DELIVERING SUSTAINABLE WASTEWATER TREATMENT USING AEROBIC GRANULAR SLUDGE – THE NEREDA® STORY

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ABSTRACT

The South African wastewater treatment industry is facing numerous challenges ranging from energy constraints, to stricter effluent requirements and these challenges are further exacerbated by budgetary constraints. The standard technology applied for secondary treatment is activated sludge. However, activated sludge systems have several disadvantages as a result of the utilisation of slow-settling flocculent sludge, such as: large secondary settling tanks; low reactor sludge concentrations; large system footprints and high energy usage for aeration, mixing and recycles.

Aerobic granular sludge has emerged as a viable alternative to activated sludge systems. Aerobic granular sludge consists of fast settling granules that enable higher biomass concentrations (8-12 g/l). Nereda® is a full-scale application of aerobic granular sludge technology that can achieve biological wastewater treatment in a single tank by applying a cyclical process. To date 27 Nereda® wastewater treatments plants (WWTPs) are currently in operation, under construction or in the final stage of design worldwide. This paper details performance results from several full-scale plants. The results show advantages, in comparison to similarly loaded activated sludge plants, including: lower energy usage (20-50%) as well as lower operational and capital costs i.e. more sustainable and cost-effective wastewater treatment. Based on the advantages of aerobic granular sludge, a case is made for the utilisation of Nereda® as a means to address some of the key challenges facing the South African wastewater treatment industry.

Keywords: Aerobic granular sludge, energy use, Nereda®, sustainable wastewater treatment

INTRODUCTION

There are more than 850 municipal wastewater treatment plants across South Africa which treat approximately 7 600 million litres of sewage on a daily basis (1). Extrapolating 2009 estimates (1), the capital replacement value of the municipal treatment infrastructure is estimated to be in excess of R32 billion, whilst the operational costs is in excess of R5 billion per annum. The municipal wastewater treatment industry in South Africa is currently facing challenges, including:

- Budgetary constraints for operational, maintenance and capital costs.
- Energy constraints – electricity is a large component of operational costs and electricity tariffs are rising well above inflation. Furthermore, there are energy supply challenges for new infrastructure and supply security issues at a national level.
- Aging treatment infrastructure.
- Capacity constraints due to increasing volumes/loads of wastewater generated as a result of urbanisation and development.
- Lowering of effluent requirements (more stringent) in an effort to protect South Africa's limited water resources.
- Increasing pressure to consider and implement sustainability best practise requirements such as effluent re-use; reduction of energy and chemical usage; as well as resource and energy recovery.

Activated sludge systems are currently the standard technology used for the secondary treatment of municipal wastewater worldwide (2). These conventional systems make use of flocculent biomass to biologically treat the wastewater and a number of different system configurations have been developed to achieve biological nutrient (phosphorus and nitrogen) removal (3). Despite their reliability and widespread use, activated sludge systems have a number of key disadvantages, including:

- Use of slow settling activated sludge (4).
- Requirement of large secondary settling tanks to separate slow-settling flocculent sludge from the purified effluent (4).
- Relatively low reactor MLSS (mixed liquor suspended solids) sludge concentrations around 2.5-4.5 gMLSS/ℓ to feasible solids/liquid separation in the secondary settling tanks (3).
- Complex process configurations (multiple tanks/compartments and multiple sludge recycles) to achieve enhanced biological nutrient removal (5).
- High energy usage for aeration, mixing and recycle pumping (3).
- Large secondary settling tanks due to slow settling sludge and high reactor volumes due to low MLSS concentrations result in large system footprints/land requirements (6).

Over the last 20 years there has been a concerted research effort, at universities and knowledge institutions, to find more sustainable wastewater treatment technologies (2). One of the technologies developed from this research effort is aerobic granular sludge. Aerobic granular sludge consists of bio-granules, without carrier material, of diameters larger than 0.2 mm (7). Aerobic granular sludge treats wastewater biologically using similar processes to activated sludge system, however the granular sludge has a distinct advantage of faster settling velocities when compared to activated sludge, which allows for higher reactor biomass concentrations of 8-15 g/ℓ (7).

Nereda® is a widely applied aerobic granular sludge technology that was developed over the last decade via a collaborative public-private partnership involving TU Delft (a Dutch University), Royal HaskoningDHV, several Dutch District Water Authorities, STOWA (the Dutch Foundation for Applied Water Research) and various other end-users, including the Overstrand Municipality in South Africa. To date 13 full-scale Nereda® plants are in operation, with plants in South Africa, the Netherlands, Poland, Portugal and Ireland. A further 14 full-scale plants are under construction or in the final stages of design including plants in Brazil, Australia and Sweden. The operational full-scale plants, as well as numerous pilot plants, have demonstrated the applicability of the Nereda® technology under variety of conditions across the world for both municipal and industrial wastewater treatment. The results achieved at the operational plants have shown that Nereda® offers significant advantages over similarly loaded conventional activated sludge systems, including:

- 50-75 % footprint reduction
- 20-50% energy usage reduction
- Lower capital and operational costs

This paper outlines how the Nereda® system works and provides performance results from several full-scale plants. Based on the results achieved to date, a case is made for the use of Nereda® as a means to achieve more sustainable wastewater treatment. Furthermore, it is argued that the current challenges faced by the South African wastewater treatment industry can and should be overcome through innovative and sustainable treatment technologies, such as Nereda®.

