Achieving sustainable wastewater treatment through innovation: **an update on the Nereda technology**

● The Nereda granulated activated sludge technology is continuing to advance, with different treatment configurations being applied. **STRUAN ROBERTSON, HELLE VAN DER ROEST** and **ANDRÉ VAN BENTEM** discuss the two latest installations of the technology at Garmerwolde and Vroomshoop wastewater treatment plants in the Netherlands.

Aerobic granular sludge has been extensively researched over the last two decades in an attempt to overcome the disadvantages of conventional activated sludge (CAS) systems, such as slow settling flocculent biomass necessitating large clarifiers and low reactor biomass concentrations (3-5 kgMLSS (mixed liquor suspended solids)/m^3), large treatment system footprints and relatively high system energy usage.

A co-ordinated research partnership in the Netherlands led to the development of the Nereda technology – a full-scale application of aerobic granular sludge (see box). The Nereda development story has been documented in two earlier *Water21* articles (April 2012 and April 2013) – starting with the pioneering fundamental research at the Delft University of Technology under Professor Mark van Loosdrecht in the early 2000s, through to the achievement of full-scale implementation by 2006, followed by further full-scale successes such as the previously documented Nereda systems at Gansbaai WWTP (South Africa), Epe WWTP (the Netherlands) and Frielas WWTP (Portugal).

To date more than 20 full-scale municipal and industrial Nereda plants are in operation or under construction worldwide. Further Nereda plants are in the planning and design phase, including plants with capacities exceeding one million PE (population equivalent). Exponential growth in the number of full-scale plants is occurring, with this trend expected to continue moving forward. The operational full-scale plants have met effluent requirements whilst achieving system space savings (small footprints) and lower chemical and energy use when compared to similarly-loaded CAS systems – i.e. more sustainable wastewater treatment. Furthermore, a new possibility for extracting alginate-like polymers from aerobic granular sludge has emerged, which could provide sustainable reuse opportunities for Nereda waste sludge, thereby further enhancing the Nereda system's sustainability credentials (see p48).

This article provides an update on the Nereda technology; profiling different system configuration options for a wide spectrum of treatment challenges and showcasing the latest performance results from two new Nereda installations – Garmerwolde and Vroomshoop WWTP – in the Netherlands.

Nereda versatility

Since implementing the first full-scale Nereda installations, new insights have emerged, allowing for further innovation, system development and design optimisation. New system configurations have been developed to suit a variety of scenarios experienced from site to site and from country to country. Two 'greenfield' or parallel extension approaches have been used and are detailed below (see Figure 1):

1. 3+ Nereda reactors: at least one Nereda reactor is fed at any given time, e.g., applied at Epe WWTP (the Netherlands).
2. Buffer(s) followed by Nereda reactor(s): typically one buffer followed by two Nereda reactors. Often results in overall lower tank volumes and capital cost savings (case dependent), e.g., applied at Wemmershoek WWTP (South Africa), Ryki WWTP (Poland).

In addition two 'brownfield' options have been developed:

3. Nereda and CAS hybrid: waste sludge from Nereda system is fed into CAS system. Improves CAS treatment efficiency and / or capacity in addition to the expanded capacity achieved via the Nereda system, e.g., applied at Vroomshoop WWTP (the Netherlands)
4. Nereda retrofit: convert existing tank(s) into a Nereda reactor (sequencing batch reactor (SBR), CAS aeration basin or any other suitable tank). Make use of existing infrastructure whilst

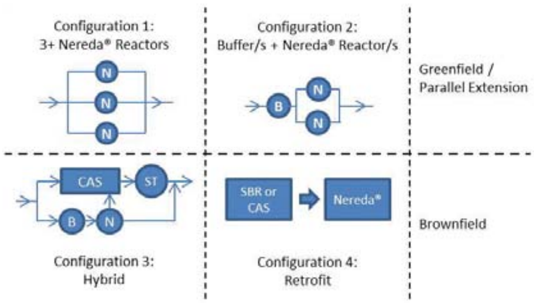
Aerobic granular sludge and the Nereda technology

Aerobic granular sludge can be formed by applying specific process conditions that favour slow growing organisms such as PAOs (polyphosphate accumulating organisms) and GAOs (glycogen accumulating organisms). Another key part of granulation is selective wasting whereby slow settling floc-like sludge is discharged as waste sludge and faster settling biomass is retained.

At the full-scale, the Nereda system consists of a cyclical process with three main cycle components or phases, namely: simultaneous fill and draw, aeration / reaction and settling. The aerobic granules formed have excellent settling properties allowing for higher biomass concentrations (8g/l), the non-use of secondary clarifiers and the exclusion of major sludge recycle pumping in the Nereda system – the result is a compact (reduced plant footprints), simple system that requires significantly less chemicals and energy when compared to conventional activated sludge (CAS) systems.

