Full-scale Experiences with Aerobic Granular Biomass Technology for Treatment of Urban and Industrial Wastewater

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Abstract:

Aerobic granulation is seen as the future standard for industrial and municipal wastewater treatment and subsequently research efforts are quickly developing in this field. As an outcome of a concerted Dutch program, an aerobic granular biomass technology has been scaled-up and implemented for the treatment of urban and industrial wastewater. This Nereda® technology is considered being the first aerobic granular sludge technology applied at full-scale. Operating data from the first municipal full-scale plant confirm the projected advantages with regard to treatment performance, energy-efficiency and cost-effectiveness. Currently approx. 40 international aerobic granular sludge plants are at various stages of development. For example, recently Brazil planned to build at least 10 plants in the coming years. The technology, now applied at tank sizes similar to the world's largest SBR-tanks, is considered proven and applicable for even the largest applications. During the presentation the latest results and lessons learned will be presented.

Keywords:

aerobic granular biomass, sustainability, innovative biotechnology, Nereda, biopolymer harvest ing, extensive biological nutrient removal, energy efficiency

INTRODUCTION

Since the development of biological nutrient removal (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 settleability 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 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.

THE TECHNOLOGY

Nereda Development

The research and development of aerobic granules commenced at DUT in 1993. In 2002 aerobic granular sludge was 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 green field 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 new Nereda plants with capacities up to 530.000 P.E. are currently under design and construction and the number of international applications in the pipeline is steadily growing. The most recent plant that was commissioned is Garmerwolde, The Netherlands. This is used to upgrade the capacity of an existing activated sludge plant with an additional flow and load from 150,000PE in just two 9,500m3 Nereda reactors. This Nereda tank size is close to the largest sequencing batch reactor tanks worldwide (Cardiff, and Ringsend).

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)

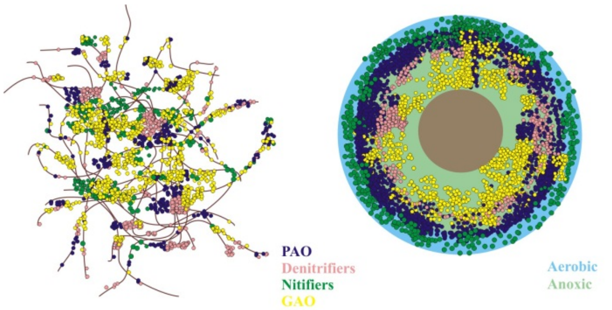
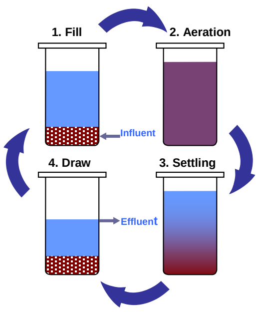


Figure 2. Difference between Activated Sludge (left) and Granular Biomass (right)

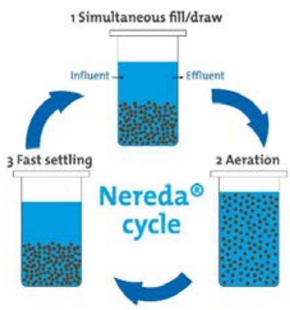
The principle of Nereda Technology utilises design and control mechanisms to encourage biomass to form granules rather than flocs. The agglomerates formed allow simultaneous anaerobic, aerobic and anoxic conditions to exist throughout the granules and hence, reduces the need for multiple tanks and recirculation. 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).

Due to the unique characteristics of granules, Nereda technology uses an optimized SBR-cycle, in which the 4 steps of a typical SBR cycle are reduced into 3 steps:

1. Simultaneous fill / draw. During this cycle step the wastewater is pumped into the reactor and at the same time the effluent is drawn.
2. Aeration. During the aeration phase the biological conversion processes take place. The outer layer of the granules is aerobic and here nitrifying bacteria accumulate. The formed nitrate is denitrified in the anoxic core of the granules. And last but not least, phosphorous uptake occurs.
3. Sedimentation. After the biological processes a sedimentation phase is required for separation of clear effluent and sludge. This time is short due to the excellent settling properties of the sludge. Then the system is ready for a new cycle.



a. A typical SBR cycle



b. Nereda® cycle

Figure 3. SBR cycle and Nereda® cycle

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

PROJECT REFERENCES

There are currently about 10 international full-scale Nereda installation in operation for the treatment of industrial and municipal wastewater, and the number of references is growing fast, as shown in table 1.

Table 1. Nereda Reference list

Site	Population Equivalent	Design Flow
Cheese speciality industry	5,000	250m^3/d
Edible oil industry (SBR retrofit)	44,000	440 m3/h
Convenience food industry	7.000	
Convenience food industry	14.000	360 m3/d
STP Epe	59.000	1.500 m^3/h
STP Vroomshoop	25.000	1.265 m^3/h
STP Dinxperlo	15,730	(close to commissioning)
STP Lisbon	700,000	3 MLD (demo)
STP Gansbaai	63,000	5 MLD
STP Stellenbosch	40,000	5 MLD (close to commissioning)
STP Garmerwolde	150,000	4,200m^3/h
STP Utrecht	530,000	15,000m^3/h (demo in operation)
Pipeline: approx. 40, inclusive larger scale, in Australia, China, Brazil, India, Middle-East, Poland		

The first full-scale Nereda was launched in 2005 by retrofitting a 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. This was followed, in 2008, by 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 m3/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

Following the success at Gansbaai, a 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 m3/day and a peak flow of 36,000 m3/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.

