Welcoming Activated Granular Sludge to the United States

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Granular sludge has been observed for a couple of decades in wastewater treatment. Originally, upflow granular sludge blanket reactors developed granulation based on the feeding patterns and characteristics of these reactors. More recently, researchers at Delft University in the Netherlands have achieved granulation of activated sludge in a sustained fashion and developed the concepts for making use of the excellent advantages that the granules provide, which include:

- Exceptionally low sludge volumetric indices (SVIs), which allow more-efficient solids separation through settling using significantly less area for clarification compared with traditional activated sludge (flocculant) clarifiers.
- Activated granular sludge (AGS) is a biofilm system that behaves like activated sludge; therefore, the biofilm can be engineered to provide the conditions desired to target specific removal of contaminants, allowing the removal of carbon, nitrogen, and phosphorus in a single reactor.
- The AGS is typically configured in a way to eliminate internal process recycles (mixed liquor recycle [MLR], return activated sludge [RAS], and anaerobic recycle), which minimizes the energy requirements compared with traditional activated sludge systems. Supplemental carbon addition in denitrification systems can also be minimized by maximizing denitrification when influent carbon is still available.
- Higher concentrations of biomass can be used in the reactor, which further minimizes reactor volume and saves on capital.
- Simplicity of operation.

Tomahawk Creek Wastewater Treatment Plant Activated Granular Sludge Pilot

A bench-scale pilot study was conducted to evaluate the feasibility of an AGS process as an alternative technology for the upgrade of the Tomahawk Creek Wastewater Treatment Plant (WWTP).

The objectives of this study were to design (from the beginning) and operate a bench-scale pilot for the purposes of:

- Determining if granulated sludge could be formed and maintained with low-strength wastewater (as compared to existing AGS systems treating higher-strength wastes).
- Ensuring that the AGS process is a feasible and robust treatment alternative for the Tomahawk Creek WWTP upgrade.
- Developing overall confidence in this relatively new technology in order to decide whether or not to take the next step in evaluation, which is a demonstration unit that is much larger than bench scale.

The objectives were pursued by developing an understanding of the phenomenon of granulation and the AGS process through bench-scale operation and experimentation. If sufficient confidence in the technology and its benefits are established, then a larger Nereda® demonstration-scale trial will be conducted on site by Royal HaskoningDHV. The demonstration-scale pilot will be started with mature granules and will be large enough to assess the customized design criteria to reach the levels of performance required by the Tomahawk Creek WWTP. It would also provide physical confirmation of equipment selection and process control criteria for transition to a full-scale system.

The set of three pilot reactors that were built for the testing consisted of a Plexiglas cylinder column supported on a polyvinyl chloride platform and an aluminum frame on casters. Each reactor column was made of interchangeable and stackable units to achieve various settling distances. For this study, there were three reactors in parallel (labeled red, white, and blue), with two units stacked on top of each other. Each unit has a 480-millimeter (mm) height and a 65-mm inner diameter. The units were constructed with a double-wall water jacket for temperature control; the temperature was held constant at 20°C. Aeration was done with compressed air. During aeration phases, compressed air was fed through a fine bubble diffuser. Mixing (without aeration) was performed by bubbling nitrogen AGS through the same fine bubble diffuser. The AGS flow was measured and adjusted manually to approximately 1 to 3 liters per minute (L/min) using a 0.4- to 5-L/min Cole Parmer rotameter. The sequencing batch reactor (SBR), approximately 3 L in. in volume, was operated with a 4- to 8-hour HRT and a 50 percent volumetric exchange ratio. A schematic of the bench-scale reactors is shown in Figure 1 and a photo of the pilot system is shown in Figure 2.

