Feature Article

A Submerged Attached Growth Bioreactor and Membrane Filtration for Water Reuse

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In recent years land developers have realized that a limited number of ideal sites for residential or commercial development remain around major metropolitan areas in the United States. This has forced many developers to look at sites that previously would not have been considered. In many cases these sites are undesirable because of topography, wetlands, contamination, proximity to areas of critical environmental concern, or the lack of available public water and wastewater infrastructure. The Jefferson in Bellingham, Massachusetts, is a project in which all of these issues were addressed. Ultimately, the project was made feasible by combining two separate proven technologies.

This paper discusses the operation and performance of a submerged attached growth bioreactor (SAGB) with hollow fiber membrane microfiltration (MF) to meet the reuse requirements for a small decentralized wastewater treatment plant designed for 54,000 gallons per day of wastewater generated at a 300-unit luxury apartment complex. The use of an SAGB for biological nitrogen removal (BNR) provides a system with a small footprint due to the ability of the system to operate with high concentrations of biomass. This particular SAGB is constructed in concrete tanks below grade, thereby reducing the area of the building required for the ancillary equipment. The SAGB produces high-quality feed water to the MF unit.

The coupling of a submerged attached growth bioreactor with microfiltration (SAGB/MF) is a technology that has applications where space is limited and stringent effluent limits exist. During the first year and a half of operation, the average effluent total nitrogen concentration was 3.57 mg/l and median fecal coliform was zero.

The Massachusetts Department of Environmental Protection (DEP) has established wellhead protection districts based on the area of influence created by a 180-day pumping of a well under drought conditions. These areas of influence are referred to as Zone II areas, and many restrictions are placed on projects within them, including strict limitations on wastewater treatment plant effluent. To protect groundwater supplies, the DEP has classified groundwater discharges within Zone II areas as a form of water reuse and therefore established stringent effluent requirements for them. The single greatest obstacle to the development of the 17-acre parcel of land in Bellingham was the proximity of the site to the public drinking water supply well. Since the proposed discharge was within the limits of a Zone II, it had to comply with the DEP's Water Reuse Guidelines. The guidelines establish three categories of reuse water: 1) urban reuse, 2) indirect aquifer recharge, and 3) toilet flushing.

Table 1 summarizes the most stringent Groundwater Discharge Permit limits, which were considered for this project but ultimately relaxed. Two limits posed the most difficulty: the zero median fecal count (not to exceed 14 colonies/100 ml) and the turbidity of less than 2 NTU. In addition to the limits indicated in Table 1, a phosphorus limit of 1 mg/l was imposed if any of the down gradient groundwater monitoring wells indicated a total phosphorus concentration >1.0 mg/l for two consecutive months.

Effluent Characteristic	Discharge Limitations
BOD5	= 10 mg/l
Total Suspended Solids	= 5 mg/l
Total Nitrogen	= 10 mg/l
Median Fecal Coliform	0 col/100 ml
Turbidity	= 2 NTU

Table 1. Most Stringent Groundwater Discharge Limits for Reuse
(Massachusetts Department of Environmental Protection)

An SAGB was selected to achieve the biological treatment of the wastewater. During the last 20 years, different configurations of SAGBs have been applied for biological nutrient removal (Andersen et al. 1995, Holbrook et al. 1998, Rogalla and Bourbigot, 1990, Pujol et al., 1991 and Yoshinobu et al., 1997). The two primary advantages of an SAGB are the small volume requirement and the elimination of the need for downstream clarification. A submerged biofilter allows for a high biomass concentration, leading to a short hydraulic retention time and thus a significantly reduced reactor volume compared to other types of fixed film reactors or suspended growth reactors (Grady et al., 1999). The media in this SAGB are fine enough to provide physical filtration for solids separation to below secondary effluent requirements.