AEROBIC GRANULAR SLUDGE AND THE NEREDA® SYTEM

Aerobic granular sludge can be formed from activated sludge by applying specific process conditions such as selectively wasting slow settling biomass and retaining faster settling sludge (8). Furthermore, favouring slow growing bacteria such as PAOs (Poly-phosphate Accumulating Organisms) enhances granulation (9). During aeration of the sludge an oxygen gradient forms within the granule whereby the outer layers are aerobic and the inner core is anoxic or anaerobic (7). This difference in conditions between the outer part of a granule and the inner core enables biological nitrogen and phosphorus removal.

Lab-scale research at TU Delft in the early 2000’s, showed that aerobic granular sludge could be formed under a variety of conditions and the formed granular sludge could be used to achieve stable biological COD, nitrogen and phosphorus removal (7). Based on this research the aforementioned public-private research initiative was set up. Following pilot-scale research, the first full-scale Nereda® wastewater treatment plant was commissioned at a cheese factory in the Netherlands in 2006 (10). The first municipal demonstration plant entered operation in South Africa at the Gansbaai WWTP (wastewater treatment plant) in 2008, with a 5 Mℓ/d capacity (6). Subsequently, 13 full-scale Nereda® treatment plants have entered operation with exponential growth in the number of plants expected in the coming years. Table 1 details the operational plants as well as the full-scale plants under construction or in the final stages of design. Further treatment plants, some with capacities exceeding 400 Mℓ/d, are in the planning or preliminary design phases.

Table 1: Inventory of full-scale Nereda® plants

Operational plants	**Average daily flow (m^3/day)**	**Peak flow (m^3/h)**	**Person Equivalents**	**Start-up**
Vika, Ede (NL)	50-250		1,500-5,000	2005
Cargill, Rotterdam (NL)	700		10,000-30,000	2006
Fano Fine Foods, Oldenzaal (NL)	360		5,000-10,000	2006
Smilde, Oosterwolde (NL)	500		5,000	2009
STP Gansbaai (RSA)	5,000	400	63,000	2009
STP Epe (NL)	8,000	1,500	54,000	2011
STP Garmerwolde (NL)	30,000	4,200	140,000	2013
STP Vroomshoop (NL)	1,500	400	12,000	2013
STP Dinxperlo (NL)	3,100	570	15,730	2013
STP Frielas, Lisbon (PT)	12,000		40,000	2014
STP Ryki (PL)	5,300	430	41,000	2015
STP Wemmershoek (RSA)	5,000	625	39,000	2013
STP Clonakilty (IRL)	4,896	626	20,500	2015
Plants under construction	**Average daily flow (m^3/day)**	**Peak flow (m^3/h)**	**Person Equivalents**	**Start-up**
Westfort Meatproducts, IJsselstein (NL)	1,400	1,400	43,000	2015
STP Carrigtohill (IRL)	6,750	844	30,000	2016
STP Jardim Novo, Rio Claro (BR)	23,500	1,764	133,000	2016
STP Deodoro, Rio de Janeiro (BR)	86,400	6,120	480,000	2016
STP Hartebeestfontein (RSA)	5,000	1,250	44,000	2016
STP Kingaroy (AUS)	2,700	450	16,000	2016
Plants under design	**Average daily flow (m^3/day)**	**Peak flow (m^3/h)**	**Person Equivalents**	**Start-up**
STP Österröd, Strömstad (S)	3,730	360	12,000	2017
STP Cork Lower Harbour (IRL)	18,280	1,830	65,000	2016
STP Tatu, Limeira (BR)	57,024	3,492	517,000	2016
STP Simpelveld (NL)	3,668	945	11,880	2016
STP São Lourenço, Recife (BR)	19,093 (1^{st} phase); 25,123 (2^{nd} phase)	1,674	139,600	2016 2024
STP Jaboatão, Recife (BR)	109,683 (1^{st} phase) 154,483 (2^{nd} phase)	11,588	858,330	2017 2025
STP Breskens (NL)	5,400	1,100	37,000	2017
STP Jardim São Paulo, Recife (BR)	19,529 (1^{st} phase) 78,117 (2^{nd} phase)	5,859	434,000	2017 2025

Nereda® operates a cyclical process with three cycle components or stages, namely: simultaneous influent fill and effluent withdrawal; aeration/reaction and settling – all of which occur in a single reactor with no partitions (6). Granulation can be achieved via an incremental start-up process using activated sludge for seeding or alternatively granular seed sludge from other Nereda® plants can be used. In comparison to activated sludge, aerobic granular sludge has enhanced settling properties, allowing for higher biomass concentrations of 8-15 g/ℓ (11). The enhanced sludge settleability of aerobic granular sludge is evident from a comparison of typical SVI (sludge volume index) values – for aerobic granular sludge the SVI_5 (5 minutes) tends towards the SVI_{30} (30 minutes), with typical values around 30-60 mℓ/g (6), whereas for activated sludge the SVI_{30} is typically in the range of 110-160 mℓ/g and the SVI_5 is not measured because activated sludge exhibits minimal settling 5 minutes (3). Typical reactor depths range from 5.5 to 9 m, with lower and deeper depths possible; whilst secondary settling tanks and major sludge recycles are not required for the Nereda® system (10).