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The reactors were operated in a SBR mode, meaning that the reactor was batch-fed and treated in sequential phases, which, when completed, were repeated. Each repeat of the sequential phases is a cycle; Figure 3 shows an example of the sequential phases comprising one cycle. An example of the SBR operating-cycle phases and timing consisted of:

- Anaerobic feed – 30 minutes
- Pre-anoxic mix – 10 minutes
- Aeration – 186 minutes
- Settling – 4 minutes
- Decant – 10 minutes

The total cycle time is 240 minutes, or 4 hours. The cycling was controlled through a four-circuit control programmable timer unit and cycle phases were identical for all three reactors. The only difference among the three reactors was the influent feed during the process performance evaluation component of the study. The influent containers were mechanically mixed during both start-up and evaluation. Throughout the entire study, the only wasting of biomass occurred via washed-out effluent total suspended solids (TSS).

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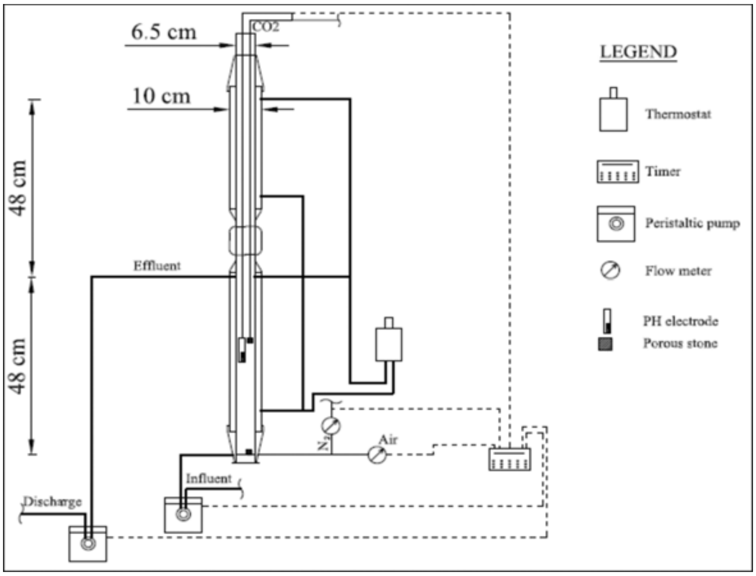

Figure 1. Schematic of the Bench-Scale Activated Granular Sludge Pilot Reactor *(courtesy of Black & Veatch)*