This SAGB process was specifically designed for the simultaneous removal of soluble organic matter (SOM), nitrogen, and suspended solids in a single reactor. The system operates as a sequencing batch reactor (SBR) in which a batch of wastewater is cycled back and forth through the filter. To achieve oxidation of SOM, nitrification, and denitrification, the reactor is intermittently aerated to create both aerobic and anoxic environments.

A typical system includes one anoxic/equalization tank, one SAGB and one clear well as shown in Figure 1. The raw wastewater enters the system through the anoxic/equalization tank, which has equalization and settling zones, and a sludge storage zone, and serves as the primary clarifier.

Flow through the SAGB alternates between forward flow and reverse flow. Aeration of the reactor is intermittent and independent of the return flow cycles. During a return, water from the clear well is pumped back through the filter following the exact same path through the SAGB as it did in the forward flow cycle. However, a check valve in the influent line of the reactor prevents the flow from returning to the anoxic/equalization tank via the same route. Instead, the flow fills the SAGB until it overflows into the return flow/backwash trough, which is set at a fixed height above the media. From the trough, the flow is by gravity back to the front of the anoxic/equalization tank.

The recycled flow mixes with the incoming raw influent and starts to flow forward when the pump shuts off. The cyclical forward and reverse flow of the waste stream affects the required hydraulic retention time, and the intermittent aeration of the filter creates the necessary aerobic and anoxic conditions to achieve the required level of biological nitrogen removal. After operating in a batch mode within the SAGB, the flow is pumped from the clear well to a pump station that feeds the denitrification filter continuously as shown in Figure 2.

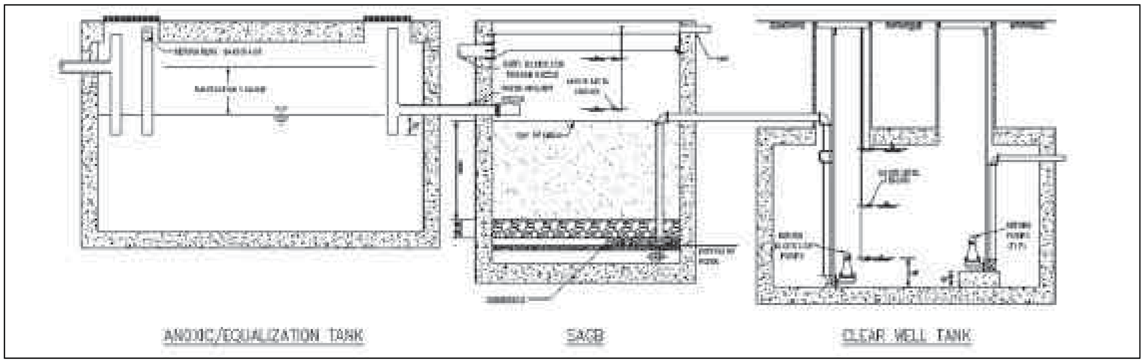

Figure 1. SAGB System

The bioreactor consists of an underdrain, support gravel, filter media and a backwash trough. The underdrain, located at the bottom of the reactor, supports the media and even distribution of air and water. It includes a manifold and laterals to distribute the air evenly over the entire filter bottom. The design allows for both the air and water to be delivered simultaneously - or separately - via individual pathways to the bottom of the reactor. On top of the underdrain is 18 inches (five layers) of four different sizes of gravel. Above the gravel is a deep bed of coarse, round silica sand media. The media functions as a filter, reducing suspended solids and provides the surface area on which an attached growth biomass can be maintained. The media-specific surface area of 820 m2/m3 results in a high concentration of biomass within the reactor and therefore allows for a short hydraulic retention time (HRT).

The system includes a separate denitrification filter (also an SAGB) to lower the nitrate levels below 5 mg/l and to chemically precipitate phosphorus. Following the BNR process is a hollow fiber membrane microfiltration system. The membranes are made of the fluorocarbon polyvinylidenefluoride (PVDF) with a nominal pore size of 0.1 micron, providing a physical barrier to protozoa such as Cryptosporidium and Giardia, as well as the Coliform group of bacteria. The fecal coliform limit of 0 counts/100ml as a median value is the primary reason for coupling the microfiltration unit with the biological process.