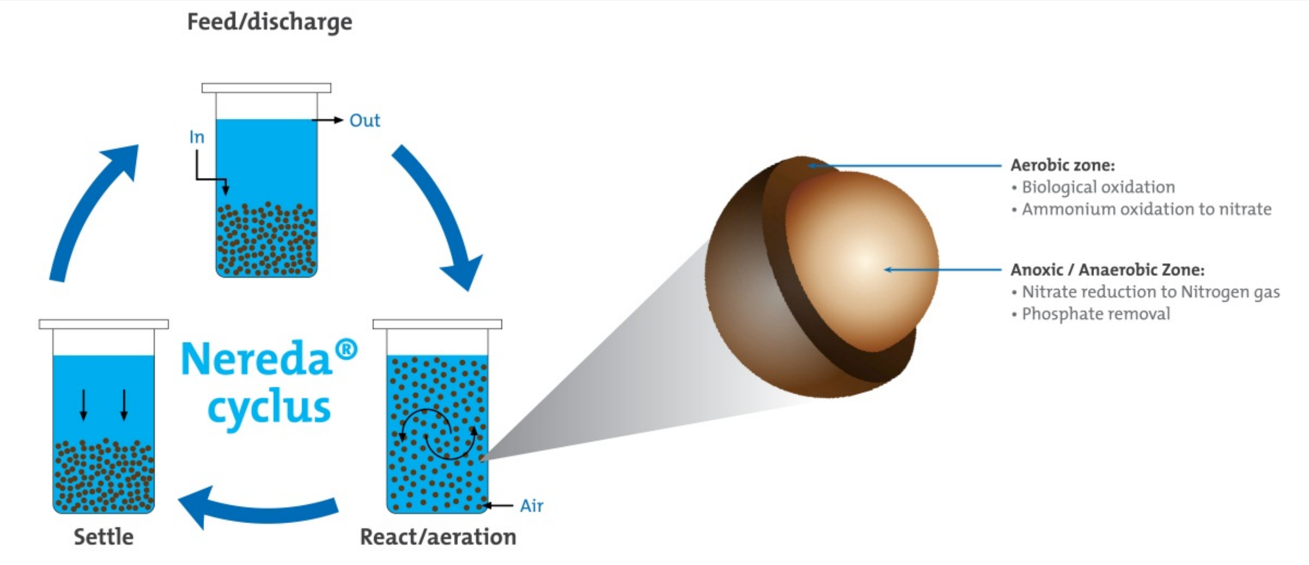


Figure 1: Schematic depiction of the Nereda® cycle and an aerobic granule (12)

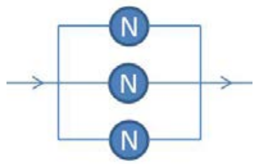
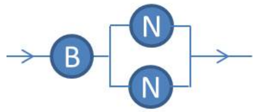
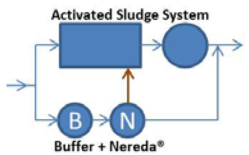
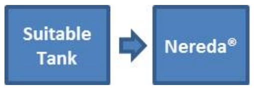
Nereda® requires conventional pre-treatment consisting of screening, grit removal and, depending on the application, FOG (fats, oils and greases) removal; whilst primary sedimentation is optional (13). The structure of aerobic granules combined with a cyclical process facilitates full biological nitrogen and phosphorus removal (9). Aerobic granules containing PAOs enable enhanced biological phosphorus removal whereby phosphate uptake occurs during aeration and phosphate rich waste sludge is subsequently removed from the system (8). During the aeration phase, the aforementioned oxygen diffusion gradient develops in the granules which results in an aerobic outer layer and an anoxic or anaerobic core (6). In the aerobic outer layer of the granules nitrifiers and heterotrophic bacteria proliferate, enabling the degradation of organics (COD removal) and nitrification (conversion of ammonia to nitrite/nitrate) respectively (8). A simultaneous nitrification-denitrification process occurs whereby the formed nitrates (from nitrification) are denitrified (conversion of nitrate to nitrogen gas) in the anoxic core of the granules (14). Nereda® can therefore achieve biological nutrient removal in a single tank without the need for separate anaerobic and anoxic compartments or tanks. In comparison activated sludge systems capable of biological nitrogen and phosphorus removal require at least 3 tanks or zones (anaerobic, anoxic and anaerobic) and multiple recycles between the zones or tanks (e.g. UCT or Johannesburg configurations) (5).

Research has shown that aerobic granular sludge has similar digestibility when compared to activated sludge (15). Furthermore, the ability to extract alginate-like exopolysaccharides (ALE) from aerobic granular sludge has been discovered (16). Alginate is used in a variety of industries as a thickener or gel and as a basis for coatings; and is currently produced from seaweed. Aerobic granular sludge has been found to contain between 15 to 25% of ALE (alginate-like exopolysaccharides) and could potentially be used in the chemical sector, textile and paper industries, as a soil enhancer to improve water retention in semi-arid areas or as a brick additive (17). The recovery of ALE from aerobic granular sludge could provide sustainable re-use opportunities for Nereda® excess sludge. This promising re-use concept is currently being researched and developed further under the National Alginate Research Programme (NAOP) in the Netherlands. This public-private sector collaborative research initiative has the goal of developing sustainable and commercially viable ALE-extraction from Nereda® excess sludge (17).

The NAOP is similar to the public-private collaborative partnership that successfully developed Nereda®.

Four main Nereda® configurations have been developed as a solution for different treatment scenarios ranging from new ‘green-field’ treatment plants to ‘brown-field’ retrofits – these configurations are further detailed in Table 2 below.

