



## AquaNereda® Aerobic Granular Sludge Technology

### Aerobic Granular Sludge

The AquaNereda® Aerobic Granular Sludge (AGS) Technology is an innovative biological wastewater treatment technology that provides advanced treatment using the unique features of aerobic granular biomass. An aerobic granular biomass is comprised of compact granules that provide advantages compared to other secondary treatment processes.

This advanced nutrient removal process can reduce footprint up to 75% and energy up to 50% when compared to conventional activated sludge systems. One of the defining characteristics of the granule is rapid settling which in turn allows for an increase in the biomass concentration. The granules are comprised of true biomass and do not require carriers. The layered microbial community that forms the granule is able to achieve enhanced biological nutrient removal, including simultaneous nitrification/denitrification and phosphorous reduction.

### Background:

A public-private research partnership in the Netherlands between Delft University of Technology and Royal HaskoningDHV led to the development of the first technology applying aerobic granular sludge, full-scale. Currently, over 30 full-scale Nereda® plants are operational or under design and construction across five continents, of which the oldest are more than 10 years in operation. As of September 2016, Aqua-Aerobic Systems, Inc. became the exclusive licensee of the technology in the United States.

### Advantages:

The aerobic granular sludge process offers numerous advantages when compared to a conventional activated sludge process, including but not limited to:

#### Enhanced Settling Properties:

In an AGS process, the bacteria are present as large dense granules as opposed to suspended flocs. The granular density increases the settling rate up to 15 times faster than sludge from a conventional activated sludge system. Figure 1 below compares the settling properties of aerobic granules and conventional activated floc after five minutes.



Figure 1: Aerobic Granular Sludge (left) vs. Conventional Activated Sludge (right)

By overcoming settling limitations seen in conventional activated sludge systems, the mixed liquor can be increased significantly which allows for a greater treatment capacity. The sludge volume index decreases to values of 30-50 mL/g which allows the bioreactor to operate at MLSS concentrations of 8,000 mg/l or well above.

Up to 75% Reduced Footprint:

Footprint is reduced due to the full nutrient removal process taking place in a single reactor. Supplemental tanks such as primary clarifiers, selector basins, separate anoxic and aerobic compartments, and secondary clarifiers are not required. In addition, the biomass operates at a higher concentration thus allowing for an increased treatment capacity within a single tank.

Up to 50% Energy Savings:

Reduction of air requirements in the bioreactor tank allow for energy savings. The substrate and oxygen utilization rates in a granular system lower the specific energy and airflow. Based on the operation in a single reactor, the equipment required for the aerobic granular sludge process is significantly reduced when compared to conventional activated sludge systems. As such, recycle sludge pumps are not needed in an AquaNereda plant.

The combination of reduced aeration and mechanical components results in an energy savings of up to 50%.

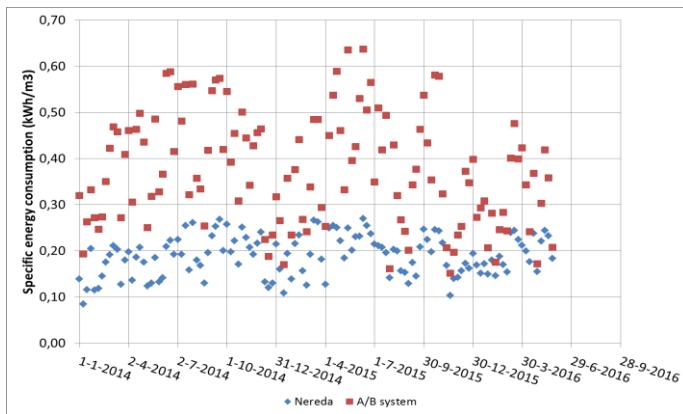


Figure 2: Full Scale Power Consumption Data from Garmerwolde WWTP (Nereda runs in parallel to CAS)

The compact bioreactor combined with the granular sludge metabolic rates allow for lower specific energy as seen in Figure 2. In addition, there is an automated control of the process that allows energy savings and process optimization.

Low Life Cycle Cost:

The reduction in mechanical equipment necessary to achieve enhanced BNR requirements lowers the construction, operating, and maintenance costs. In addition, chemical consumption is reduced due to the high bio-P uptake in the granular biomass. These savings in operation and maintenance, as well as the lower construction costs, result in attractive whole life cycle costs.

**Process:**

Aerobic Granule:

Aerobic granular sludge combines the technical advantages of biofilm systems, including compactness and high metabolic rates, with those of activated sludge, such as the ability to achieve full biological nutrient removal in one mixed biomass population, without the need for biofilm carriers. Aerobic, anoxic and anaerobic biological

processes take place simultaneously in the granular biomass. Figure 3 below displays the differences between activated sludge floc and aerobic granular sludge.