The microfiltration unit is a compact, skid-mounted, packaged system that comes pre-fabricated with all the plumbing, automation, and controls required to operate the system in automatic, semi-automatic, and manual modes. The control system is designed

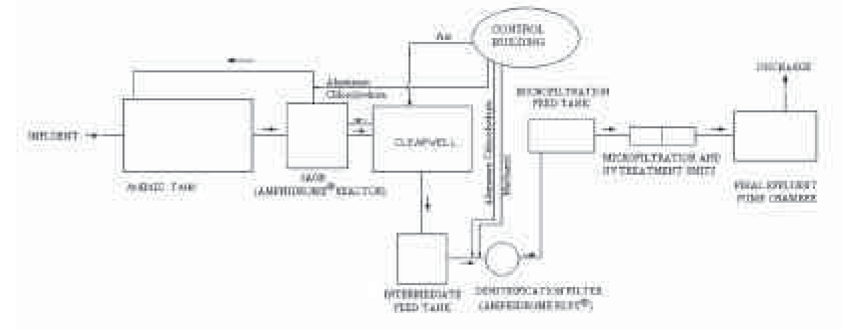

Figure 2. Process Flow Schematic (System operates as an SBR until intermediate feed tank.)

with networking capability so that the system can be integrated to work seamlessly with upstream and downstream equipment. From the microfiltration unit, flow is by gravity into a UV disinfection unit; however, the rate is controlled by the permeate pump on the microfiltration unit. Although the fecal coliform counts from the microfiltration unit were low (<5 counts/100 ml) the UV unit serves as a second barrier to ensure the low effluent requirement is met. After disinfection, the flow enters the effluent pump chamber and is discharged to a soil absorption system (SAS).

Performance and Operation

Results from the first 18 months of operation are presented in Figures 3 to 6. During this time, the sampling requirements were once a month for composite influent and effluent and once a week for nitrogen species in the effluent. Influent TKN values were not required; therefore, very little data are available to assess the nitrogen loading into the plant. The design flow was 54,000 gpd; however, the average flow during the time period examined was 16,440 gpd as shown in Figure 3. This is 30.4% of the design flow and represents approximately 72% of the total occupancy. The plot also indicates the gradual increase in flow as the occupancy of the development increased.

The BOD5 limit of 10 mg/l, originally required, was changed to 30 mg/l when the permit was issued. The average BOD5 was 7.2 mg/l, as shown in Figure 4 along with the effluent limit and median value. When effluent BOD5 was above the detection limit of 2 mg/l, the cause was likely due to excess methanol in the effluent. In Figure 5, the effluent BOD5 and nitrate values are plotted together. The lower nitrate concentrations correspond to higher BOD5 values, supporting the assumption that the cause of high BOD5 was excess methanol.

The effluent total nitrogen limit was 10 mg/l, and the average total nitrogen was 3.6 mg/l. The effluent total nitrogen concentrations are shown in Figure 6, except for three samples collected during the period when the denitrification filter was plugged.

