OPERATING RESULTS FROM THE FIRST FULL SCALE AEROBIC GRANULAR SLUDGE "NEREDA®" PLANT – EPE WWTP

Monita Naicker[1], Ronald Niermans[2], Bart de Bruin[2]
1. Aquatec-Maxcon, Queensland, Australia
2. Royal HaskoningDHV, Amersfoort, The Netherlands

ABSTRACT

Aerobic granular sludge is one of the path-breaking innovative technologies that have the potential to change the biological nutrient removal of waste water treatment process. The first full scale municipal wastewater treatment plant in the world is in Epe, Netherlands. The Epe WWTP was designed to treat flows up to 60,000 EP with more than 30% industrial waste contributions (including abattoir waste). The plant has been in operation for over a year. This paper discusses the operational results that are being achieved at the Epe WWTP and the potential this new technology can provide the wastewater industry in Australia.

INTRODUCTION

Since the development of BNR systems for activated sludge, the research on municipal wastewater treatment processes has focussed on improved separation techniques for activated sludge by improving settlability, 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. Discovered by Professor Mark van Loosdrecht from Delft University *(2012 Lee Kuan Yew Water Prize winner)* aerobic granular sludge has been applied successfully in pilot plants..

Aerobic granular sludge has several advantages over conventional activated sludge flocs that has been well-documented. These include superior 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 process has been engineered to suit commercial applications by DHV (now known as Royal HaskoningDHV) and has been commercially branded as Nereda® Technology. Nereda® Technology uses control measures to ensure that the environment within the bioreactor is favourable to the natural selection processes. It is conducive to aerobic, anoxic and anaerobic bacteria to aggregate and hence, enable biological processes to occur within a single reactor. Full scale plants have been applied in Netherlands, Portugal and South Africa with six plants with capacities up to 150.000 EP being currently constructed.

Nereda® Development

The research and development of aerobic granules commenced at Delft University in 1993. Delft University, DHV, STW (Dutch Foundation for Applied Science) and STOWA (Dutch Foundation for Applied Water Research) and six Dutch Water Boards combined to form Dutch National Nereda Development Programme (NNOP) to develop and market aerobic granular sludge technology in 2007.

Professor Mark van Loosdrecht and his team discovered aerobic granular sludge and achieved stable laboratory scale granulation in 2002. 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 full scale Nereda® technology was applied for an industrial plant upgrade in 2007 by converting existing SBR tanks into Nereda® bioreactors. Two demonstration Nereda® plants (Gansbaai, South Africa and Frielas, Portugal) were built in 2008. Epe WWTP was designed and built in 2011 and has been in operation for more than a year. Post the successful design, construction and operation of Epe WWTP, there are several plants at various stages of development in and outside Europe.

Aerobic Granular Sludge

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 SVI_5 of aerobic granules being comparable to SVI_{30} 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 Sludge compared to Activated Sludge

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.

Below (Figure 2) is 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).

