Full-scale Experiences With Aerobic Granular Biomass Technology For Treatment Of Urban And Industrial Wastewater

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Abstract
The Nereda® aerobic granular biomass is an innovative wastewater treatment technology for biological nutrient removal that is considered to be the first game-changing innovation offspring of activated sludge since its birth in 1914. The Nereda® technology has been developed and matured as outcome of Dutch concerted research and development, and is now applied in several industrial and urban wastewater treatment plants in the Netherlands, South Africa and Portugal. These plants have demonstrated significant improvements with regard to process stability, effluent quality (TN<5mg/l, TP<0.3mg/l), and energy savings (up to 40%), compared to traditional activated sludge processes. Another 20 plants are in various stages of design, construction, and commissioning in a range of countries, including The Netherlands, Australia, Poland, South Africa and Brazil. With tank-sizes similar to the world's largest SBR tank volumes, the technology is now mature and ready to be applied for even the largest treatment challenges. By delivering enhanced treatment standards at lower CAPEX, lower OPEX, and smaller footprints than existing solutions, this technology is considered a real game-changer in the treatment arena and will probably replace her grandfather activated sludge as the new modern biological wastewater treatment standard.

Keywords
Aerobic granular biomass, energy efficiency, innovative biotechnology, Nereda, sustainability

NEREDA® TECHNOLOGY

Since the development of BNR systems for activated sludge, the research on biological wastewater treatment processes has focused on improved separation techniques for activated sludge by improving settling properties and physical separation techniques (i.e. MBR systems). The fundamental requirements to improve settlability are compact, dense, large particles with higher specific gravity. This became the foundation for the research and development of aerobic granules by Delft University of Technology (DUT). Discovered by Professor Mark van Loosdrecht from DUT (2012 Lee Kuan Yew Water Prize winner), the process has been engineered to suit commercial applications by DHV (now known as Royal HaskoningDHV) and has been commercially branded as Nereda® Technology.

Aerobic granular biomass has several advantages over conventional activated sludge flocs that has been well-documented. These include good settling ability that leads to better biomass retention and higher biomass concentrations, provision of a structured matrix for biomass growth, and ability to withstand high load variations. These all lead to a compact reactor design that can reduce plant footprints significantly.

Development

The research and development of aerobic granules commenced at DUT in 1993. In 2002 aerobic granular sludge is discovered and stable laboratory scale granulation was achieved.

This was followed by the pilot scale research at Ede WWTP and several pilot plants have been in operation for both industrial and municipal influent since 2003, in and outside the Netherlands. The first industrial full scale Nereda® prototype was implemented in 2005 by retrofitting an existing tank and was followed by several greenfields and industrial plant upgrade applications.

In 2007, DUT, STOWA (Dutch Foundation for Applied Water Research), Royal HaskoningDHV and six Dutch Water Boards joined forces in the Dutch National Nereda Development Program (NNOP) to scale-up and implement aerobic granular biomass technology for municipal applications. In parallel two Nereda® demonstration plants (Gansbaai, South Africa and Frielas, Portugal) were instrumental in the further scale-up. Epe WWTP was designed and built in 2010/2011 and has been in operation for more than two years. Following the successful design, construction and operation of Epe WWTP, various other municipal Nereda® plants were projected and currently the number of municipal applications already amounts to 6. With more than 20 others in the international pipeline, the technology seems to grew-out from an innovation into a proven new standard for urban and industrial biological wastewater treatment.

One of the recent plants is Garmerwolde STP in The Netherlands. Here Nereda® is used to upgrade the capacity of an existing activated sludge plant with an additional maximum flow of 4,200 m3/h and load from 150,000 PE in just two 9,500 m3 Nereda® reactors. This Nereda® tank size is close to the largest sequencing batch reactor tanks worldwide. In Brazil the first two of the (at least) ten planned Nereda® installations are designed for 517,000 PE (57,024 m3/day) in Limeira (Tatu) and for 480,000 PE (86,400 m3/day) in Rio de Janeiro (Deodoro).

Aerobic Granular Biomass

Aerobic granules were defined at the First Aerobic Granule Workshop 2004, Munich, Germany which stated “Granules making up aerobic granular activated sludge are to be understood as aggregates of microbial origin, which do not coagulate under reduced hydrodynamic shear, and which subsequently settle significantly faster than activated sludge flocs.”

The main features in defining aerobic granules are minimum diameter of 0.2 mm and SVI5 of aerobic granules being comparable to SVI30 of activated sludge. Figure 1 illustrates the settling properties of aerobic granular sludge compared to activated sludge after 5 minutes of settling.