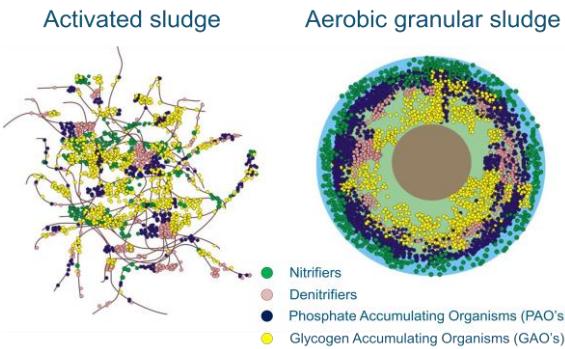


Figure 3: Activated Sludge vs. Aerobic Granular Sludge (courtesy Delft University of Technology)

In a conventional activated sludge system, bacteria are present in flocs which are suspended in bulk liquid. Liquid solid separation in a flocculant sludge system occurs by using sedimentation in clarifiers. Due to the fact that flocs have low density, the settling time is much greater than a denser granular biomass, which will achieve full settling in five minutes.

As a result, a conventional plant is designed at 2,500 mg/l – 5,000 mg/l of mixed liquor, compared to an aerobic granular sludge plant at 8,000 mg/l or higher. Aerobic granular sludge, as seen on the right in Figure 4, displays a greater concentration of specialized microorganisms that are layered. Different types of microorganisms will grow in the granule that can result in a typical particle size of 1.2-1.5 mm in diameter. Nitrifiers reside on the outer layer of the granule and denitrifying bacteria are present in the deeper layers.

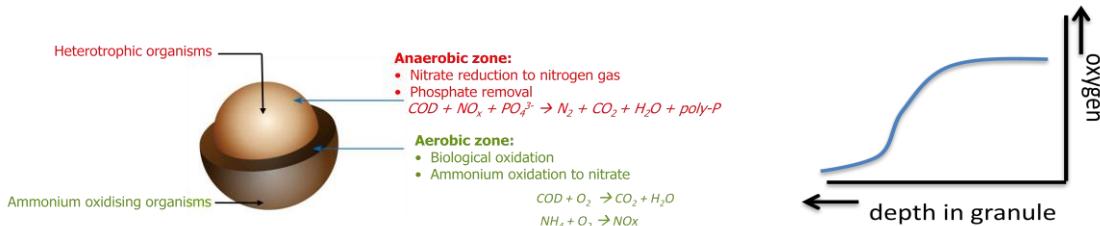


Figure 4: (left) Zones of the Granule / Figure 5: (right) Oxygen Penetration

During aeration oxygen can penetrate about 100-200 microns into the granule before the oxygen is depleted as seen in Figure 5. This results in the inner part of the granule near the core to be an anaerobic zone and the outside layers to be aerobic and anoxic zones as seen in Figure 4. Both the oxygen and substrate are transported into the granule via diffusion.

Phosphate accumulating organisms (PAO's) and glycogen accumulating organisms (GAO's) are present throughout the biomass and have the ability to form extracellular polymeric substance (EPS) that is the building block for granular formation.

#### Extra Cellular Polymeric Substance (EPS):

Due to its robust structure, the granule has the ability to withstand upset conditions. The extracellular polymeric substance serves as the backbone of the granule and enables the system to withstand fluctuations in chemical spikes, load, salinity, pH, toxic shocks, etc. This chemical backbone makes it difficult to interfere with the

enhanced settling and stable process characteristics. This process stability along with superb settling properties results in a reliable robust granular system that is easy to operate.

#### Granule Formation:

With AquaNereda Aerobic Granular Sludge Technology, selection mechanisms are applied to create dense granules from flocculant biomass, see Figure 6. As an alternate, a plant can be seeded with granules from another site.

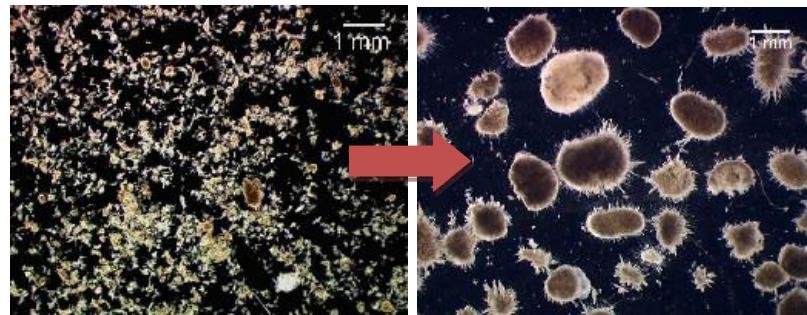


Figure 6: The Transformation of Conventional Activated Sludge to Aerobic Granular Sludge

The conventional biomass flocs are selectively wasted by increasing sedimentation stress. The stress continues to increase thus enlarging the size and density of the flocs which causes the flocs to settle faster and evolve into granules. Only the bacteria that can adapt due to the selection mechanisms are able to survive in a granule form.

