AQUA-AEROBIC SYSTEMS, INC.
A Metawater Company

AquaNereda® Aerobic Granular Sludge Technology
Frequently Asked Questions

ADVANTAGES

1. What are the key advantages of AquaNereda®?

- Up to 50% energy savings
- Up to 75% smaller footprint (i.e. up to 4x smaller)
- Cost-effective in CAPEX and OPEX
- Excellent effluent quality
- Robust and resilient to toxic shocks and influent load fluctuations
- No or minimal chemical consumption and related waste
- Easy to operate

2. For what applications is the AquaNereda® technology suitable?

The AquaNereda® technology can be utilized wherever other biological wastewater treatment technologies are applied for the purification of municipal or industrial wastewater. AquaNereda is an especially attractive option for sites that need to meet nutrient removal limits, have footprint limitations, high land or energy costs, or are looking to increase capacity with existing infrastructure, just to name a few.

The AquaNereda technology can be utilized for applications including greenfield, retrofits/upgrades, and parallel or hybrid capacity extensions.

3. Is AquaNereda® sustainable?

Extensive life cycle analyses reveal AquaNereda® as a truly sustainable technology. Compared to conventional processes, AquaNereda not only has significantly lower energy consumption and associated greenhouse gas emissions but also produces high quality effluent, commonly without the use of waste-generating chemicals. In addition, the technology requires fewer construction materials and less mechanical equipment resulting in a better environmental construction profile and a smaller physical footprint.

- Significantly lower energy consumption
- Significantly smaller footprint
- Fewer construction materials required
- Remarkably high effluent quality

6306 N. Alpine Rd. Loves Park, IL 61111-7655 p 815.654.2501 f 815.654.2508 www.aqua-aerobic.com

- More efficient nutrient removal
- No or minimal use of chemicals and related waste

4. Why does AquaNereda® have a small physical footprint? How much smaller?

AquaNereda® installations require a fraction of the build area of traditional plants. This is because the process operates with an extremely fast-settling biomass present in high concentration within a single tank therefore not requiring selectors, separate compartments, or clarifiers.

The footprint savings are incredibly advantageous in urban areas or mountainous locations where land is at a premium. Additionally, existing conventional continuous flow or SBR plants can be retrofitted with AquaNereda technology enabling treatment of significantly higher quantities and/or quality of wastewater.

- Up to 75% savings compared to conventional biological nutrient removal activated sludge processes with clarifiers
- Up to 50% savings compared to conventional SBRs
- Up to 25% savings compared to conventional MBRs

5. How much more cost effective is AquaNereda®?

Precise investment savings are site-specific and vary by project which makes it difficult to provide a generalized answer; however, AquaNereda® delivers extensive treatment in a compact and simple design.

Cost savings derive from reduced mechanical equipment compared to a conventional process. For example, separate clarifiers, return sludge pumping stations, and moving decanters are not necessary. Additionally, AquaNereda results in lower construction costs as reactor volumes are up to 4x smaller. This decreases the capital cost for the technology.

Operating costs are also lower due to fewer maintenance demands and chemical needs as well as more efficient aeration.

- Compact and simple reactor design
- Less mechanical equipment
- No separate clarifiers
- Lower capital expenditures
- Lower operation and maintenance costs
- Reduced operator time
- Lower energy consumption
- No or minimal chemicals and waste disposal costs
- Lower life cycle costs

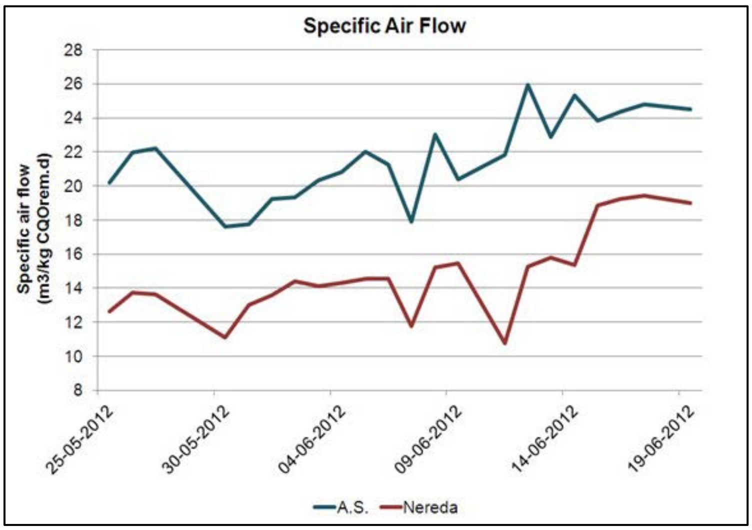
6. What are the energy savings?

The AquaNereda® technology exhibits energy savings of up to 50% compared to conventional BNR activated sludge processes. This is achieved in two ways:

6306 N. Alpine Rd. Loves Park, IL 61111-7655 p 815.654.2501 f 815.654.2508 www.aqua-aerobic.com

- An AquaNereda® system requires less mechanical equipment in that items such as return sludge pumps, mixers, and moving decanters are not necessary. The energy savings related to the reduction in mechanical equipment is typically in the range of 25-35%.
- Additional energy savings are achieved from a reduction in air requirements. This is achieved by smart aeration control and the difference in biological behavior (substrate and oxygen utilization) between flocs and granules.