Figure 1. Settling Properties of the Aerobic Granular Biomass (left) compared to Activated Sludge (right)

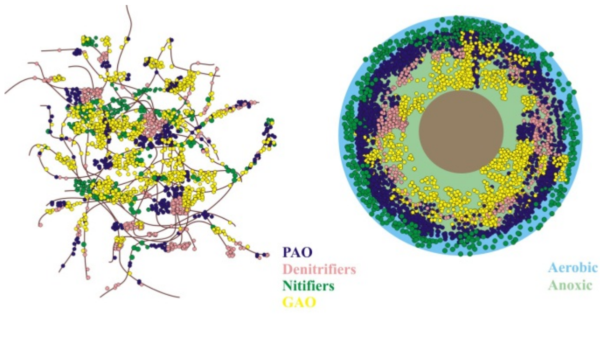

Figure 2. Difference between Activated Sludge (left) and Granular Biomass (right)

The principle of Nereda Technology is utilising design and control mechanisms to encourage biomass to form granules rather than activated sludge. The agglomerates formed allow simultaneous anaerobic, aerobic and anoxic conditions to exist throughout the granules and hence, reduces the need for multiple tanks and recirculation. Figure 2 shows a pictorial representation of the distribution of biological organisms within aerobic granules compared to activated sludge, including phosphate accumulating organisms (PAO), nitrifiers, denitrifiers and glycogen accumulating organisms (GAO).

The process operates intermittently, with the fill and decant phase occurring simultaneously (Figure 3 illustrates the basic Nereda process cycle). Due to good settling capacity of the aerobic granules, the process does not require mechanical decanters to ensure low solids in the effluent.

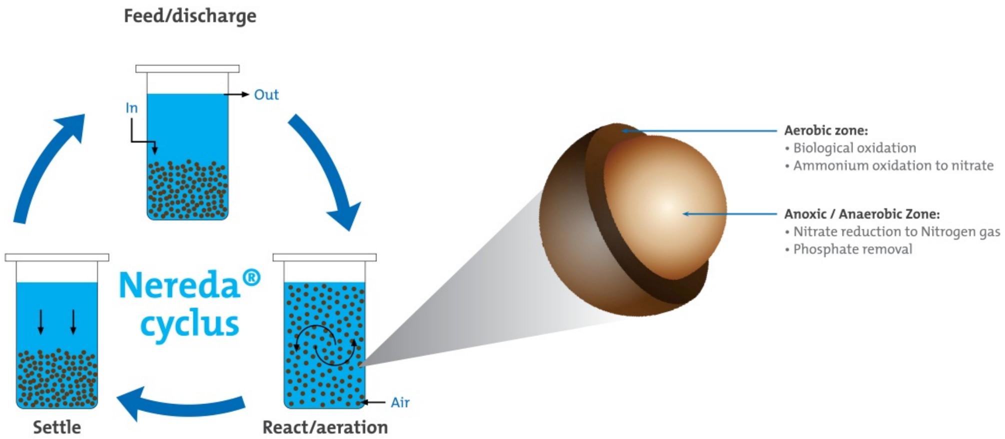

Figure 3. Nereda® Process Cycle

SOME PROJECT DATA

As mentioned above, the first full-scale Nereda® was launched in 2005 by retrofitting a milk storage tank into a treatment tank for a waste water flow of 250 m^3/day at a cheese specialty production factory in The Netherlands. The success of this first milestone confirmed the applicability of the technology and led to various other industrial applications. In parallel the technology was scaled-up for municipal applications, which resulted, in 2008, in the first demonstration installation for treatment of municipal waste water at Gansbaai sewage treatment plant (STP), South Africa. The treatment facility is designed for 5,000 m^3/day of high strength septic influent. It was designed for moderate effluent discharge limits. It shows nevertheless a remarkable high performance (see Table 2), especially when taking into account the minimal attendance for operation and maintenance, the regular power outings in the region and the high solids loading. Most of the treated wastewater from the site is reused for irrigation, after disinfection.