Table 2: Nereda configurations (adapted from 13)

Nereda® Configuration	Typical Layout		Configuration characteristic	Advantages	Reference examples	Potential Applications
1 Continuous feed, 3+ reactors	3 reactors		At least 1 reactor in feed phase at any given time	Scalable for application to large (>100 Mℓ/d) and mega (>500 Mℓ/d) treatment plants	Epe WWTP (Netherlands) 	'Greenfield sites'; or extension to existing plants with parallel Nereda® system
2 Influent buffer followed by X reactors	1 buffer + 2 reactors		Buffer stores influent between feeds to reactors	Optimised investments (2 versus 3 reactors)	Wemmershoek WWTP (South Africa) 	'Greenfield sites'; or extension to existing plants with parallel Nereda® system
3 Hybrid	1 or more Nereda® reactors with excess sludge connection to activated sludge system		Waste Nereda® sludge to activated sludge system	Enhance activated sludge system performance; Optimal use of existing infrastructure	Vroomshoop WWTP (Netherlands) 	'Brownfield sites'; Extension / optimisation scenarios, utilising existing infrastructure
4 Retrofit	Convert existing activated sludge reactor or any suitable tank		Use existing tanks or reactors	Cost-effective capacity and performance enhancement using existing infrastructure	Frielas WWTP (Portugal) 	'Brownfield sites'. Limited space or budget but require enhanced capacity and/or performance

RESULTS FROM FULL-SCALE NEREDA® TREATMENT PLANTS

Vroomshoop WWTP (the Netherlands)

A Nereda® hybrid configuration was selected for the upgrade of the Vroomshoop WWTP (the Netherlands), whereby Nereda® waste sludge is fed into a parallel activated sludge system. The existing treatment works consisted of an outdated oxidation ditch system that would not be able to meet future nutrient removal requirements. The hybrid configuration (Configuration 3 in Table 2) was selected for the following reasons:

- An effective means to re-use an existing secondary settling tank from the old plant.
- Optimal flow routing to accommodate the high rain weather to dry weather ratio at the plant.
- Meet innovation targets.
- Meet sustainability targets such as reducing energy usage.

The new 2.8 Mℓ/d Vroomshoop WWTP entered operation in 2013. Figure 2 shows a schematic depiction of the hybrid configuration.

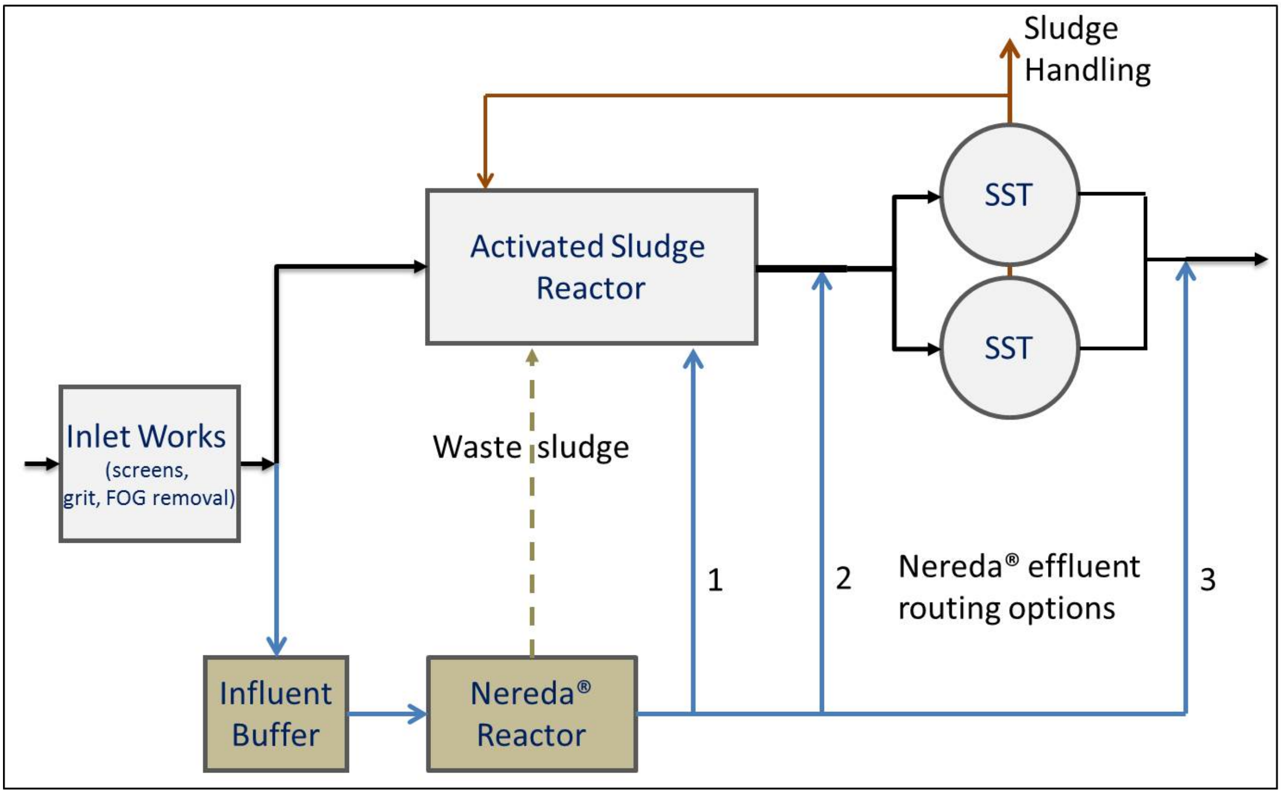


Figure 2: Schematic depiction of the Vroomshoop WWTP (adapted from (18))

The plant is designed with a dry weather hydraulic capacity of 156 m^3/h and rain flow of 1 000 m^3/h during, whilst the design pollution load is 22 600 PE (population equivalent at 150 gTOD/PE). The discharge of the Nereda® waste or excess sludge into the activated sludge system has been found to significantly improve the sludge settleability of the activated sludge. Figure 3 shows how the SVI (sludge volume index) in the activated sludge system steadily decreased as a result of the addition of the Nereda® waste sludge, indicating improved sludge settleability.