#### **AquaNereda® Cycle Structure:**

Within a single reactor, the AGS technology creates proper conditions to reliably maintain a stable granule, without the need of a carrier. Due to the layered microbial community within the granule structure, simultaneous processes take place in the granular biomass, including enhanced biological phosphorus reduction, and simultaneous nitrification/denitrification.

Based on the unique characteristics of granular biomass, the AquaNereda Aerobic Granular Sludge Technology uses an optimized batch cycle structure, see Figure 7. There are three main cycles of the process to meet advanced wastewater treatment objectives. The duration of the phases will be based upon the specific waste characteristics, the flow and the effluent objectives:

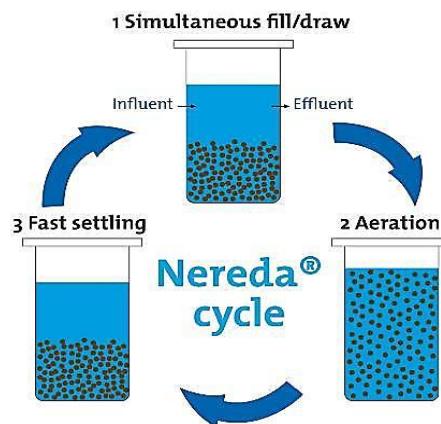


Figure 7: The AquaNereda® Cycle Structure

Fill/Draw:

The first phase of the cycle structure is Fill/Draw where the influent flow first enters the reactor. The anoxic and anaerobic conditions provide biomass conditioning and phosphorus release. At the same time, treated water is displaced towards the effluent.

React:

Influent flow is terminated in the second phase of the cycle structure known as the React (Aeration) phase. In this phase the biomass is subjected to aerobic and anoxic conditions. The granules perform simultaneous nitrification/denitrification. Concurrently, nitrate is transported by diffusion between outer aerated and inner anoxic layers of the granule, eliminating the need for pumping large recycle flows in the plant. Within the bioreactor, luxury uptake of phosphorus is promoted. The automated control of the process allows energy savings and process optimization.

Settling:

Upon completion of the aeration phase, the technology proceeds into a Settle phase. Here the influent flow still does not enter the reactor. The granular biomass is separated from the treated water during a very short settling period. Excess sludge is wasted in order to maintain the desired amount of biomass. Finally, the technology is ready for a new cycle and influent enters the reactor while the treated water is discharged.

Advanced Controls:

The process and cycle structures are optimized through the use of automated controls. When wastewater flows, loadings and temperatures fluctuate, the process parameters will be adjusted for efficient performance.

**Applications:**

Typical applications for an aerobic granular sludge system include: retrofit of existing tanks, increasing treatment capacity, upgrade of existing treatment systems to meet more stringent effluent requirement, or greenfield sites, and enhanced biological nutrient removal. See Figure 8 for some typical configurations in which these AquaNereda technologies have been and can be applied. There is not a limit on the number of Nereda reactors that can be used in each application.

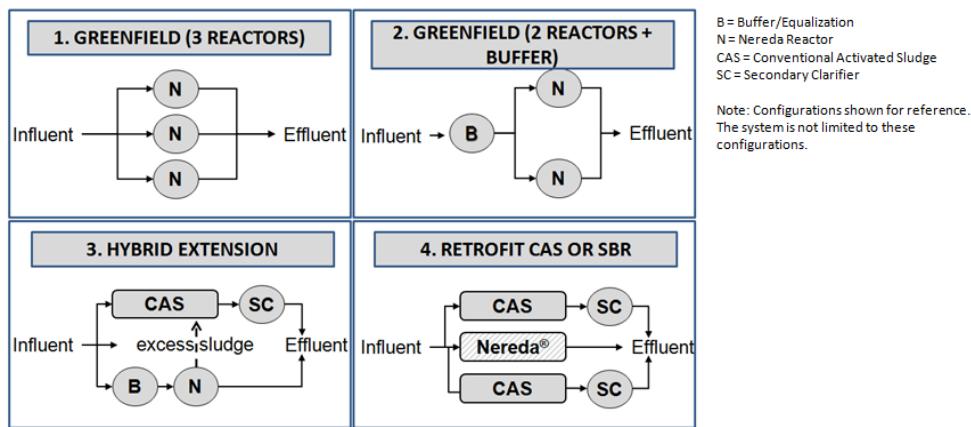


Figure 8: Typical Aerobic Granular Sludge Configurations

Greenfield:

Configuration 1: New construction of 3 Nereda reactors or more. In this case at least one of the Nereda reactors is being fed at any time throughout the cycle structure.