Figure 2. Bench-Scale Pilot *(courtesy of Black & Veatch)*

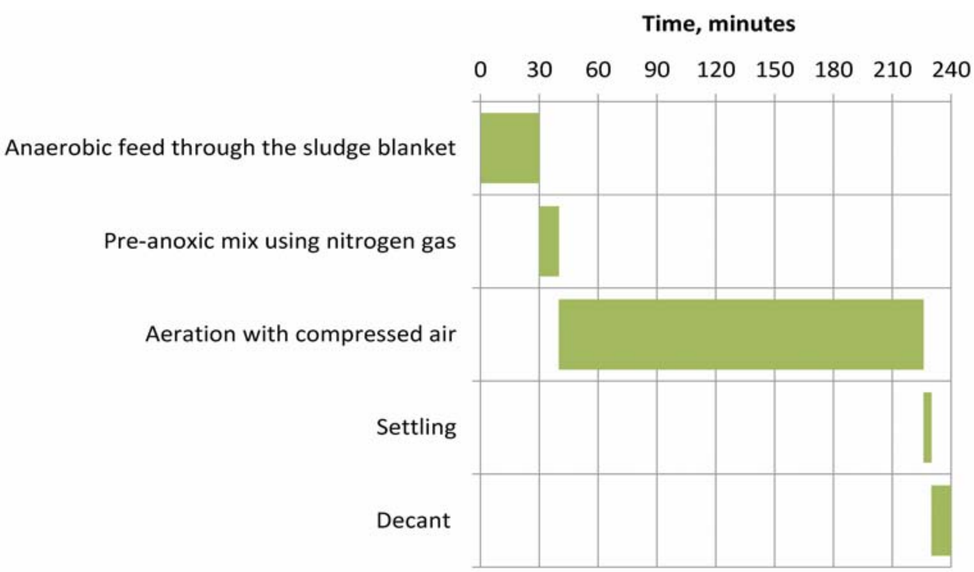

Figure 3. Example of Sequencing Batch Reactor Operating Cycle Phases and Timing

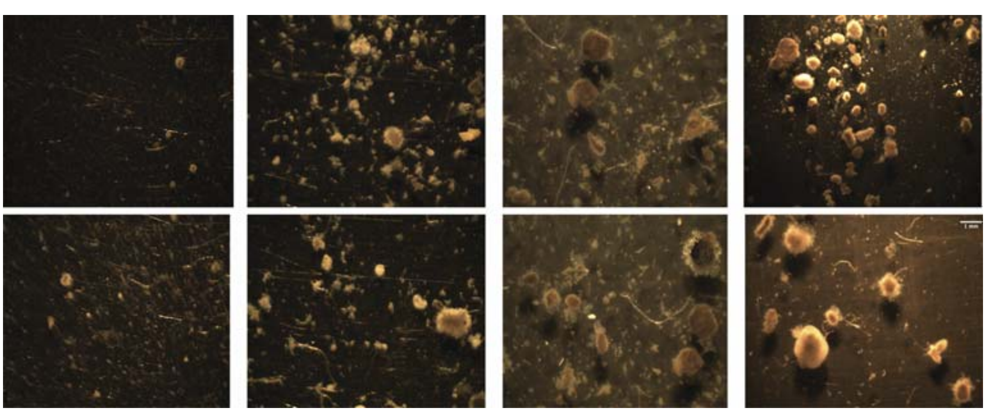

Figure 4. Progression of Granule Enrichment *(courtesy of Black & Veatch)*

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The influent to the AGS reactors was raw wastewater collected before primary clarification. The low-strength influent wastewater at Tomahawk Creek was supplemented with fermented primary sludge supernatant (fermentate). Fermentation of primary sludge converts particulate biochemical oxygen demand (BOD) into soluble and readily biodegradable forms. The primary sludge was collected from the primary clarifier underdrain and fermented for three to four days. The supernatant was then added to the raw influent wastewater to increase its strength (by 10 to 20 percent by volume) and the sludge solids were discarded.

The primary sludge fermentation process was initially operated automatically as a timer-controlled process and temperature-controlled at 30°C. Complications with the automatic operation, such as clogged pumps and poor mixing, created methanogenesis and consumption of rapidly biodegradable chemical oxygen demand (rbCOD). As an alternative to automatic operation, the primary sludge was collected and fermented in the collection bucket, which was mixed once per day to represent the more-likely full-scale scenario. The automatic operation was conducted from October through December 2014, after which the passive bucket fermentation method was used. Both automatic and bucket fermentation methods produced approximately 5 to 10 L/day of fermentate.

Pilot samples were delivered to the Johnson County Wastewater Laboratory one to three times per week for analysis. Influent and effluent samples of the fermenter were analyzed for soluble COD, TSS/volatile suspended solids (VSS), and volatile fatty acids (VFAs). Influent and effluent samples of the reactors were analyzed for TSS/VSS, total and soluble COD and BOD, ammonia-N, nitrite + nitrate-N, orthophosphorus, and VFAs.

After start-up, the reactor was having difficulties achieving granulation due to the high initial settling velocity target of 15 mi/hour. After adjusting the settling velocity to 7.5 mi/hour, selective washout was achieved without hindering the biological coagulation and filtration. Two months after start-up, the reactors granulation was achieved (Figures 4 and 5).

Rock River Activated Granular Sludge Demonstration Plant

The Rock River demonstration facility has an average capacity of 0.2 mil gal per day (mgd) average annual daily flow (AADF). The plant is part of Aquaerobic's research and development efforts and will be used to validate (among other things) the AGS process in the United States. The plant consists of an AquaNereda® reactor (Figures 6 and 7) that takes primary effluent water and treats it in a single Aquanereda SBR reactor. The plant does include pretreatment, which consists of a grinder to remove solids that can impact the flow distribution in the Aquanereda reactor. The reactor itself includes influent flow distribution, aeration diffusers and associated blowers, effluent flow collection trough, sludge wasting mechanism, and sludge holding tanks. Granular sludge is onsite, which was imported from Europe to speed up the stabilization of the plant. Figure 8 shows a 3D perspective of the demonstration facility.