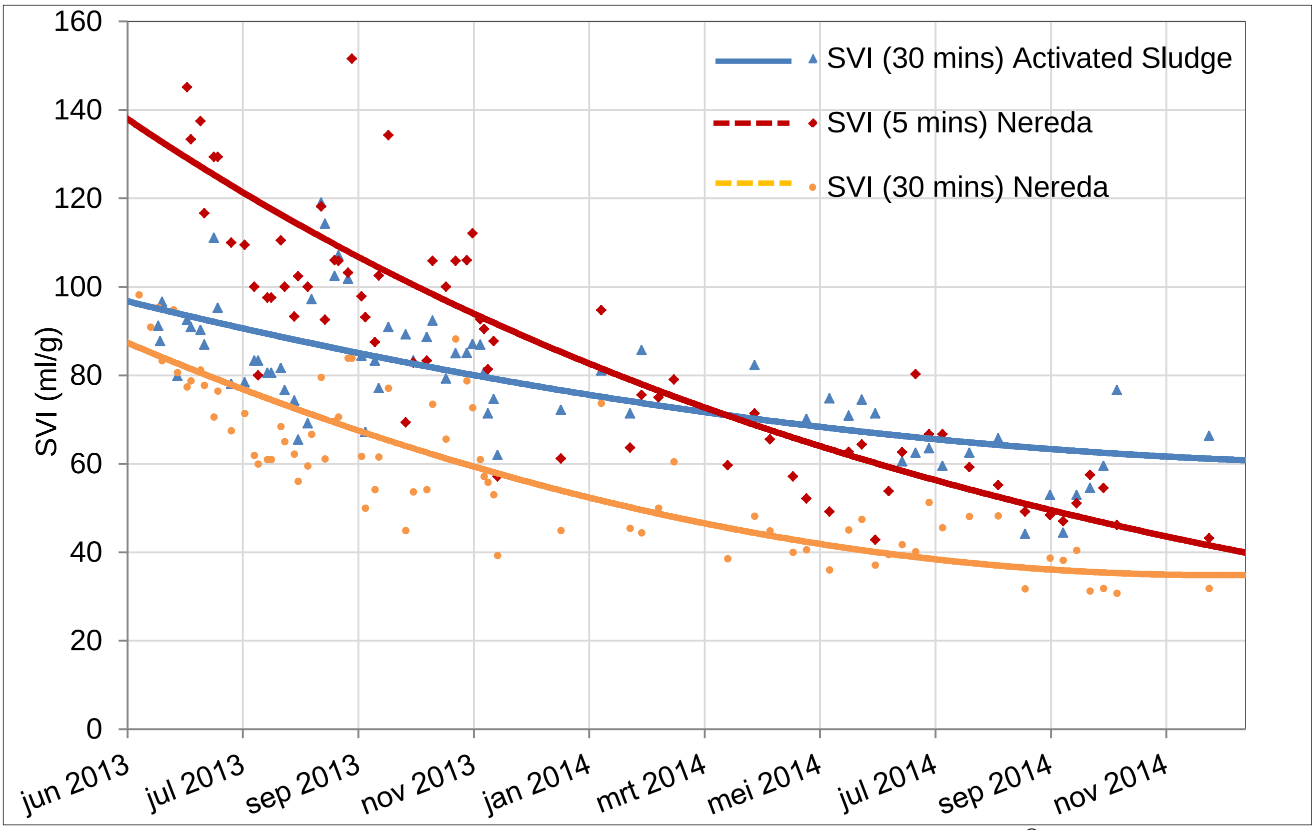


Figure 3: Comparison of SVI (sludge volume indexes) of the Nereda® and activated sludge systems at Vroomshoop WWTP (data from end-user: *Waterschap Vechtstromen*)

Figure 3 shows how the addition of Nereda® waste sludge can improve settleability in a parallel activated sludge system using a hybrid configuration. The potential advantages of improved sludge settleability in an activated sludge system include:

- The ability to increase MLSS (mixed liquor suspended solids) concentrations in the activated sludge system and therefore increase the biological treatment capacity and/or;
- The ability to allow higher hydraulic loading on the secondary settling tanks since the sludge settling rates are improved.

Another potential advantage of this hybrid configuration is an improvement in biological phosphorus removal in the activated sludge system, because Nereda® waste sludge contains higher concentrations of PAOs (polyphosphate accumulating organisms) in comparison to activated sludge.

Between June and November 2014 energy usage monitoring at the Vroomshoop WWTP showed that the Nereda® side of the plant used on average 35% less energy than the activated sludge side. During 2014 effluent performance monitoring showed the compliance of the plant under full loading conditions – see Table 3 below.