The plant was designed to meet the effluent consents as outlined in table 3. The design temperature range was 8°C – 25°C. Wastewater flow and load variation can be considered to be similar to typical UK conditions.

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 4 shows the steady growth of the biomass during the commissioning phase.

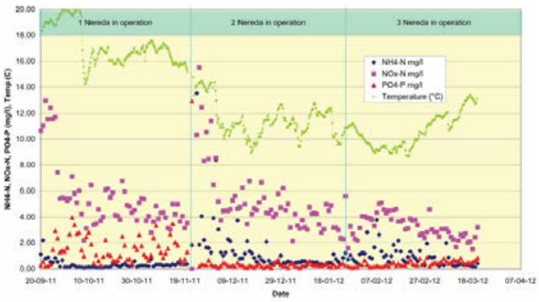


Figure 4. Start-up of Nereda Epe WWTP
Figure 5. Effluent performance during the start-up of Nereda Epe WWTP

The produced water quality during the start-up period is shown in Figure 5. 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.

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 2. Whilst Dutch effluents are typically based on average values, 95 percentile values are also shown.

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 influent characteristics and loads with quite large quite fluctuations and with pH-values frequently peaking to above pH 10. Also during the pilot trails - that run in parallel to the existing ASP at Epe STP- the remarkable process stability of Nereda has been noticed: whilst low 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 35% 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 6) 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.

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.

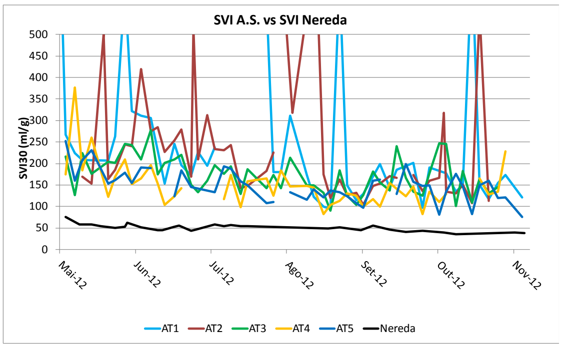


Figure 6. Comparison between the settleability of the biomasses from the Nereda reactor and the activated sludge (AS) from the other five biological reactors (AT) in the Frielas WWTP

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 7. 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.

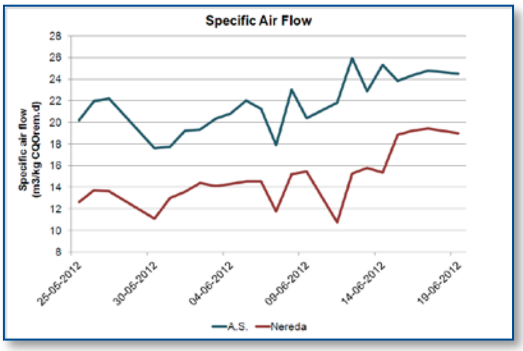


Figure 7. Comparison between the airflow rates to activated sludge and Nereda plants

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 CODremoved, representing approximately 30% electricity savings compared to aeration for the AS system. Combining this with the energy saving that granules brings 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 have 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. The reactor will have a treatment capacity of 12,000m3/d and 40,000 inhabitants. After this upgrade the Frielas WWTP will 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

One of the most recent Nereda start-ups is in the north of the Netherlands, in Garmerwolde. For the upgrade of the 375,000 pe STP Garmerwolde of the District Water Board Noorderzijlvest, the consortium of contractors GMB/Imtech and their consultant Witteveen + Bos selected Nereda as the most promising technology. Since its 2005 retrofit into an AB-system, the Garmerwolde STP was not able to meet the nutrient removal targets. The water board decided to launch a Design & Build tender to modify and optimize the plant. Based on evaluation of more than twenty options, the winning consortium selected as their best solution to extend the biological and biological nutrient removal capacity with Nereda. The addition of two Nereda reactors, with 150,000 p.e. total capacity, in parallel to the existing plant convincingly outcompeted a full range of different solutions provided by other bidders. Capacity of this addition is 2,000 m3/day and 4,200 m3/h peak flow. The overall plant capacity is 9,600 m3/day and 13,500 m3/h peak flow (375,000 p.e.). Tank sizes in Garmerwolde are similar to the world’s largest SBR-tanks such as Alanya (Turkye), Cardiff (UK) and Ringsend (Ireland).

CONCLUSIONS

The aerobic granular biomass technology has been developed, scaled-up and matured from laboratory, pilot and prototype into various large scale applications. The data from industrial and municipal applications demonstrates that biological nutrient removal in combination with high energy-efficiency and cost-effective plant construction is possible.

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

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