The reactor has been in operation since January 2018. Imported AGS from Europe was used to seed the reactor to speed up the granulation process. Currently, the reactor has achieved steady-state granulation and training is being performed at the facility.

Wolf Creek Water Reclamation Plant

The current Wolf Creek Water Reclamation Plant (WRP) has a permitted capacity of 2 mgd; however, to get an expanded plant capacity of 3.5 mgd, Riviera Utilities decided to replace the existing oxidation ditch process with an AGS system.

The plant was built in 1980 and expanded in 1997. The effluent permit requirements include (summer/winter):

- TSS = 30/30 mg/L
- Biochemical oxygen demand after five days (BOD_5) = 7/10 mg/L
- Ammonium (NH_4) = 2/4 mg/L
- Total Kjeldahl Nitrogen (TKN) = 4/6 mg/L

The current plant includes oxidation ditches, ultraviolet disinfection, screw press dewatering, and a sludge dryer with biosolids disposed at a landfill. City staff decided to upgrade the capacity to 3.5 mgd with the possibility of a 7-mgd final expansion. Other technologies were considered, including integrated fixed-film acti-

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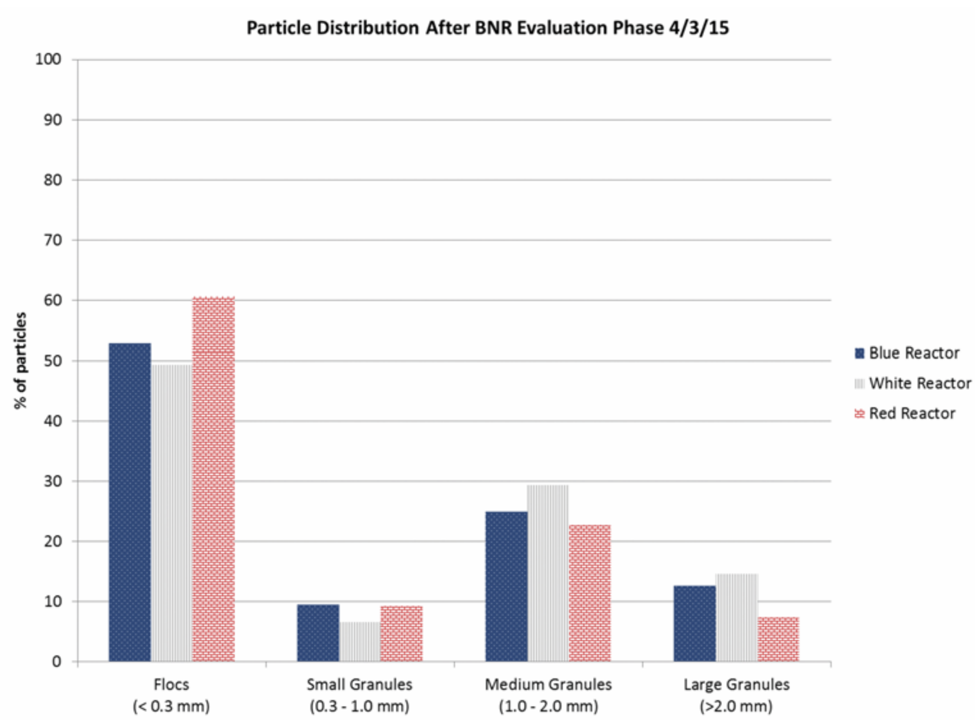

Figure 5. Granulation Development *(courtesy of Black & Veatch)*

Figure 6. Rock River Aquanereda Reactor *(courtesy of Aquaerobic)*

Figure 7. Rock River Aquanereda Reactor *(courtesy of Aquaerobic)*

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vated sludge (IFAS), MBR, and ballasted floc, but AGS was selected for its simplicity and proven performance, given that the new process could be built while the existing process was untouched (small footprint process), with full BNR capability, and its reduced energy use.