Table 3: Performance of the Vroomshoop WWTP in 2014 (data from end-user: *Waterschap Vechtstromen*)

Parameters		**Average Influent (mg/ℓ)**	**Average Effluent (mg/ℓ)**	**Requirement (mg/ℓ)**	**Regulatory Compliance Criteria**
Organics	COD	720	55	125	Limit (3 x per year up to 250)
	BOD_5	263	4	10	Limit (3 x per year up to 20)
Nitrogen	TN	-	7.2	10	Yearly Average
	TKN	66	5.2	-	-
	NH_4-N	-	Summer=1.4; Winter = 3.0	Summer = 2 Winter = 4	Average (1 May - 1 Nov.) Average (1 Nov. - 1 May)
	NO_2/NO_3 -N	-	2.0	-	-
Phosphorus	TP	8.9	0.9	2	Moving average of 10 successive samples
	PO_4-P	-	0.6	-	-
Suspended Solids	TSS	317	10	30	Limit

Garmerwolde WWTP (the Netherlands)

Nereda® was selected as the preferred technology for a 20 Mℓ/d extension to the Garmerwolde WWTP, which treats predominantly domestic sewage from the city of Groningen. The design pollution load for the extension was 140 000 PE (population equivalents) at 150 gTOD/PE where TOD is the total oxygen demand. A configuration consisting of a single influent buffer tank (4 000 m^3) followed by 2 Nereda® reactors (9 500 m^3 each) was found to be optimal for the extension (Configuration 2 in Table 2). The Nereda® system is preceded by a conventional inlet works (screening, grit and FOG removal, whilst the Nereda® effluent is not followed by any further treatment step i.e. direct discharge to a canal next to the plant. Figure 4 shows an aerial photo of the original activated sludge system as well as the Nereda® extension.

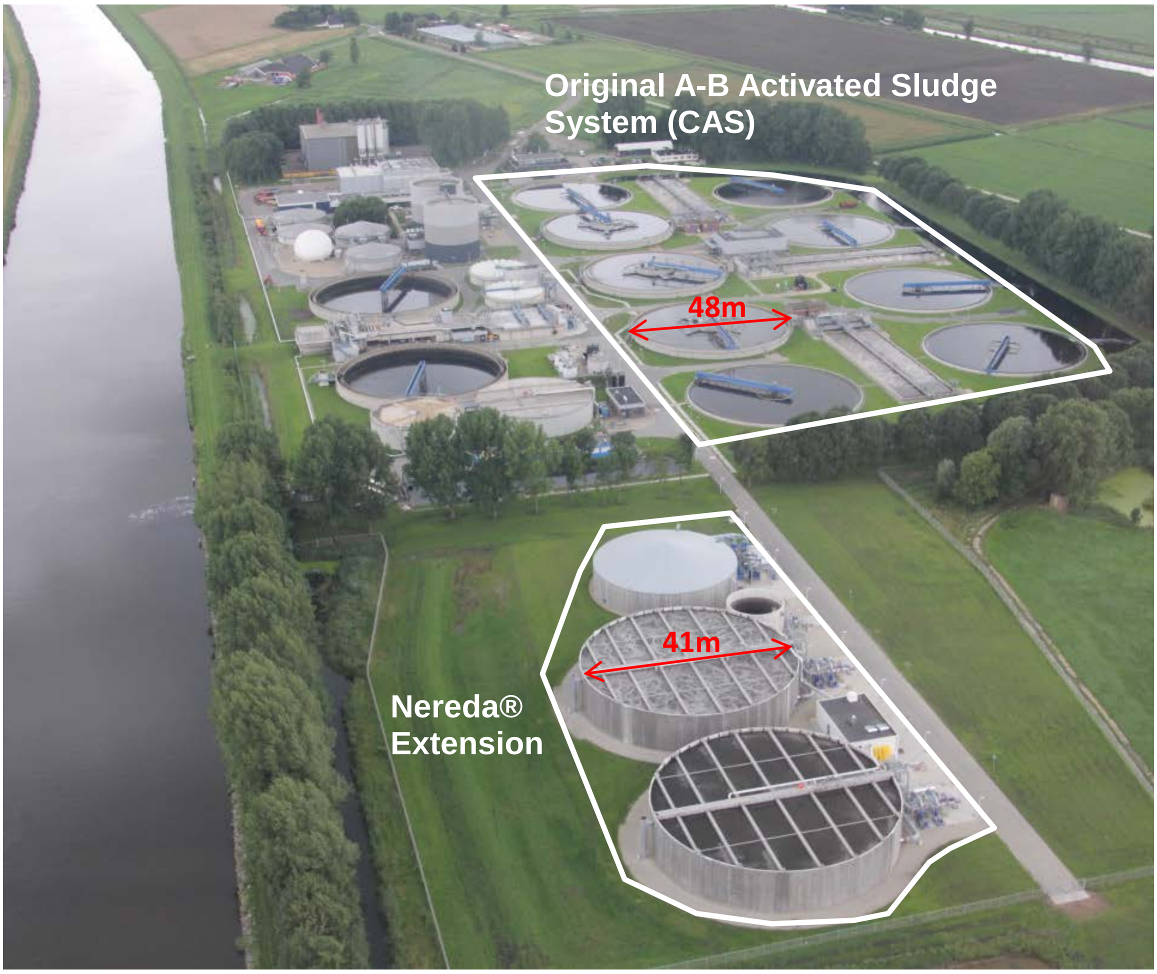


Figure 4: Garmerwolde WWTP (*Waterschap Noorderzijlvest*)

The Nereda® extension entered operation in late 2013, and Table 4 shows the Nereda® nutrient removal performance in 2014 and 2015 (up until 08/08/2015).