Table 2: Performance data of the demonstration installation at Gansbaai STP (2011)

Parameter	Influent (mg/L)	Effluent (mg/L)	Requirement (mg/L)	Efficiency (%)
COD total	1,265	40	75	97
N_{Kj}	115			
NH_4-N	75	< 1	6	> 98
TN		< 10	15	89
TP	19	3,2	10	82
SS	450	< 5		99

Epe WWTP, The Netherlands

Following the success at Gansbaai, a first Dutch municipal full-scale plant was constructed at Epe WWTP. The Epe WWTP (Figure 4) was designed and constructed by Royal HaskoningDHV in 2010-2011 and is operational since September 2011. Prior to design, a pilot trial was carried out for four years and the data was used to design the full scale plant. The plant consists of the following main processes; inlet works with screens and grit removal, followed by three Nereda® reactors and effluent polishing via gravity sand filters. The Nereda® reactors are designed to take flows with an average daily flow of 8,000 m^3/day and a peak flow of 36,000 m^3/d. If necessary, metal salt is added during effluent polishing to ensure P-levels are within the plant specification. The waste sludge is thickened via a gravity belt thickener and transported off-site.

Figure 4: Nereda® Epe WWTP

The plant was designed to meet the effluent consents as outlined in table 3. The design temperature range was 8°C – 25°C..

Table 3: Epe WWTP – Design Criteria

Parameter	Influent	Effluent limits	Comments
	(kg/d)	(mg/l)	
COD	5,420		
BOD	2,230	7	Average. Maximum value 15 mg/l
Kj-N	570		
TN	570	5	Summer average. Winter average 8 mg/l
TP	61	0.3	Summer average. Winter average 0.5 mg/l
TSS	2,120	30	Maximum value
pH	5-10	6-9	

Since September 2011 the influent to the plant was progressively increased to 100% over a period of four months. The existing plant continued to process the influent along with Nereda® Bioreactors whilst granules were building-up within the bioreactor. It should be noted that part of the "granulation period" was over the winter months when the average wastewater temperature was well below 10°C. Figure 5 shows the steady growth of the biomass during the commissioning phase.

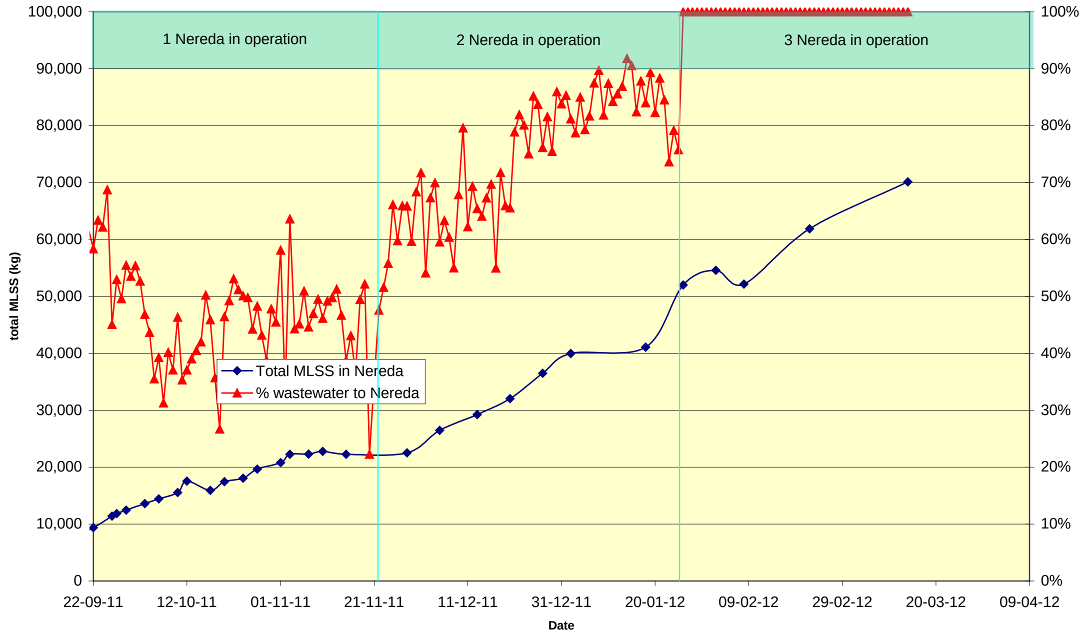

Figure 5: Start-up of Nereda Epe WWTP

The produced water quality during the start-up period is shown in Figure 6. Even though the overall start-up took 4 months, the reactors were able to produce a good quality effluent within just a few days of having been seeded with standard activated sludge. Whilst a 4 month start-up period could be seen to be to detract from the process, these results show that a good effluent quality can be obtained rapidly.