The project includes a new influent pump station, new headworks with rotary drum screens and grit removal system, a repurposing of existing tanks to equalization basins, AquaNereda AGS reactor, and tertiary filtration and disinfection. Existing clarifier tanks will be converted from their existing usage to aerobic sludge digesters. Additional AGS tanks are planned for the site of the two small ditches (removed from service by the current upgrade) when additional capacity is needed in the future.

The AGS reactor will be designed for 8000-mg/L mixed liquor suspended solids (MLSS). Hybrid blowers and fine bubble diffusers will be used for oxygen delivery. The AGS project was awarded in March 2018, construction is ongoing (Figure 9), and the AGS process start-up is planned for summer 2019.

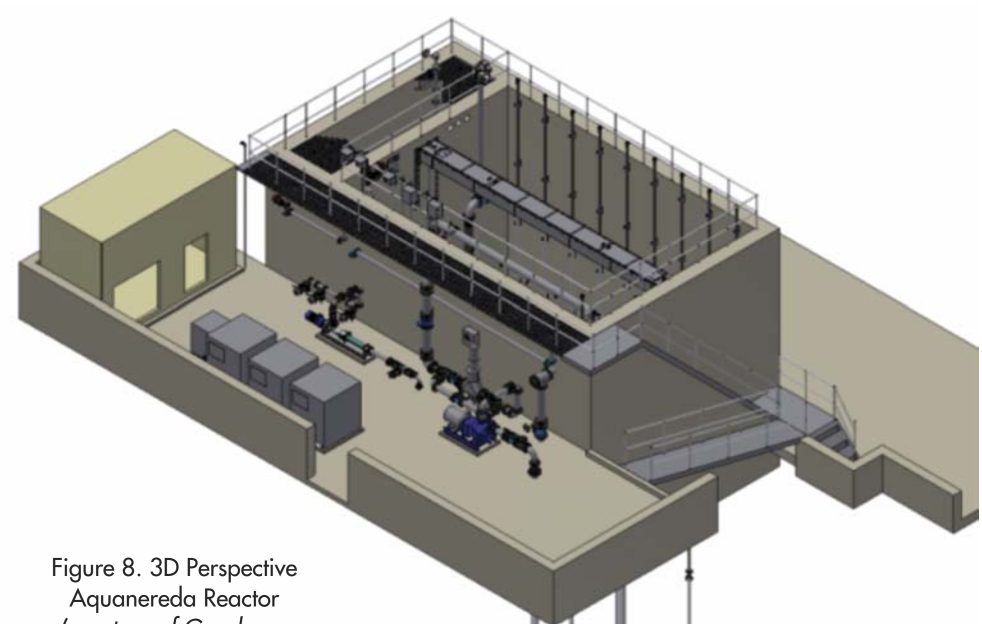

Figure 8. 3D Perspective Aquanereda Reactor *(courtesy of Goodwyn, Mills & Cawood)*

Conclusions

The AGS is a proven technology that is making its way into the U.S. market. Granulation has been observed in pilot and demonstration facilities, and by the time this article is published there will be multiple full-scale installations in design or under construction, with full-scale operation beginning in 2019. The AGS allows treatment process intensification because all biological reactions are achieved in a single reactor, minimizing tank volume and energy use (aeration and mixing). A possible obstacle of AGS implementation in the U.S. is the lack of suppliers, as the process control logic used for growing granules is patented, and there is only one supplier in the U.S. at the moment, limiting direct competition.

Acknowledgments

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Figure 9. Wolf Creek Wastewater Treatment Plant Construction, September 2018 *(courtesy of Goodwyn, Mills & Cawood)*