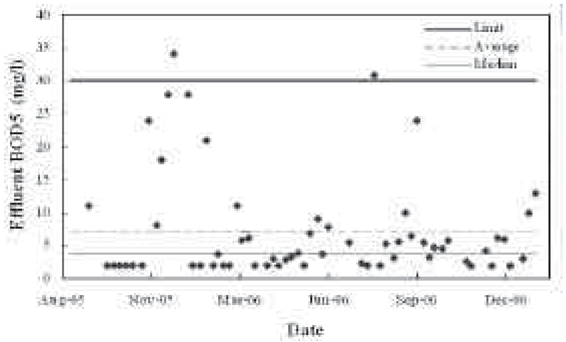

Figure 4. Effluent BOD5

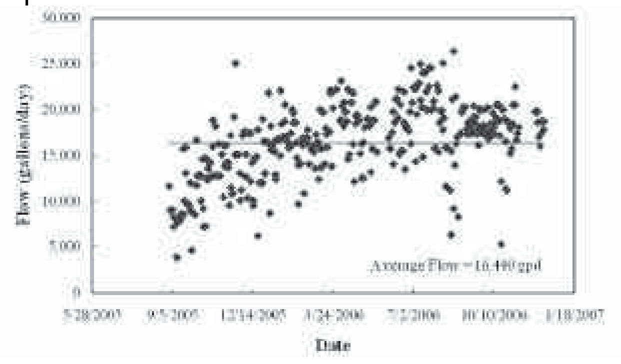

Figure 3. Influent Flow into Treatment Plant

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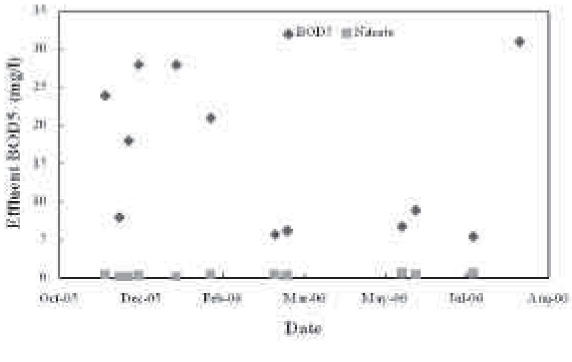

Figure 5. Effluent BOD5 and Nitrate (low nitrate values correspond to high BOD5)

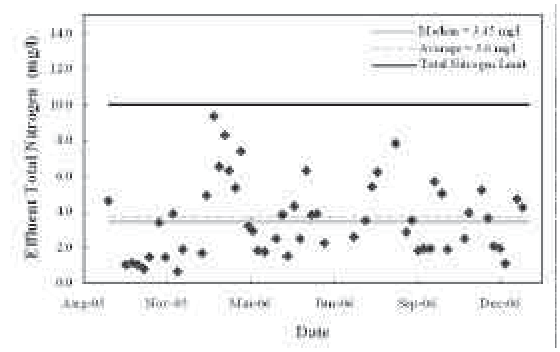

Figure 6. Effluent Total Nitrogen

Providing the biological treatment within an SAGB allows for intermittent aeration without concern for membrane fouling, one of the primary advantages of this technology. The duration of both the aeration on and off periods is a function of the biochemical requirements and is adjusted to achieve the minimum aeration period while still achieving fractional ammonia levels, therefore, reducing the energy costs. In Figure 7, the average monthly power cost per 1,000 gallons treated is shown. The average daily energy requirement was 207 kilowatt-hours/day and is shown in Figure 8. These meter readings include all the power requirements of the plant, including the building heat. The average annual cost based on 11 cents per kilowatt hour is $8,325 per year.