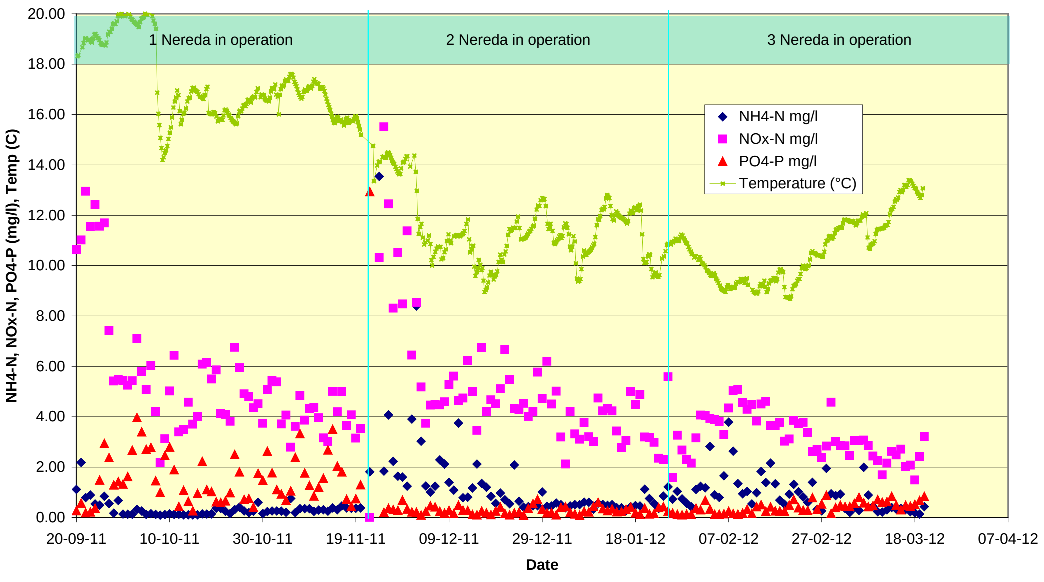

Figure 6: Effluent performance during the start-up of Nereda Epe WWTP

The process proving period for Epe WWTP was completed between March - May 2012. The effluent quality achieved, based on twenty-four hours/ seven days a week composite samples, is summarised in Table 4. Whilst Dutch effluents are typically based on average values, 95 percentile values are also shown for comparison to other consents.

Table 4: Epe WWTP – Performance Results during Process Verification March - May 2012

Parameter	Influent	Effluent (Average)	Effluent (95%ile)
	(mg/l)	(mg/l)	(mg/l)
COD	879	27	32
BOD	333	< 2.0	< 2.0
NKj	77	1.4	1.8
NH4-N	54	0.1	0.1
N-total		< 4.0	5.1
P-total	9.3	0.3	0.34
Suspended Solids	341	< 5.0	< 6.0

Due to industrial discharges, the plant has to cope with large fluctuations in influent characteristics and loads – in particular with pH-values frequently peaking to above pH 10. During the pilot trials, that ran in parallel to the existing ASP, the remarkable process stability of Nereda® was noticed: whilst pH peaks caused complete loss of nitrification in the conventional ASP system taking several weeks to recover, the Nereda® pilot unit receiving the same influent resumed smooth operation after a few cycles and was back to normal operation in 1-2 days after the occurrence.

A key advantage of Nereda® is reduced power consumption. At Epe, the original plant energy consumption was approximately 3,500 kWh/d. With Nereda®, the average daily consumption is now 2,000 kWh - 2,500 kWh. This is approximately 40% less than all types of similar sized conventional plants in the Netherlands. This was further demonstrated at the demonstration plant at Frielas WWTP, Portugal, discussed below.

Results Demo Nereda Frielas Portugal

The Frielas WWTP is a 70,000 m^3/d plant currently at 70% of its biological design capacity and receives, mainly, domestic wastewater from 250,000 inhabitants, in the Greater Lisbon area. Regarding effluent quality, the WWTP has carbon removal and disinfection requirements (i.e., COD < 125 mg/l and TSS < 35 mg/l) and no specific discharge limits for nitrogen and phosphorous. Since start-up in 1997, the Frielas WWTP suffered from several operational constraints related to some technological decision made at the design phase but also because the wastewater characteristics became quite different from those used for the original plant design. To validate if Nereda could improve the plant performance under realistic field conditions, one of the six continuous activated sludge reactors was retrofitted into a Nereda reactor (Figure 7) with a volume of approximately 1,000 m^3, which was then run in parallel to the remaining five activated sludge reactors. This was the first continuous Activated Sludge Nereda retrofit application.