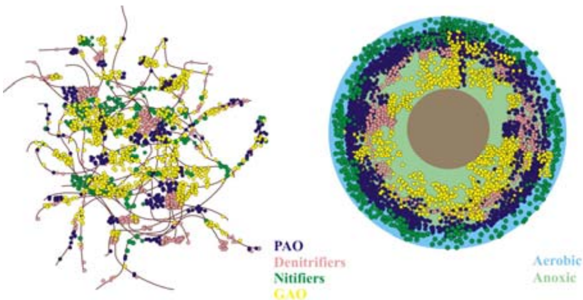

Figure 2: Difference between Activated Sludge and Granular Sludge

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

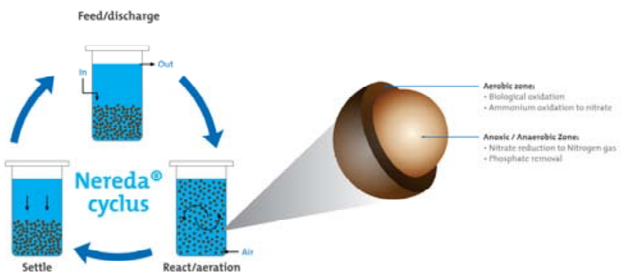

Figure 3: Nereda® Process Cycle

METHODOLOGY/ PROCESS

The Epe WWTP (Figure 4) was designed and constructed by DHV in 2010-2011 and was operational in September 2011. A pilot trial was carried out for two years and the data was used to design the full scale plant. The plant consists of the following main processes; inlet works with 3mm screens and grit removal, followed by three (3) Nereda® Bioreactors and effluent polishing via gravity sand filters. The Nereda® Bioreactors 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 effluents polishing to ensure P-levels are within the plant specification. The waste stream is thickened via a gravity belt thickener and transported off-site.

Figure 4: Epe WWTP – First full scale Nereda® Technology Plant

The plant was designed to meet the following criteria (Temperature range 8°C (winter) – 25°C (summer)):

Table 1: Epe WWTP – Design Criteria

Parameter	Influent average kg/d	Effluent Limits mg/L	Comments
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	6-9	6-9	

This study looks at the following aspects of Epe WWTP:

- Nereda® plant start-up phase
- Effluent Quality achieved during the plant verification period.
- Energy Consumption over the past year
- Sludge Production and Polymer Usage

RESULTS/ OUTCOMES

Epe WWTP Start-up

Epe WWTP has been online since September 2011. Figure 5 shows the mixed liquor build-up during this period, as well as when each of the Nereda® Bioreactors were brought online.

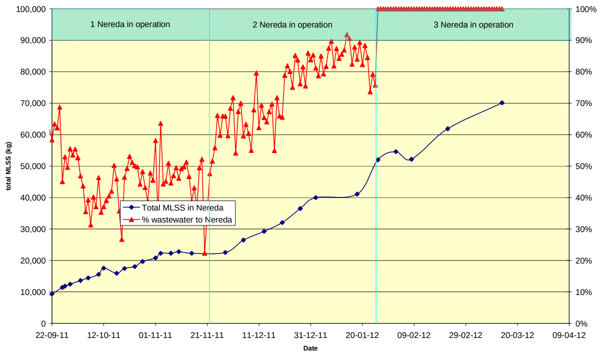

Figure 5: MLSS Build-up at Epe WWTP

Progressively, the influent to the plant was increased to 100% over a period of four (4) 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 the "granulation period" was over the winter months when the average wastewater temperature was below 10°C.

Plant Verification Period (Effluent Quality)

The process proving period for Epe WWTP was successfully completed between March to May 2012. The average effluent quality achieved based on twenty-four (24) hour composite samples are summarised in Table 2.

Table 2: Epe WWTP – Performance Results during Process Verification March - May 2012

Parameter	Influent mg/l	Effluent (Average) mg/l	Removal
COD	879	27	96.9%
BOD	333	2.0	99.4%
N_{Kj}	77	1.4	98.1%
NH_4-N	54	0.1	99.8%
N-total		< 4.0	>94.7%
P-total	9.3	0.3	97.2%
Suspended Solids	341	< 5.0	>98.5%

The wastewater temperature ranged from 14°C to 16°C with ammonia and nitrate results well within the design envelope.

Figure 6 shows the daily Ammonia, Nitrate and Temperature results at Epe WWTP. As the wastewater temperature started rising, the ammonia levels are below 1mg/L and nitrate levels are below 5mg/L. The design levels for both these criteria (compare Table 1, summer and winter conditions)were easily met.

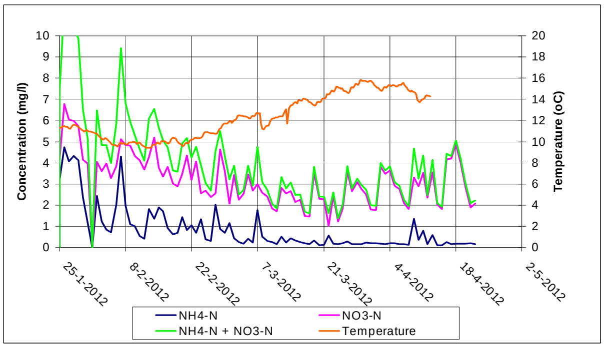

Figure 6: Ammonia, Nitrate and Temperature at Epe WWTP

Figure 7 shows the daily PO_4- P results at Epe WWTP.