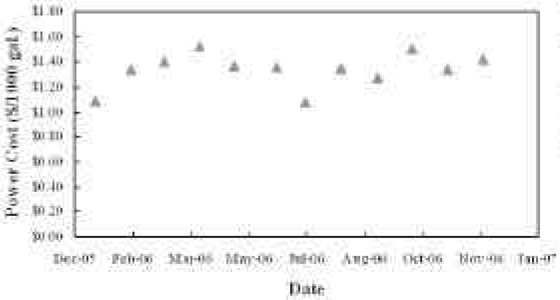

Figure 7. Average Monthly Power Cost per 1,000 Gallons Treated

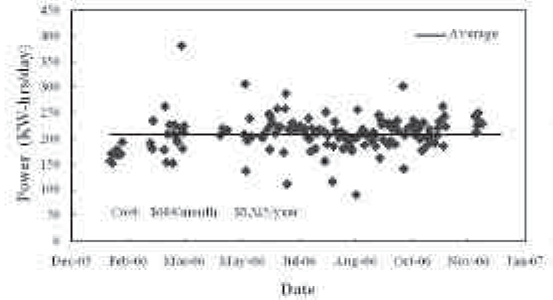

Figure 8. Average Daily Power Consumption

The intermittently aerated SAGB operates as a sequencing batch reactor by cycling back and forth through the reactor. During the cycles, the environment fluctuates between aerobic and anoxic, before finally discharging from the clear well to the intermediate pump station. At this stage the total nitrogen concentration is less than 10 mg/l. The process is then changed from batch to continuous flow and is pumped to the denitrification filter (also an SAGB), which provides enhanced biological denitrification (see Figure 2). For denitrification the electron donor (i.e. carbon source) was methanol and was injected upstream of an inline static mixer in the force main before the filter. The average daily dose of methanol was 2.35 gpd which, at approximately $4.00 per gallon (freight included), results in an annual cost of $3,425.

In addition to enhanced denitrification, the reactor functions as a physical filter for the aluminum phosphate compounds (Sedlak, 1991) generated from chemically precipitated phosphorus. The plant has a conditional phosphorus limit of 1.0 mg/l that is achieved by the addition of aluminum chlorohydrate at multiple injection points. Chemical addition occurs into each of recycle/backwash streams of the two main SAGBs and upstream of the inline static mixer before the denitrification filter. The choice of aluminum chlorohydrate was based on jar tests conducted on the waste stream in the first month of operation. However, the limit was not imposed until July 2006. The initial results indicate that the phosphorus limit of 1 mg/l will be achieved at an aluminum to phosphorus molar ratio (Al/P) in the range of 2.0 to 2.5 as suggested in the USEPA Design Manual for Phosphorus Removal (1987). The average daily chemical dosing rate is 2.37 gpd at an annual cost of $8,220.

In addition to the removal of nutrients, the weekly tests for fecal coliform and the quarterly tests for viruses (MS2-Phage and total viruses), in the effluent, were all non-detect. Although fecal coliform counts, after the microfiltration unit, have been between non-detect and 5 colonies/100ml, ultraviolet (UV) disinfection was required to meet the original fecal coliform limit of 0 colonies /100 ml (median value), not to exceed 14 colonies /100 ml. This requirement was relaxed in the final discharge permit. Although the UV unit was sized based on an ultraviolet transmittance (UVT) of 60%, measurement of the UVT downstream of the microfiltration process has been recorded at 80% to 85%. The original permit also required monitoring of viruses, but placed no limits on them. During this year and a half of operation, all virus tests were negative, and therefore, this monitoring requirement was eliminated by the DEP in January 2007.

Conclusions

After the first 18 months of operation the coupling of a submerged attached growth bioreactor with membrane microfiltration has demonstrated its effectiveness for treatment to reuse standards. Biological removal of nitrogen to the average total nitrogen of 3.6 mg/l is near the limit of technology. The fecal coliform limits have been met and the sampling has been relaxed. All virus testing results were non-detect. In addition the plant has met the turbidity requirements. This technology cost $390,650 for the equipment (excluding concrete tanks) and $1.35 million overall. It met the requirements for wastewater reuse while being installed in a small area where space was limited.

SAGBs require less area then many other types of biological treatment processes because of the high concentration of viable biomass and because there is no need for downstream clarification. The consequence of intermittent aeration of the biofilter is that low dissolved oxygen (DO), just high enough to achieve nitrification, can be maintained in the SAGB. This facilitates denitrification and reduces the cost of any supplemental carbon source that may be required. This is supported by the low dosage of methanol (2.37 gpd) required to achieve fractional levels of nitrate in the effluent.

The ability to bury the tanks provides both aesthetic and financial value to the system. Underground installation of the tanks significantly reduces the size of the building. Therefore, it has to house only the blowers, microfiltration system, UV system, odor control, chemical feed systems and controls. Consequently, the only visible portion of the WWTP is a 20- by 30-foot building designed in the same style as the rest of the project and therefore may go unnoticed. The SAGB/MF system provides an economical option for wastewater treatment plants subject to stringent effluent limits and is a viable alternative, particularly when space is limited. ■

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