  An example of a practical monitored difference in specific airflow between aerobic granular sludge and activated sludge systems is shown in the below figure (Ref. Frielas WWTP, Portugal).



7. Why is an AquaNereda® system so easy to operate?

Plant operation is easy and process performance robust due to the nature of the technology. Every AquaNereda® plant is equipped with a smart, integrated process controller that ensures fully automated plant operation, reliable performance, and ease-of-operation with an option for unmanned or remote control.

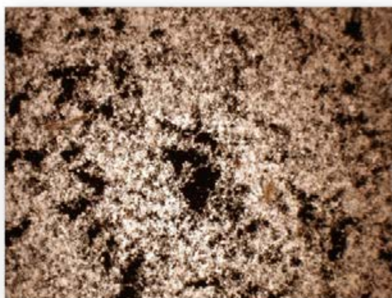
PROCESS

8. What is aerobic granular sludge?

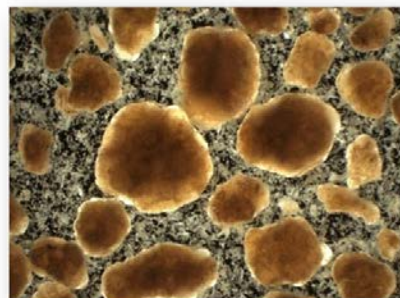
"Granules making up aerobic granular activated sludge are understood to be aggregates of microbial origin, which do not coagulate under reduced hydrodynamic shear, and which subsequently settle significantly faster than activated sludge flocs." (de Kreuk et al. 2005)

Aerobic granular sludge (AGS) is an aggregate of microbial biomass that has grown into a granular shape rather than floc. The objective of the AquaNereda® technology is to utilize design and control mechanisms to encourage biomass to form these granules rather than activated sludge. The agglomerates formed allow simultaneous aerobic, anoxic, and anaerobic conditions to exist throughout the granules. This enables extensive biological nutrient removal to take place without the need for multiple tanks, mixers, or recirculation. Granules from dense microbial communities that settle significantly faster than conventional activated sludge without the need for a media carrier.

- True microbial biomass
- Minimum particle diameter of 200 µm
- Enhanced biological phosphorus removal
- Simultaneous nitrification / denitrification
- SVI5 of AGS is comparable to an SVI30 of activated sludge



Conventional Activated Sludge



Aerobic Granular Sludge

9. How was the aerobic granular sludge developed?

The development of aerobic granular sludge began in 1993 at Delft University of Technology (DUT) in the Netherlands. DUT initially discovered how to achieve stable granulation within a laboratory setting in 1995 with nutrient removal integration accomplished by 2002. Extensive pilot-scale research began the following year with the first full-scale Nereda® prototype implemented in 2005 for an industrial retrofit application.

Two municipal demonstration plants were constructed in 2007 with the positive experience prompting the construction of the first full-scale municipal application in the Netherlands in 2011.

10. How is aerobic granular sludge cultivated?

A combination of hydraulic (allowing only fast-settling sludge to remain in the bioreactor) and biological selection (anaerobic-aerobic conditions) mechanisms are applied resulting in extracellular polymer substance (EPS) production that acts as a glue to granulate the biomass. These conditions are intrinsically part of the AquaNereda® cycle will hence always be maintained in the system.

11. Are specific chemicals or carriers added to the system to form the granules?

No, aerobic granular sludge is a true microbial biomass with no carrier or added chemical required to develop it. The structure of the granule is formed by the biopolymer extracellular polymeric substances (EPS) that is produced by the slow-growing organisms in the system.

12. Does the time required for full granulation depend on operating SRT?

The SRT itself will not affect granulation. Granules are ultimately formed through selective wasting. If there is less sludge production and less wasting, it will take longer to form granules from conventional activated sludge.

13. What is the EPS-biopolymer?

The extracellular polymeric substance (EPS) that the bacteria produces and forms the backbone of the granule seems to be comprised of a biopolymer that is very similar in characteristics to biopolymers extracted from brown algae. The biopolymer extracted from wasted granules is called Alginate-like Extractant (ALE) that shows great potential from a sustainability and plant operation perspective: The alginate-like biopolymer is a high-end product used in food and medical applications as well as technical applications such as concrete production and paper or textile coating.

14. Does the biopolymer have to be inoculated to develop the granules?

No, the biopolymer is produced by the bacteria (PAOs and GAOs) and does not require inoculation.

15. What is the average granule size?

Granules are defined in the scientific definition as particles with a diameter greater than 0.212 mm. Typically about 70% of the biomass in an AquaNereda® reactor can be classified in accordance with this definition. In addition, quite a large fraction of the smaller than a 0.212 mm biomass in AquaNereda show fast-settling and granular characteristics and could be classified as "baby" granules.

Granules between 0.2 and 1.5 mm are often preferred as smaller granules have a larger surface area and hence provide a larger overall treatment capacity.

16. What factors have an effect on granulation process stability?

Stability of formed granules is excellent as long as the system is operated appropriately. The reason for the outstanding stability of the granules is its biopolymer backbone that makes it impossible to create, for example, bulking sludge that could occur in activated sludge processes.

17. What is the consumption of granules? How long do they last, and where do we get more?

There is no consumption of granules. Granulation is a natural process: granules are formed by the operation of the AquaNereda® technology without the need for chemicals or media carriers.