Figure 7 – Conversion of reactor nº6 of Frielas WWTP to Nereda® technology

Besides providing a robust and efficient operation during all influent conditions, a driver for the retrofit was to evaluate the possibility to substantially lower the electricity demand of a conventional WWTP. Another important motivation for the implementation of Nereda® was the possibility of working at higher hydraulic loads and achieving nutrient removal without the (eventual) future need for increasing reactor volume.

The demonstration reactor start-up was made with normal activated sludge from one of the other aeration streams. Operation reached a steady state SVI30 around 40 ml/g, a SVI5 as low as 60 ml/g, a granulation fraction above 80% and an increasing biomass concentration in the range of 6 to 8 g/l. It is important to note that the start-up was made partially during winter time with diluted wastewater (i.e. COD levels below 300 mg/l) contributing to a slower biomass growth and transformation rate.

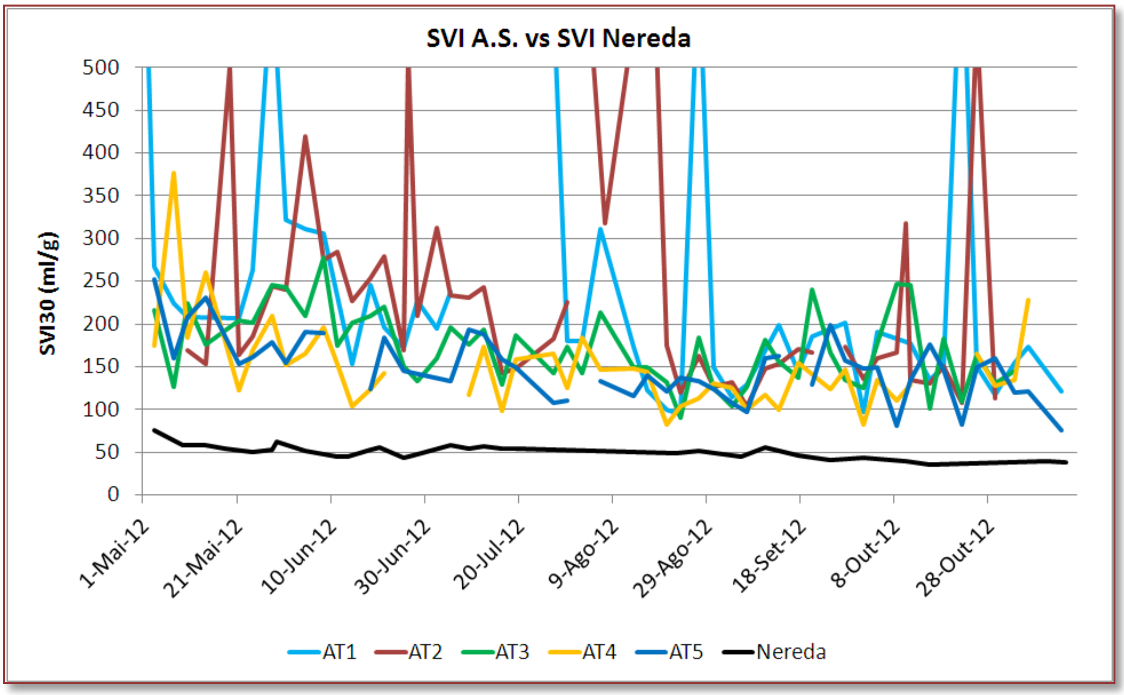

Figure 8 – Comparison between the settleability of the biomasses from the Nereda® reactor and the activated sludge (AS) from the other five biological reactors (AT) in the Frielas WWTP

After more than one year of plant operation the effluent quality was shown to be significantly better and far more consistent than the quality obtained in the original continuous AS system. This plant also gave a unique opportunity to observe the power consumption of Nereda® in parallel to an AS system. Airflow rates are shown in figure 9. A significant decrease in energy consumption was observed. Since Nereda® is operated in parallel with the conventional aeration tanks using the same water depth, existing and common air supply equipment, the comparison between the two technologies is reliable and representative. During a two month monitoring period the air consumption of both systems was measured with the dissolved oxygen (DO) levels similar and nitrification in Nereda® fully suppressed to mimic the biological performance of the AS reactors.