Table 4: Performance of the Nereda® system at Garmerwolde WWTP from March to December 2014 (data from *Waterschap Noorderzijlvest*)

Parameter	**Unit**	**2014 Average Influent**	**2014 Average Effluent**	**2015 Average Effluent (up until 08/08/2015)**
Total Nitrogen	mgN/ℓ	49.4	8.11	8.8
Total Phosphorus	mgP/ℓ	6.7	0.87	0.7

The effluent performance detailed in Table 4 was achieved despite the Nereda® system treating on average 27.5 Mℓ/d in 2014 and 31.3 Mℓ/d in 2015, which is in excess of the design 20 Mℓ/d. The parallel Nereda® and activated sludge systems at the plant allow for a direct comparison of energy usage because both systems treat the same influent source. Figure 5 shows energy usage at the plant in 2014. The presented data was calculated as follows:

- Specific energy usage was compared i.e. flow weighted usage of kWh per m^3 treated.
- The Nereda® energy usage includes pumping from the influent buffer to the reactors.

- The energy comparison excludes sludge treatment and a SHARON® (Single reactor system for High activity Ammonium Removal Over Nitrite) treating the sludge liquors at the plant.

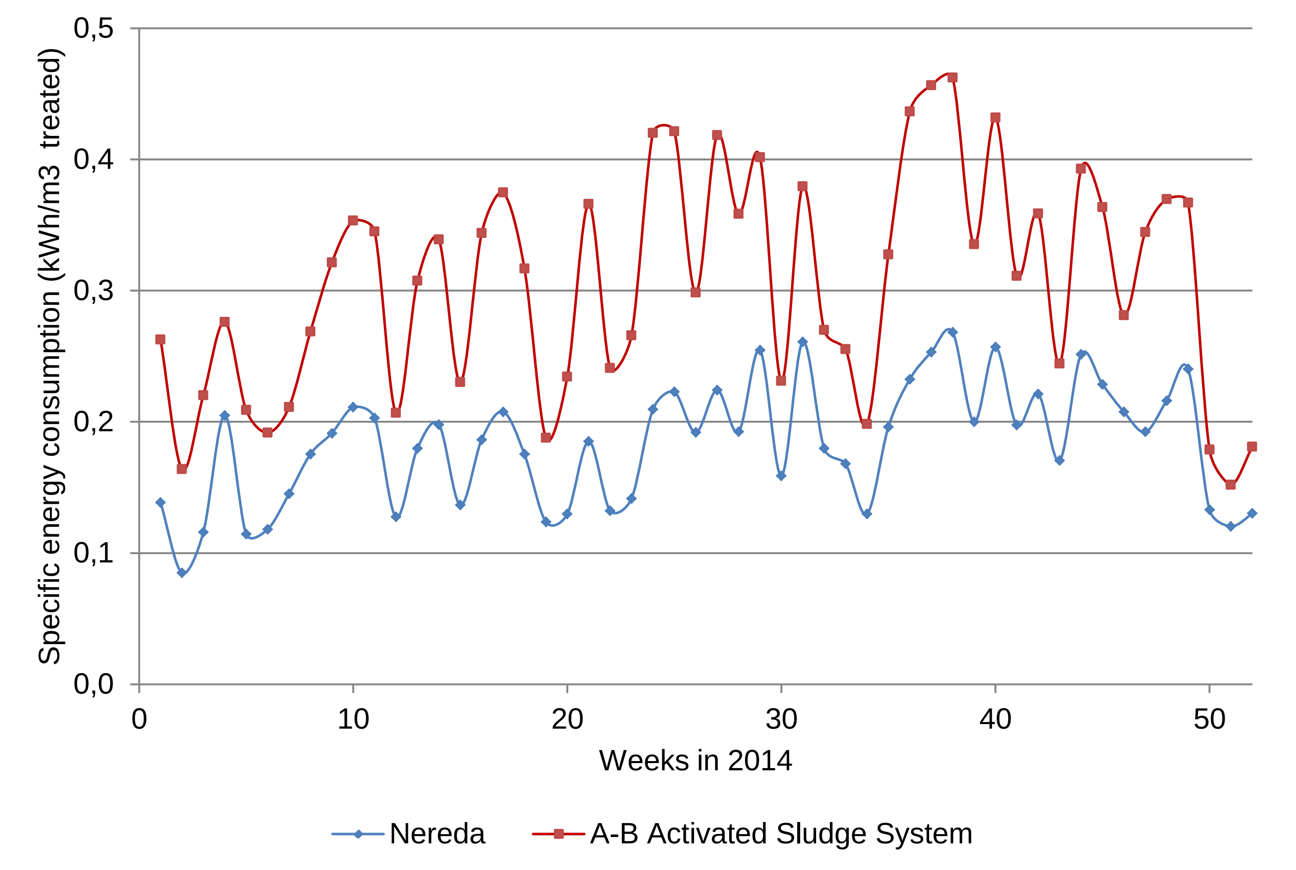


Figure 5: Energy usage at the Garmerwolde WWTP in 2014 (data from *Waterschap Noorderzijlvest*)

Figure 5 shows that the Nereda® extension used substantially less energy than the parallel activated sludge system. On average, in 2014, the Nereda® system used 0.17 kWh per m^3 of influent treated, whilst the parallel A-B activated sludge system used 0.33 kWh per m^3, which amounts to the Nereda® system using on average 48% less energy than the parallel activated sludge plant. In terms of plant footprint, the Nereda® system covers an area of 6 000 m^2 which is substantially lower than the 40 000 m^2 footprint of the parallel activated sludge system (see Figure 4).