6306 N. Alpine Rd. Loves Park, IL 61111-7655 **p** 815.654.2501 **f** 815.654.2508 **www.aqua-aerobic.com**

Granules are produced and excess granules are regularly wasted from the reactor during the purification process.

18. What prevents the loss of granules? Has this ever occurred?

The design of the system ensures that washout of granules is nearly impossible. This is due to the true batch nature of the system in which the react time of the cycle is unimpeded by continuous inflow while the rapid settling rate of the granules allows for a high clarified volume per batch. Hypothetically, a plant could quickly reestablish granules by partially or fully re-seeding from another plant. Note that even without granules, the system will still operate as a normal SBR and therefore achieve a certain level of treatment.

To date, no unintended loss of granules has been experienced at a plant.

19. How long can granules be stored before start-up?

In principle, granules can be stored for very long periods (years) without losing their granular structure. For a swift start-up, the biological activity of the granules should remain. Therefore, storage under anaerobic conditions and moderate climatological conditions (e.g. ambient temperatures around 20°C) should be limited to 3-4 months. Storage time can be increased by avoiding anaerobic conditions.

20. How does aerobic granular sludge nitrify and denitrify at the same time?

In a conventional activated sludge floc, the nitrifiers and denitrifiers are spread out around the floc with no organization. This requires the bulk liquid to change conditions (aerobic, anoxic, or anaerobic) to provide the environment necessary for the growth of specific bacteria. In aerobic granular sludge, the bulk liquid can retain a residual dissolved oxygen (DO) concentration which allows oxygen to penetrate into the outer layers of the granule. This oxygen is consumed as it moves further into the granule eventually depleting to a level where the granule layer becomes anoxic.

Due to this oxygen gradient, the bacteria congregate into layers. The size of these layers can be modified by adjusting the DO concentration of the bulk liquid with a higher DO resulting in a deeper aerobic layer.

21. How does the DNA composition of aerobic granular sludge compare to that of conventional activated sludge?

DNA analysis has shown that there is 2.5x the PAOs in aerobic granular sludge compared to a well-run conventional BNR plant. The amount of nitrite- and ammonia-oxidizing bacteria is similar (Ref. Microbe Detectives of Wisconsin).

22. Anaerobic granules have difficulties dealing with suspended solids in the feed. Does aerobic granular sludge have the same problem?

Aerobic granular sludge has no problems with normal sewage solids and shows similar performance as well-designed activated sludge systems.

23. What quality effluent can be achieved?

Compared to activated sludge technologies, the AquaNereda® process has greater biological treatment power due to the considerably higher concentration of active biological mass that is applied in addition to a higher concentration of microorganisms that are crucial for nitrogen and phosphorus removal. This is reflected in an effluent quality that is at least similar but typically better than what other biological technologies can achieve:

BOD*/TSS*/NH_3/TN/TP* 10/10/1/3/1 (biologically) 0.5 (with chemical)

*Tertiary filtration with pile cloth media filtration can further reduce TSS and particle-associated BOD and TP.

24. Is tertiary treatment necessary?

This depends on effluent requirements. Like conventional activated sludge, tertiary treatment is only necessary if more stringent effluent limits such as low TP (< 1 mg/L) are in place.

25. Can AquaNereda® effluent be reused?

Yes. Just like conventional systems, the effluent from the AquaNereda® process can be reused. The biological process ensures a strong reduction in organics, harmful bacteria, and targeted nutrients. Remaining solids can be further decreased with tertiary treatment such as pile cloth media filtration. Multiple existing installations reuse effluent for parks irrigation.

26. How reliable is the bacterial quality of the treated effluent?

Like all other biological treatment processes, the effluent is not free of bacteria or viruses with the type and number of bacteria varying with application. Disinfection must be used to eliminate these microorganisms. Any type of disinfection process can be used downstream of the AquaNereda® process.

27. How well does the AquaNereda® technology remove micropollutants and emerging contaminants such as endocrine disrupting chemicals?

The AquaNereda® technology effectively removes micropollutants and EDCs to the same level or higher compared to conventional processes with the following improvements:

- The AquaNereda's batch process has the additional benefit of increasing removal rates of organic micropollutants that is further enhanced by the additional adsorption of the hydrophobic granules.
- The AquaNereda technology does not rely on media carriers or polymeric membranes that can contribute to the emission of micro-plastics.

The effectiveness of micropollutant removal of the technology was demonstrated at Epe WWTP, Netherlands in a 2012 study. The process underwent extensive monitoring of 18 micropollutants, including EDCs. The results from the plant were compared with activated sludge and MBR

6306 N. Alpine Rd. Loves Park, IL 61111-7655 **p** 815.654.2501 **f** 815.654.2508 **www.aqua-aerobic.com**

plants: the aerobic granular sludge technology ranked top for removal efficiency against all parameters.

28. How do fats, oils, and greases affect the granules?

FOG limits to the reactors are 60 mg/L average and 90 mg/L max for any application, municipal or industrial.

29. What is the acceptable temperature range for influent wastewater to an AquaNereda® system?

Like all other biological treatment processes, the treatment performance of an AquaNereda® system can be affected by influent wastewater or reactor temperatures that are too high or too low.