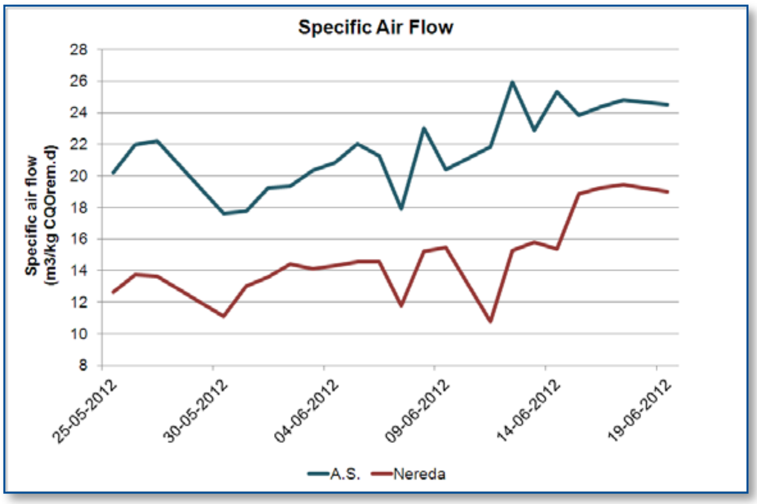

Figure 9 – Comparison between the airflow rates to activated sludge and Nereda plants

Taking into account the efficiency of the air blowers, the measured air flow consumed in each system per mass of chemical oxygen demand (COD) removed was translated into the specific electricity consumption. It was observed that the average specific consumption for the Nereda® amounts to 0.35 kWh/kg COD removed, representing approximately 30% electricity savings compared to aeration for the AS system. Combining this with the energy saving that granules bring by not using settling tanks, sludge recirculation pumps and post-filtration units, the overall electricity saving potential for the plant was computed to 50%.

Following the positive results obtained with the Nereda® demonstration reactor, Royal HaskoningDHV has been commissioned to design and implement an extension of the demonstration to a full-scale reactor operated parallel to the existing continuous Activated Sludge treatment reactors. Plant start-up is foreseen Mid 2014. The reactor will have a treatment capacity of 12,000m^3/d and 40,000 inhabitants. After this upgrade the Frielas WWTP will be able to meet the current discharge requirements and be operated as a hybrid Nereda® plant; the granular excess biomass from the Nereda® reactor is pumped to the continuous AS lines. By this inoculation process, the sludge characteristics and settling performance of the existing AS plant will improve, resulting in a further increase of its hydraulic and biological treatment capacities. It is possible that in future more reactors at the plant will be retrofitted.

WWTP Garmerwolde, The Netherlands

Since its 2005 retrofit into an AB-system, the Garmerwolde STP was not able to meet the required nutrient removal targets. For the upgrade of the 375,000 pe STP, the consortium of contractors GMB/Imtech and their consultant Witteveen + Bos selected Nereda as the best approach to extend the biological treatment and biological nutrient removal capacity. The solution involved the addition of two 9,500 m^3 Nereda® reactors, with 150,000 p.e. total capacity in parallel to the existing plant (Figure 10). Capacity of this addition is 30,000

m^3/day average and 4,200 m^3/h peak flow. The Nereda® tank sizes at Garmerwolde are similar to the world's largest SBR-tanks. The plant was commissioned in Summer 2013. The plant was primarily seeded with activated sludge and during the sludge transformation process the treated flow was gradually increased and met the design flow within approx. 3 months. Since activated sludge from an extended aeration system was used as a seed, during start-up the nitrogen removal was almost instantaneous meeting the discharge, while extensive biological phosphate removal developed over the three month period. Currently the plant is in the one-year performance test period to validate that the combined effluent meets the target of TN <7 mg/l and TP<1 mg/l. The energy consumption of both the Nereda® as the AB-system is closely monitored and shows that the Nereda treatment line is 50-60% more energy efficient.

Figure 10 – Nereda® Garmerwolde WWTP
(The two Nereda tanks in front treat approx. 40% of the sewage. The existing AB-system in the back 60%.)

Conclusions
Like activated sludge a century ago, its innovative offspring aerobic granular biomass is a game-changer in the biological treatment arena and considered to become the new aerobic treatment standard. The last two decades, the Nereda® aerobic granular biomass technology has been developed, scaled-up and matured from laboratory, pilot and prototype into a dozen full scale applications. The data from these industrial and municipal applications demonstrate that biological nutrient removal in combination with high energy-efficiency and cost-effective plant construction are obtained.

The steadily growing number of international Nereda® applications and tank sizes close to the largest sequencing batch reactor tanks worldwide, mark that the innovation has matured into an applied technology that is now ready for implementation for even the largest-scale wastewater treatment applications.

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