The activated sludge system at the plant requires C-source dosing (carbon source for denitrification) and metal salts dosing (phosphorous removal). This chemical dosing also results in a sludge production in the activated sludge system that is approximately double that of the parallel Nereda® extension. The overall operational costs (energy usage, chemicals and sludge treatment) of the activated sludge plant are therefore significantly higher than the Nereda® extension. Currently, the Nereda® system is treating more than 30 Mℓ/d which is just under half of the total influent flow to the plant. Increasing flow to the Nereda® system and reducing flow to the activated sludge plant has resulted in significant operational cost savings.

Wemmershoek WWTP (South Africa)

Nereda® was chosen for a 5 Mℓ/d wastewater treatment system at the Wemmershoek WWTP in the Western Cape (close to Franschhoek). The chosen configuration for the plant was an influent buffer followed by 2 Nereda® reactors (Configuration 2 in Table 2). Table 5 provides further technical details for the plant.

Table 5: Wemmershoek WWTP specifications (adapted from (13))

Design Component	**Wemmershoek Design Details**
Primary treatment	Screening and grit removal
Secondary treatment	1 x 600m^3 Nereda® Influent Buffer; 2 x 1 800m^3 Nereda® reactors
Tertiary treatment	Chlorine disinfection followed by maturation pond
Sludge treatment	Mechanical thickening and dewatering
ADWF (Average Dry Weather Flow)	5 Mℓ/d
PWWF (Peak Wet Weather Flow)	14.4 Mℓ/d
Effluent discharge	Discharge to Berg River and re-use for irrigation (pumped to Franschhoek)

The plant entered operation in August 2014, however various technical hardware challenges were encountered. Despite the aforementioned issues, granulation has progressed well and promising effluent results have been achieved. Table 6 provides the most recent effluent results from 22/09/2015 to 10/11/2015 (testing done by SANAS accredited Integral Laboratories).

Table 6: Performance of the Wemmershoek WWTP from 22/09/2015 to 10/11/2015 (8 testing days)

Parameter	**Unit**	**Design Influent**	**Actual Influent (Integral Laboratories)**	**Average Final Effluent (Integral Laboratories)**	**Effluent Requirement (General Limit)**
COD	mgCOD/ℓ	870	927	22	<75
TKN	mgN/ℓ	60	-	-	-
Ammonium	$mgNH_4$-N/ℓ	45	56	<1	<6
Nitrate	$mgNO_3$-N/ℓ	-	-	<1	<15
Nitrite	$mgNO_2$-N/ℓ	-	-	-	
Total phosphorus	mgP/ℓ	12	-	-	-
Ortho-phosphate	$mgPO_4$-P/ℓ	-	6.1	2.9	<10
TSS	mgTSS/ℓ	-	385	11.4	<25

Table 6 shows that near complete nitrogen removal is being achieved. The effluent ortho-phosphate concentrations are well within the limit, however in the future process optimisation could potentially bring the effluent ortho-phosphate concentrations below 1 $mgPO_4$-P/ℓ in line with results achieved at full-scale Nereda® plants such as Garmerwolde WWTP in the Netherlands.

Figure 6: Effluent discharge from a Nereda® reactor at the Wemmershoek WWTP

DISCUSSION AND CONCLUSIONS

The South African municipal wastewater treatment industry is facing challenges including budgetary limitations, energy constraints and stricter effluent requirements. Furthermore, existing infrastructure is ageing, with many treatment works at capacity or overloaded, with wastewater volumes increasing as South Africa continues to develop and urbanise. Activated sludge systems remain the preferred choice of technology for secondary treatment. To achieve enhanced biological nutrient removal (stringent nitrogen and phosphorus requirements) at larger treatment plants (>5 Mℓ/d), the current approach is to select activated sludge systems such as the modified UCT or Johannesburg configurations. These activated sludge systems can achieve low nitrogen and phosphorus requirements; however they require multiple tanks or compartments in combination with multiple pumped recycles and extensive mixing, which equates to higher energy usage.

The ‘activated sludge approach’ applied in South Africa has been reinforced by extensive local knowledge of this technology, as well as the proven capabilities and robustness of the technology. South Africa played a leading role in developing advanced activated sludge systems such as the UCT and Johannesburg configurations. Activated sludge systems have become firmly entrenched within the wastewater treatment sector. However, activated sludge systems do have disadvantages including high energy requirements, relatively low biomass concentrations and large secondary clarifiers (necessitated by the slow settling activated sludge).

Results from full-scale Nereda® treatment plants over the last 10 years have shown that Nereda® has numerous advantages when compared to similarly loaded activated sludge systems, including:

- 25-75% reduction in treatment system footprints as a result of higher reactor biomass concentrations and the non-use of secondary settling tanks;
- 20-50% energy usage reduction and;
- Associated capital and operational cost savings.

Nereda® treatment plants have been shown to achieve similar or improved enhanced biological nutrient (nitrogen and phosphorus) removal. Furthermore, the possibility to recover alginate-like exopolysaccharides (ALE) from Nereda® waste sludge has the potential to generate a usable product with commercial value (17). Four main Nereda® configurations have been developed for a wide range wastewater treatment scenarios ranging from 'green-field' systems to retrofits at 'brown-field' sites.

Research and innovation leads to new technologies capable of addressing evolving societal challenges. For instance, eutrophication concerns in the 1980s led to the development of advanced activated sludge systems capable of biological phosphorus removal, with South Africa playing a leading role. Currently sustainability requirements (including cost-effectiveness) are driving technological advancement and innovation. The advantages of Nereda® in comparison to activated sludge systems ultimately translate into more sustainable and cost-effective wastewater treatment. A shift away from the 'activated sludge approach' towards an 'aerobic granular approach' would assist in addressing the challenges facing the wastewater treatment industry in South Arica and beyond.

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