At temperatures below 10°C, the kinetics that drive many of the biological processes (such as nitrification rates) are slowed while excessively high temperatures can inhibit other processes (such as phosphate uptake).

There are currently plants operating with wastewater temperatures less than 10°C that are achieving effluent total nitrogen concentrations down to 5 mg/L. An industrial installation in Belgium operates with an average influent waste temperature over 38°C.

30. What is the acceptable pH range for the AquaNereda® process?

The optimal pH range for the AquaNereda® process is similar to that of conventional activated sludge or biofilm processes. For optimal carbon removal, a pH range of 6.0-8.5 is ideal with a range of 6.5-8.5 preferred for full BNR applications.

In terms of biomass stability, the granules are more resilient to incidental high and low pH values. Extended exposure at high pH values will eventually result in partial liquefaction of the granular EPS backbone causing the granule structure to weaken.

Nitrification has been achieved at remarkably low pH values. This is likely a result of the pH gradient within the granules that is caused by simultaneous nitrification / denitrification; a pH increase of up to 1 pH unit has been observed. This enables the pH-sensitive nitrifiers at low bulk pH-values to find a suitable place deeper within the granule.

31. What is the acceptable F/M range for the AquaNereda® process?

The F/M range for the AquaNereda® process is similar to the organic loading ratio suitable for activated sludge processes targeting similar performance objectives. In general, better BNR is obtained as a result of the abundance of microorganisms responsible for performing nitrogen and phosphate removal.

6306 N. Alpine Rd. Loves Park, IL 61111-7655 **p** 815.654.2501 **f** 815.654.2508 **www.aqua-aerobic.com**

32. What is the MLSS to be maintained?

The AquaNereda® process is typically designed at an MLSS concentration of 8 g/L as that provides a conservative, safe design value that is nearly twice as high as a conventional activated sludge system.

Operators often operate AquaNereda systems at much higher MLSS concentrations and can do so without experiencing a significant drop in aeration efficiency as occurs with other technologies operating at similarly elevated MLSS levels, such as MBRs. Reactors have been successfully operated between 2 and 20 g/L.

33. Will the biomass multiply like in a conventional activated sludge system?

Yes, the biomass will grow just like in a conventional activated sludge system with a comparable yield. The types of bacteria are similar to those found in activated sludge; however, the design and operation of an AquaNereda® system encourages the bacteria to grow into the granular form.

34. Are the PAOs able to compete with GAOs, particularly in warmer climates?

Yes, there are several plants operating in warmer climates that have not measured a change in granule formation. This is partially due to the low density of GAO microorganisms which are wasted with the lighter floc as part of the hydraulic selection process that occurs during each cycle. By comparison, PAOs are denser and therefore settle with the granules.

35. Can AquaNereda® technology be implemented for low COD/N ratio wastewater?

Yes, the AquaNereda® technology can be implemented for low COD/N ratio wastewater applications (e.g., following primary clarification). However, stoichiometric limitations still apply when considering denitrification: a minimum amount of COD is required to allow for the reduction of nitrates, just like any other biological system.

36. What is the air requirement during the aeration phase?

The conversion processes (COD/BOD oxidation, nitrification, and denitrification) that take place in conventional activated sludge systems are the same as those that occur in aerobic granular sludge. Therefore, the biological oxygen requirement is similar.

37. What are the mixing requirements?

Due to the high MLSS concentration, the aeration density is such that mixing is not required.

38. Is chemical addition necessary for phosphorus removal?

In certain circumstances, not even the abundance of phosphate accumulating organisms (PAOs) in the AquaNereda® granule can achieve the required effluent total phosphorus (TP) requirements. This may be due to an adverse BOD/P ratio, excessive nitrogen loads, or very tight TP limits. Some chemical dosing can be added to the system to polish the effluent and remove the final parts of ortho-phosphate. Metal salts can be added directly to the reactors or into the discharge pipes. The dose in optimized by the process controller.

6306 N. Alpine Rd. Loves Park, IL 61111-7655 **p** 815.654.2501 **f** 815.654.2508 **www.aqua-aerobic.com**

39. Is the addition of activated carbon or ozone necessary for the removal of micropollutants?

The removal of micropollutants by the AquaNereda® process is similar to that of activated sludge. Micropollutant removal can be increased with downstream ozonation and filtration or PAC dosing directly to the biological process.

40. What can affect the effluent solids concentration?

Overall, the TSS concentration in AquaNereda effluent is similar to a well-operated activated sludge system. Just as for conventional activated sludge, the factors affecting effluent solids include:

- Primary clarification
- Aeration control (preventing denitrification during settling)
- Scum removal

41. Have there been any installations that have lost biological treatment capabilities?

To date, there have not been any full-scale or pilot plants that have lost biological treatment.

OPERATION

42. Is feeding to AquaNereda® reactors by gravity or pumped flow?

AquaNereda® reactors can be fed by either gravity or pumped flow.

43. How is water introduced into an AquaNereda® reactor?

Regardless of whether influent is pumped or gravity fed, wastewater in introduced into the bottom of the reactor by an influent distribution grid that covers the reactor floor producing optimal vertical plug-flow conditions and preventing short-circuiting.

44. What does the effluent decanter look like?

Unlike an SBR, the AquaNereda® process does not utilize a moving decant mechanism. Instead, effluent flows over fixed v-notch weirs, similar to those seen on conventional settlement tanks.

