large floc particles caused by polymer addition (needed for the treatment process) may be shielding *Enterococci* from the UV light, and the dose is being increased to meet permit limits.
- Magnetite loss appears to be more than just through the magnetic drum recovery and is dependent on the loss in the scum skimmings and in the effluent stream.

All of these items are currently being studied further.

Conclusions

Full-scale pilot testing and initial operation after installation of the treatment system at the WPCF has shown increased removal efficiencies for total suspended solids and effluent total nitrogen. The ballasted mixed liquor has decreased SVI values, allowing the clarifiers to effectively double the mixed liquor concentration. Some unexpected items have occurred during start-up that are still being investigated and should be topics for future papers and presentations.

References

- McConnell, W.; Moody, M.; and Woodard, S. *Full-Scale BioMag Demonstration at the Mystic WPCF and Establishing the Basis-of-Design for a Permanent Installation.* WEFTEC10 Conference Proceedings.
- Moody. M.; Bishop, A.; and McConnell, W. *Beyond Desktop Evaluation: Key Design Criteria for Mixing and Settling of Magnetite-Impregnated Mixed Liquor.* WEFTEC11 Conference Proceedings.