The development of Nereda was the result of a public-private research and development programme, realised through a co-ordinated collaborative partnership involving the Dutch Foundation for Applied Water Research (STOWA), six Dutch Waterboards, the Delft University of Technology (DUT) and Royal HaskoningDHV, as well as the contribution of various international industrial and municipal end users.

Figure 1: Nereda configurations / approaches



increasing system capacity and reducing energy, chemical use, e.g., applied at Frielas WWTP (Portugal) (in combination with the hybrid approach).

The four basic configurations or approach options outlined above have covered all of the treatment scenarios experienced to date at the full-scale. The Epe and Frielas WWTPs are examples of configuration 1 and 4 respectively and have been discussed in previous *Water21* articles. Details of the Garmerwolde WWTP (configuration 2) and Vroomshoop WWTP (configuration 3) are presented below to provide a complete overview of the possibilities of the Nereda system and to outline the sustainability results achieved at these two plants.

Garmerwolde WWTP (the Netherlands)

The Garmerwolde WWTP was retrofitted into an AB activated sludge system in 2005 and was subsequently not able to meet the required nutrient removal targets, which necessitated a plant upgrade. Nereda was selected as the preferred solution to extend the capacity and improve the biological nutrient removal capabilities of the plant. The solution, which commenced operation in 2013, involved the addition of two 9500m³ Nereda reactors, preceded by a 4000m³ buffer in parallel to the existing plant. The extension was designed for 140,000 PE (150 gTOD) of pollution load and hydraulically for 20,000m³/d (average flow) and 4200m³/hr (peak flow). The use of one buffer and two Nereda reactors (configuration 2) enabled an overall tank volume saving of approximately 35% when compared to the three Nereda reactor option (configuration 1, e.g. Epe WWTP) for this specific case.

The extension (Nereda) performance requirement for nutrient removal (without any downstream filtration step) is a total nitrogen level of 7mg/l (yearly average) and total phosphorus level of 1mg/l (average of ten successive samples). After a year-long monitoring period (2014) the Garmerwolde WWTP was found to fully comply with the overall effluent requirements, despite receiving on average 28,500m³/d (designed for 20,000m³/d).

The Garmerwolde WWTP offers the possibility to directly compare the performance of the Nereda and activated sludge technologies. The energy consumption of the Nereda installation (including intermediate pumping) was consistently more than 40% lower than the energy consumption of the parallel AB system in 2014. Furthermore, the AB system requires chemical dosing, including C-source (denitrification), coagulants (sludge properties) and iron salts (phosphorus removal). Apart from the high chemical costs incurred, the dosing also results in a sludge production almost double that of the parallel Nereda extension. Consequently the overall operational costs (energy, chemicals, sludge treatment) of the activated sludge plant are significantly higher than the Nereda extension.

Considering that the Nereda installation treats 41% of the daily influent flow and the original installation (AB-system) 59%, Figure 2 shows Nereda's advantage in terms of system footprint.

Vroomshoop WWTP (the Netherlands)

In 2008, the Dutch Waterboard Vechtstromen became interested in helping with the development of the Nereda technology as a part of its strategic commitment to advancing the wastewater treatment technology field. At the Vroomshoop WWTP an opportunity emerged to use Nereda for the expansion and replacement of the existing treatment plant, which consisted of an ageing oxidation ditch system that would not be able to meet future effluent requirements, especially

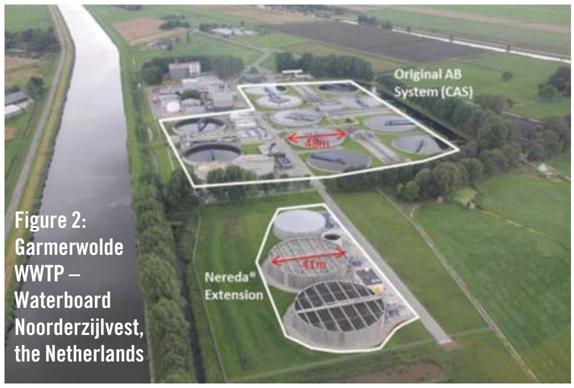


Figure 2: Garmerwolde WWTP – Waterboard Noorderzijlvest, the Netherlands

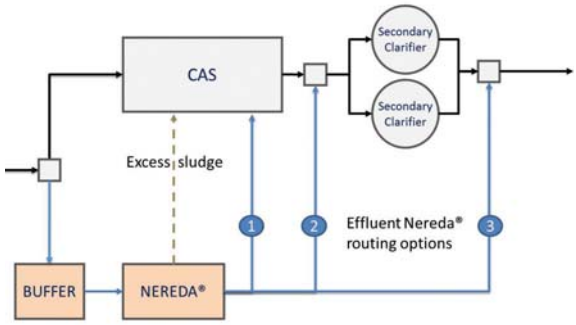


Figure 3: Flow scheme at Vroomshoop WWTP with full hydraulic routing options (1, 2 and 3)

with regard to nutrient (nitrogen and phosphorus) removal.