45. How is influent injected and effluent decanting at the same time without influent wastewater being ejected with the treated effluent? How is short-circuiting prevented?

This is prevented by proper tank design and process operation. The reactor internal piping is designed in such a way such that short-circuits will not occur within the designed for operation range. The influent distribution grid on the reactor floor ensure vertical plug-flow through the sludge bed and prevent breakthrough of the influent through overflow weirs at the reactor surface. This achieves an impressive exchange ratio exceeding half of the reactor volume, significantly greater than a traditional SBR.

46. What are the AquaNereda® cycles?

AquaNereda® works on an optimized version of typical SBR cycles. Thanks to the characteristics of the granular biomass, the influent feed and effluent decant steps are combined for an anaerobic simultaneous fill/draw phase. Organics reduction, simultaneous nitrification/denitrification, and phosphorus uptake are achieved in one aerobic phase.

This streamlined cycle structure offers process flexibility to respond to changing influent conditions while still consistently achieving the desired effluent quality.

47. When would you modify the cycle time?

Cycles can be modified in order to adjust the system's response to changes in organic and/or hydraulic loads. Cycle times, as well as the duration of a specific phase within a cycle, can also be adjusted to optimize air supply and nutrient removal.

48. How does the AquaNereda® system react to changes in the organic or hydraulic load?

Based on measurements collected from the online instrumentation and flow data received from the plant, the PLC will adjust the cycle structure and aeration time of each cycle. Hydraulic variation will be met with changes in the fill/draw time and cycle duration. If there is an influent buffer, the feed pumps (pumps operated on VFDs) allow for variations in pump speed.

By comparison, variations in the organic load will be processed by changes in the blower operating speed (blowers operated on VFDs) based on measurements from the online instrumentation (typically DO, ORP, and ammonia). Operating on the set-points defined in the PLC will provide reduced energy consumption compared to a strictly time-based aeration system.

49. How is sludge discharged?

Sludge is discharged from the reactor by gravity by opening a valve in the sludge discharge pipe during the settle phase of every cycle.

50. Slow-settling sludge is discharged preferentially, but how often are the fast-settling granules de-sludged?

Fast-settling sludge is retained in the reactor, but as granules grow in size, they break into smaller granules which are then discharged as slower settling particles. To maintain granule size, desludging is augmented with incidental desludging, when necessary.

51. What instrumentation is required for an AquaNereda® system?

The standard instrumentation package for an AquaNereda® system includes DO, pH/ORP, and TSS. Ammonia, phosphorus, and nitrate sensors/analyzers may be included to provide additional process control, depending on the effluent requirements.

52. What is the control based on?

The AquaNereda® system is controlled by standard PLC-based architecture with a SCADA-style process controller which supports additional functionality. The PLC is capable of operating the plant in the event the primary controller is offline.

The control of an AquaNereda system is based on optimizing batch cycles. Process parameters and the duration of the different cycle phases are continuously optimized in response to influent conditions to ensure optimal and efficient performance as wastewater flow, composition, and temperature fluctuate. The necessary adjustments are fully automated by the controller.

Similar to activated sludge processes, control parameters include flow, DO, ammonia, redox, nitrate, and/or phosphate, depending on effluent treatment objectives. The controller also optimizes chemical addition for phosphorus removal.

53. What parameters are monitored daily for plant optimization?

The parameters that need to be monitored for optimization depends on the plant's effluent requirements with the level of monitoring similar to the best-practice for conventional activated sludge plants. It is common to monitor DO, ORP, DS level, and if needed, NH_4, NO_3, and PO_4. Additional monitoring may include MLSS and, during start-up, sludge fractionation.

PLANT DESIGN

54. What are the necessary design parameters?

The necessary design parameters are similar to those required for conventional biological batch processes:

- Biological load (BOD, COD, TKN, TP)
- Hydraulic load (Max. Month, Max. Day, Diurnal profile)
- Temperature

55. What type of wastewater strength is suitable for the AquaNereda® technology?

The AquaNereda® system can operate with both concentrated and dilute influent wastewater. Apart from granule formation, wastewater strength is not seen as a very important parameter. Similar to a conventional system, nutrient addition may be required if the waste stream is deficient. Speed of granule formation during start-up with conventional activated sludge is highly dependent on sludge growth and hence organic loading. Very dilute wastewater would result in slower granule formation. However, once granules are present, variations in wastewater strength are relatively unimportant. Start-up experience currently covers influent concentrations of 150 to thousands mg/L COD.

56. What equipment is required and/or included for an AquaNereda® system?

The following equipment is included in an AquaNereda® system:

- Influent valve
- Influent distribution system piping
- Effluent weir assembly
- Aeration system (Diffusers + Blowers)
- Sludge removal piping
- Instrumentation
- Sludge buffer manifold piping
- Pumps for sludge buffer and equalization, if necessary

6306 N. Alpine Rd. Loves Park, IL 61111-7655 **p** 815.654.2501 **f** 815.654.2508 **www.aqua-aerobic.com**

- Controls

57. Do you need to provide tanks operating in parallel for higher flows?

The AquaNereda® technology is scalable: multiple reactors can be divided into separate trains for large systems. There is no limit to plant flow.