Configuration 2: New construction of Nereda reactors and a pre-equalization tank: This configuration is proven to be one of the most common and cost effective. This configuration is not limited to two reactors, and in some cases, depending on the magnitude of peak flows to the plant, a pre-equalization may prove beneficial in systems with more than 2 reactors.

Hybrid:

Configuration 3: In a hybrid extension configuration, the surplus granules from the AquaNereda technology can be utilized to inoculate an existing conventional activated sludge plant. This can result in increased plant capacity and robustness.

Retrofit:

Configuration 4: Retrofit an existing Conventional Activated Sludge, SBR or MBR system with the AquaNereda technology. This configuration makes use of the existing infrastructure while increasing the system capacity and reducing energy and chemical use.

### Full-Scale Installations Profiles:

Epe, Netherlands:

Epe is an example of Configuration 1. Greenfield (3 reactors), see Figure 9. This plant has an average design flow of 2.11 MGD and a peak hour flow of 9.5 MGD. The plant is performing very well and easily stays within the discharge requirements of total nitrogen below 8 mg/l and total phosphorus of less than 0.5 mg/l in the winter. The energy consumption is 40% lower than similar size CAS systems in the area.



Figure 9: Full Scale Installation Epe, NL

Garmerwolde, Netherlands:

Garmerwolde is an example of Greenfield (2 Reactors + Pre-Equalization Tank), see Figure 10. This plant has an average design flow of 7.9 MGD and peak hour flow of 26.5 MGD. The plant was designed to split the flow 60% to the existing CAS system and 40% to the Nereda system. At this point, the Nereda reactors are processing up to 60% of the overall plant capacity while meeting permit. The plant well exceeds the discharge requirements of total nitrogen below 7 mg/l and total phosphorus of less than 1 mg/l.



Figure 10: Full Scale Installation Gammerwolde, NL

Frielas, Portugal:

Frielas is an example of Configuration 4. Retrofit CAS, see Figure 11 below. The Frielas STP was designed for an average design flow of 18.5 MGD average flow. Only one of the six existing aeration reactors was retrofitted as a Nereda reactor, designed for 3.17 MGD and a peak hour flow of 11.76 MGD. The reactor comprises approximately 1.06 million gallons. Since the start-up of the Nereda reactor, the whole Frielas STP is now in compliance; the other reactors are currently under review to determine if augmentation and inoculation of granular sludge is possible.



Figure 11: Full Scale Installation Frielas, Portugal

Deodoro, Brazil:

Rio de Janeiro, Deodoro is an example of a Greenfield application, see Figure 12. This is the largest Nereda application in the world thus far and is currently treating a first phase average design flow of 17.1 MGD and a peak hour flow of 28.8 MGD. The plant will be expanded and completed in 2025; it will be able to treat an average design flow of 22.8 MGD and a peak hour flow of 38.8 MGD. This six tank Nereda plant became

operational in May 2016 just before the start of the Olympic Games in Rio de Janeiro. The system was designed for effluent limits of 25 mg/l BOD, 10 mg/l TSS, 1 mg/l ammonia and 1.5 mg/l phosphate.



Figure 12: Full Scale Installation Deodoro, Brazil

Dublin Ringsend, Ireland:

Ringsend, Ireland is currently under design and is an example of a full scale retrofit SBR application, see Figure 13. Upon completion, the Nereda plant will treat an average design flow of 159 MGD and a peak hour flow of 315 MGD. The design mixed liquor concentration will be increased from 2,500 mg/l with the previous system to 8,000 mg/l with the Nereda process. Due to the robust process stability of the aerobic granules, the Nereda technology will be able to withstand the high salinity of the influent wastewater which was detrimental to the treatment with activated sludge. The existing system was designed to achieve an effluent TN of 20 mg/l. The Nereda technology is designed to achieve a more stringent effluent limit of 10 mg/l TN and the technology will achieve Bio-P removal, without the addition of treatment volume.



Figure 13: Retrofit Full Scale Installation Dublin Ringsend, Ireland

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