A hybrid configuration (configuration 3) was selected because it was found to be an effective means of making use of an existing settling tank at the site – an optimal way to deal with the high rain weather to dry weather flow ratio at the plant – and this option provided an opportunity to meet innovation and sustainability targets such as reducing energy usage. The hybrid arrangement of the treatment plant is schematically shown in Figure 3.

The new Vroomshoop WWTP entered operation in mid-2013. The plant is designed for a pollution load of 22,600 PE (150 gTOD) and hydraulically to receive 156m³/hr of wastewater during dry weather conditions and 1000m³/hr during wet weather conditions. The introduction of Nereda excess / waste sludge into the CAS system has proven to be an effective way to improve the performance of the CAS system. The settleability of the CAS sludge showed a marked improvement (lower SVI) as can be seen in Figure 4.

Using Nereda waste sludge to improve settleability in CAS systems (hybrid – configuration 3) offers numerous advantageous possibilities, such as:

- The potential to increase biomass concentrations in the CAS system, thereby increasing biological treatment capacity
- Enabling higher hydraulic loading through the CAS system

Furthermore, Nereda waste sludge contains a high fraction of polyphosphate accumulating organisms (which

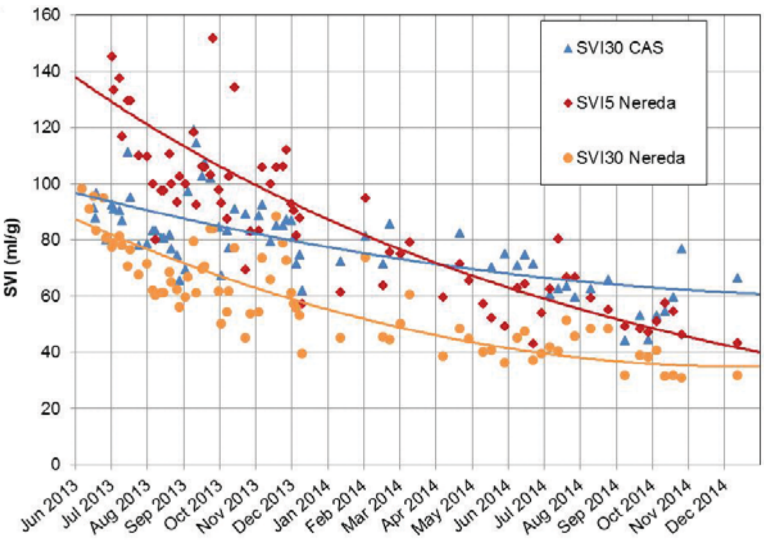
Table 1: Vroomshoop WWTP - overall treatment performance in 2014

Parameter (mg/l)	Influent	Effluent	Requirement	Compliance conditions
COD	720	55	125	Limit (3 x per year up to 250)
BOD5	263	4	10	Limit (3 x per year up to 20)
TN	-	7.2	10	Yearly average
TKN	66	5.2	-	-
NH_4-N	-	2.2	Summer = 2	Average (1 May - 1 Nov.)
			Winter = 4	Average (1 Nov. - 1 May)
NO_x-N	-	2.0	-	-
TP	8.9	0.9	2	Moving average of ten successive samples
PO_4-P	-	0.6	-	-
TSS	317	10	10	Limit (3 x per year up to 30)

Data from Waterboard Vechtstromen

drive bio-phosphorus removal) and therefore improvement in biological phosphorus removal in the CAS side of a hybrid system is possible. With the plant at full loading, the performance in terms of effluent quality has met all requirements (see Table 1). Furthermore, energy consumption monitoring at Vroomshoop (June-November 2014) showed the Nereda side of the treatment plant used approximately 35% less energy than the CAS side.

Figure 4: SVI comparison of the Nereda and CAS systems at Vroomshoop from start-up in June 2013 until the end of 2014



Conclusions

Nereda is an innovative and sustainable technology for municipal and industrial wastewater treatment born out of an extensive research and development programme over the last decade. In 2006 the first full-scale Nereda was commissioned and to date more than 20 systems are in operation or under construction worldwide, thereby demonstrating system robustness and stability. Nereda treatment plants with capacities in excess of one million PE are currently being designed for several locations around the world showing that Nereda can be applied for the largest wastewater treatment challenges. A number of system configurations have been developed to cover a wide spectrum of treatment scenarios and requirements from greenfield sites to retrofits of existing treatment infrastructure, which shows Nereda's versatility.

The full-scale results achieved at Garmerwolde, Vroomshoop and other full-scale Nereda plants prove that the technology is compact (small system footprint) and requires significantly lower amounts of chemicals and energy when compared to conventional activated sludge systems – i.e. a sustainable and cost-effective treatment solution. With full-scale applicability proven for a broad range of scenarios across the world, the next step is widespread implementation as a means to move wastewater treatment towards improved sustainability, in line with environmental and societal demands.●

About the authors
Struan Robertson, Helle van der Roest and André van Bentem are at Royal HaskoningDHV, The Netherlands.