58. What sort of pre-treatment is required ahead of the AquaNereda® process?

Grit removal and 6 mm perforated plate screens are required as pre-treatment ahead of the reactors. The main purpose behind this requirement is to prevent wipes from entering and potentially clogging the influent distribution system.

59. Do the screening requirements change if primary clarification is utilized prior to the AquaNereda® process?

The grit removal specification can be relaxed if the AquaNereda® system is preceded by primary clarification.

60. Is pre-equalization required ahead of the AquaNereda® process?

Pre-equalization is required for AquaNereda® systems with only one (1) or two (2) reactors to account for non-filling periods in the batching process. When designing systems with three (3) or more reactors, we carefully consider whether or not an influent buffer tank may help reduce the overall cost of the system.

61. Is equalization required for return streams?

Equalization is recommended but not required. The AquaNereda® reactors are sized based on the maximum flow expected at the plant, including returns. This will impact the sizing of the in-basin process piping of the reactors and should be taken into consideration as the design is developed.

62. Is there a depth limitation for the process?

To fully optimize the benefits of the AquaNereda® process, the optimal depth rage is 18’ to 23’. This enables optimum plug-flow conditions and achieves maximum treatment capacity. Lower operational depths are possible but will decrease unit treatment capacity and should be evaluated on a case-by-case basis. There is no actual limit to the maximum process depth; this is instead influenced by blower selection.

63. Can sloped floors be utilized in the AquaNereda® process?

No, the AquaNereda® process operates as a vertical plug-flow process so a flat reactor floor is necessary to ensure uniform flow throughout the reactor.

64. Can dissolved air flotation (DAF) be used as pre-treatment as influent to AquaNereda® reactors should not be aerated due to undergo the anaerobic feeding phase?

The air input in a DAF unit is typically much smaller than in a biological reactor; therefore, little degradation takes place. Typically, a DAF unit is used for industrial applications where there is a relatively high influent COD concentration.

65. How does the AquaNereda® technology handle scum formation?

Scum formation is common with all wastewater treatment processes, but there are measures that can be taken to reduce scum formation and remove it from the reactors. In the AquaNereda process, there are two key factors that reduce the growth of filamentous bacteria:

1. The anaerobic fill/draw phase acts as a selector period with the settled granules having first access to the raw influent at the bottom of the reactor.
2. Each cycle includes a phase where lighter floc material is wasted from the reactor.

For plants with lower solids effluent limits, the effluent laterals through which effluent decants can be installed with baffles to prevent the discharge of any scum that does develop.

66. How does the AquaNereda® process handle peak and storm flows?

The AquaNereda® system is based on processing the influent flow in separate batches while alternating which reactor is receiving flow. The volume of each batch is determined by the time spent in the fill/draw phase.

As flow to the plant increases and concentrations subsequently decrease due to dilution, the AquaNereda system will monitor the influent flow and begin to adjust the duration of the fill/draw phase as well as the cycle duration of the reactors allowing the system to process more (and/or larger) batches.

67. How is redundancy handled with an AquaNereda® system?

Taking a reactor offline should be a very rare occurrence as the only in-basin equipment that would require maintenance are the disk diffusers along the reactor floor. These should only need to be replaced every 7-10 years.

Depending on the level of redundancy required (e.g., at average or max flow), a larger system may be able to operate with one less basin during average flow conditions. If complete redundancy is required, then an additional reactor can be utilized.

68. What are the key steps to implement AquaNereda® technology at an existing treatment plant with traditional aerobic treatment?

The steps to retrofit an existing treatment plant depends on the type of existing system. If it is an SBR, the retrofit would include adding an influent distribution grid to the bottom of the reactor and replace the moving decanter with fixed overflow weirs. By doing so, the treatment capacity of an existing SBR can typically be doubled. Flow-through activated sludge systems and clarifiers can also be retrofitted into AquaNereda® reactors with similar equipment changes. Often, other pre-existing infrastructure can also be re-purposed into, for example, buffer tanks.

69. What are the typical AquaNereda® configurations?

Greenfield

An AquaNereda® plant comprises multiple modular reactors (3+) with one tank being fed and decanted at a time, or one or two reactors with a feed buffer tank to store flow during non-filling periods of the reactors.

Retrofit CAS, SBR, or MBR

Since the detailed configuration of the AquaNereda system is quite flexible, the technology can often be used to convert existing CAS, SBR, or MBR plants into the aerobic granular sludge process. Often the technology enables the use of approximately a 2x higher biomass concentration with outstanding settling characteristics. As result of a retrofit to AquaNereda, the biological and/or hydraulic capacity of existing plants will be significantly increased and/or the effluent quality considerably improved. Rectangular or circular tanks can be retrofitted.

Parallel or Hybrid Capacity Extension

In a parallel application, a new AquaNereda plant is fed with only part of the plant's raw wastewater while the remaining part is treated by the existing conventional treatment system. This parallel capacity extension has an upward potential to design the plant as a hybrid which will augment the conventional activated sludge reactors. By feeding granular surplus sludge from the AquaNereda into the conventional activated sludge reactors, this inoculation process will improve the sludge characteristics and settling performance of the activated sludge and subsequently increase capacity and enhance biological nutrient removal.

SLUDGE & SOLIDS HANDLING

70. Are there significant differences in sludge treatment efficiency between granules and activate sludge flocs?

No. Solids handling processes (thickening, dewatering, and digestion) perform similarly or better with aerobic granular sludge relative to activated sludge. Additionally, the same type of equipment used for conventional systems can be utilized for the AquaNereda® process.

71. How much sludge is produced?

Surplus sludge production is similar to conventional BNR activated sludge systems operating under similar conditions as the bacteria in the biomass are the same.

72. Is the wasted slow-settling sludge separated from the wasted granules or is it disposed of together?

The wasted slow-settling sludge is not disposed of alongside wasted granules as granules are only selectively wasted to maintain a healthy biomass concentration.

INDUSTRIAL & TOXICITY

73. Are there any reference applications for the treatment of industrial wastewater?

There are many industrial references in sectors including food & beverage, vegetable oil, slaughterhouse, paper & pulp, and industrial parks. The technology was actually first applied in industrial settings.

74. Is there any experience with petroleum refinery wastewater?

Royal HaskoningDHV has executed successful bench-scale testing followed by long-term piloting with petrochemical wastewater for a confidential oil & gas client in the Middle East. Following the success of the pilot, the client has approved the use of aerobic granular sludge technology for such an application.

75. How does fluctuation in salinity affect the process?

The granules are not significantly affected by large or sudden salinity changes. Aerobic granular sludge can withstand greater salinity fluctuations (> 5x) relative to conventional activated sludge.

76. Are the granules very sensitive towards toxic compounds or large fluctuations in wastewater composition?

Granules are less sensitive towards general toxic components or variations in feed composition compared to normal activated sludge. In the lab as well in the field, it has been demonstrated that granules are less sensitive towards toxic feed conditions, sudden load fluctuations, less favorable process conditions, or sudden salinity changes compared to activated sludge.

The robustness and resiliency of aerobic granular sludge is due to the following:

- Microorganisms are better shielded from toxic effects due to the limited surface of the granule.
- The stable EPS-biopolymer backbone of the compact granule protects the biomass during short-term toxic conditions preventing disintegration.
- The high concentration of biomass makes the process less sensitive and quicker to recover after an upset.
- It has been observed that the amount of nitrifying organisms in granules is much greater than those that are actually active during treatment. Therefore, if for whatever reason nitrifying bacteria are killed off, others will take over their role.
- The batch operation is suitable for large fluctuations in wastewater composition and automatically tunes the required amount of aeration.

Testing has shown that a combination of a pH greater than 10.5 and a temperature greater than 70°C is required to dissolve the EPS-biopolymer.

6306 N. Alpine Rd. Loves Park, IL 61111-7655 p 815.654.2501 f 815.654.2508 www.aqua-aerobic.com

START-UP

77. How is start-up performed?

Start-up can be performed either by seeding with conventional activated sludge (CAS), with granules from another AquaNereda® plant, or with a mixture of granules and CAS.

78. What is the duration of start-up?

Experience shows that reaching full design capacity takes between 3 to 6 months for municipal applications if seeded with conventional activate sludge (CAS). The start-up period can be greatly reduced if the system is seeded with granules from an existing AquaNereda® installation; however, effluent requirements can still be met during the granulation process.

The Wolf Creek WWTP in Foley, AL was started up using CAS and consistently met effluent targets of <10 mg/L BOD/TSS and <5 mg/L TN within 30 days of start-up.

79. What factors affect the speed of start-up?

The duration is dependent on the influent wastewater composition, loading rate, and temperature as these influence the rate of biomass growth. When seeding with CAS, the treatment capacity of the system is gradually increased while the sludge characteristics transition towards a population of predominantly granules. By doing so, discharge limits can be met early on while the system capacity increases to its maximum design value. Granulation will continue for several more months developing more and larger granules that further improve the plant's robustness.

80. Is the start-up time longer than a conventional activated sludge process?

If granules from an existing AquaNereda® installation are used to seed a system, then start-up is typically faster than conventional activated sludge (CAS). It should also be noted that the time required for construction for an AquaNereda plant is typically shorted than that for a CAS system due to the smaller overall construction volume.

PROCESS COMPARISON

81. What are the key parameters for an AquaNereda® plant compared to conventional activated sludge (CAS)?

- **Effluent Quality:** AquaNereda® technology is similar or better than CAS.
- **Process Stability:** AquaNereda® technology is similar or better than CAS.
- **N-Removal:** For CAS, good via intermittent aeration or separate compartments. With AquaNereda® technology, N-removal is extensive and simultaneously occurs during aeration.
- **P-Removal:** For CAS, accomplished biologically and through chemical addition. For AquaNereda® technology, P-removal is mainly accomplished biological.
- **Footprint:** AquaNereda® technology is typically 25-50% of the footprint of a CAS system.

- **Energy Demand:** AquaNereda® technology typically consumes 25-25% less energy than a CAS system.
- **Sludge Production:** AquaNereda® technology produces a similar amount of sludge with similar solids processing and digestion characteristics.
- **Reactor MLSS:** MLSS in CAS systems is typically 2-5 g/L. MLSS for the AquaNereda® process is designed around an MLSS of 8 g/L but could potentially be operated at higher concentrations without experiencing a significant drop in aeration efficiency as seen in other technologies.
- **CAPEX and OPEX:** Due to factors including smaller footprint, lower energy demand, lower chemical use, etc., the CAPEX and OPEX of the AquaNereda® technology can be significantly lower than a CAS system.

82. What is the difference in settleability between aerobic granular sludge and conventional activated sludge?

An SVI5 for aerobic granular sludge (AGS) is comparable to an SVI30 for conventional activated sludge (CAS). This means that AGS will settle and compact to a certain volume in one-sixth the time that it takes CAS. AGS typically shows an SVI5 of between 30 and 50 mL/g.

83. How does the amount of sludge produced compare to an MBBR system?

The biological sludge production will be similar between aerobic granular sludge (AGS) and MBBR systems; however, as the AquaNereda technology removes phosphorus biologically and the MBBR does so through chemical fixation, the overall sludge production for the AGS technology is typically lower.

84. How does odor control for AquaNereda® compare to other technologies?

Experience shows that odor emission from the AquaNereda® process is comparable to that of conventional activated sludge plants so considerations for odor control are similar.

As emissions from the biological treatment section are relatively limited, there is, even in urban and residential environments, typically no need for covers and air treatment. This is also illustrated by the fact that several of the plants that use this technology comply with very stringent odor emission targets and meet those without covering the biological reactors and subsequent odor treatment.

The main sources of odor are the raw wastewater and the processing of bio-solids. Therefore, adequate covering and treatment of the emitted air is typically applied for the inlet works, screening, degritter, sludge thickening, digestion, sludge dewatering, and sludge storage. Primary clarifiers can also be a significant source of a plant's odor emissions. Covering primary clarifiers is not only relatively expensive but associated air treatment can also be power intensive. An AquaNereda® plant can achieve low power consumption without the use of primary clarifiers

85. How does the AquaNereda® process compare to continuous flow SBRs, such as ICEAS?

Similar to an SBR system operating under continuous flow, continuous flow in an AquaNereda® system can be achieved by having multiple reactors working together. The primary advantage of an AquaNereda system over conventional activated sludge is that it operates at a significantly higher MLSS. Combined with the enhanced settleablity and innate BNR capabilities of aerobic granular sludge, the required system volume is nearly halved. For example, the Ringsend plant outside of Dublin, Ireland was originally designed as a double-tier ICEAS SBR but is currently being transformed into a Nereda® plant to increase treatment capacity and meet BNR requirements without additional reactor or reaction time.

86. What is the difference between AquaNereda® and MBR processes?

Both AquaNereda® and MBR technologies have similar compact footprints but differ in solids separation and cost:

- The suspended solids concentration in AquaNereda effluent is comparable to a normal activated sludge system and thus higher than in MBR effluent. Tertiary treatment with pile cloth media filtration can further reduce the solids content in AquaNereda effluent. If high quality effluent with very low solids content is required, micro or ultrafiltration can be used as a polishing step. Contrary to an MBR, however, the membranes do not have to filter the high concentration of MLSS but instead just the low TSS concentration in the AquaNereda effluent. As a result, the membranes can be operated at a higher flux (fewer membranes), lower differential pressure, and with significantly less energy use. Additionally, using tertiary membrane filtration as opposed to an MBR allows for only the actual desired reuse flow to be filtered by the membrane system thus eliminating the need for extra membrane capacity necessary to handle excess flows.
- Because AquaNereda technology does not need to apply membrane filtration for solids separation, the capital and operational costs are significantly lower without the need for membrane maintenance, cleaning, and replacement. Additionally, maintaining the high biomass concentration in an MBR system results in significantly reduced aeration efficiencies. This is not the case with AquaNereda as no energy penalties apply due to the granular biomass.

87. How does the AquaNereda® technology differ from side-stream densification processes?

The AquaNereda® technology and side-stream densification processes both improve settleability and deselect for bulking and floating sludge.

Unlike densification processes, the AquaNereda technology is capable of providing inherent BNR for both nitrogen and phosphorus in a fully integrated treatment process without the use of a side-stream tank to augment the process. Additionally, the process de-selects for grit and inert material meaning that the entirety of the granule is capable of performing treatment providing a robust and resilient response to upsets. The AquaNereda technology also offers cycle flexibility as a batch process and eliminates the need for secondary clarifiers.

6306 N. Alpine Rd. Loves Park, IL 61111-7655 p 815.654.2501 f 815.654.2508 www.aqua-aerobic.com

PROJECT EXECUTION

88. I think I have a project opportunity for AquaNereda®. Who should I contact?

Please visit aqua-aerobic.com to complete and submit a Design Request Form or use the website's Rep Locator to locate the nearest Aqua-Aerobic Systems sales representative.

89. Are there opportunities to pilot? If so, how long does a pilot typically last?

Aqua-Aerobic Systems currently operates multiple aerobic granular sludge pilot units with 20' deep reactors to model the full depth of a typical system. Pilots typically last three (3) months but can be extended if desired. Please contact your local sales representative for more information.

90. Is piloting required?

Piloting would typically not be necessary for most typical municipal applications. We recommend piloting for unique applications or other situations where the project might benefit.

91. Does the price for an AquaNereda® system include any license agreements? Is there an annual fee or royalties?

No, there are no licensing fees for the AquaNereda® process.

92. What is patented?

There are several patents attached to the Nereda® technology. All patents are owned by Royal HaskoningDHV.

6306 N. Alpine Rd. Loves Park, IL 61111-7655 p 815.654.2501 f 815.654.2508 www.aqua-aerobic.com