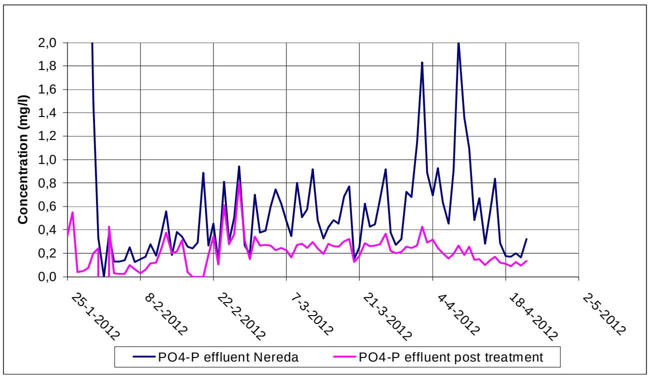

Figure 7: PO_4- P for both filtered and unfiltered effluent at Epe WWTP

The phosphate levels are shown in Figure 7 for both filtered and unfiltered effluent (unfiltered effluent is directly from the Nereda® overflow.

Plant Summary - Full year of Operation, January-December 2012

A summary of operational data (including influent loads, plant flows, chemical usage and solids over the 12month period is tabulated below.

Table 3: Plant operating summary (Jan –Dec 2012)

Parameter	Plant Operating Data (Jan – Dec)	Comments
Influent loads (Averages)		
COD	3,790 kg/d	
BOD_5	1,435 kg/d	
TKN	345 kg/d	
P_{total}	41 kg/d	
Load/capacity	41,250 Pop. Eq.	Design capacity: 59,000 Pop. Eq.
Total Effluent flow	1,745,000 m^3	Includes Sand filter flush flow of 90,810 m^3
Average Daily Flow	4,780 m^3/d	
Maximum Daily flow	25,260 m^3/d	
Total Recirculation flow	2,215,000 m^3	
Recycle flow Ratio	1.25 Q_{in}	Note: In conventional BNR plants this Q_R would be 5-8 times higher than Q_{in}
Alum	2.310 kg/yr	Alum concentration 67 kg/m^3. Volumetric consumption 34.5 m^3.
Me/PO_4 ratio in Nereda overflow	1.5	Note: this ratio is between PO_4 levels in the Nereda effluent, not plant influent. The ratio between plant inlet PO_4 and Me is approximately 0.05.
Total Sludge production	513, 000 kg DS/yr.	
Dry Solids Content	4.1 %	
Polymer use for Sludge Thickening	1,605 L/yr.	Pure liquid product with 50% active Polymer
Specific Polymer use	1.7 g PE active / kg DS	

The sludge production over the past year is summarised in Table 3. The Epe sludge is anaerobically co- digested and dewatered at a large WWTP nearby. The dewatered sludge is incinerated at a centralized facility. The dry solids content of the sludge is maintained at 4% to ensure that this is easily transportable. It is expected that aerobic granular sludge should have improved dewatering capability than activated sludge; however, further studies are currently carried out to substantiate this.

The average effluent concentrations (based on the online data) is summarised in Table 4 demonstrating that the plant is meeting its design criteria.

Table 4: Effluent Concentrations (based on Online Analysers)

Parameters	Effluent Concentrations (Average of flow proportional daily average values)
NH_4	0.8 mg/L (Nereda overflow)
NO_3	4.1 mg/L (Nereda overflow)

PO_4	1.0 mg/L (Nereda overflow)
P_{total}	0.5 mg/L (sand filtration overflow)[1]

Figure 8 shows the plotted results for PO_4 levels over the long-term. For a period of 6weeks, the PO_4 levels in Nereda® overflow and sand filter effluent were the same due to adjustment of the metal salt dosing system. The rising PO_4 in Nereda® reactor overflow in November 2012 is mainly due to plant low load conditions and a strategy is developed to control this in future.

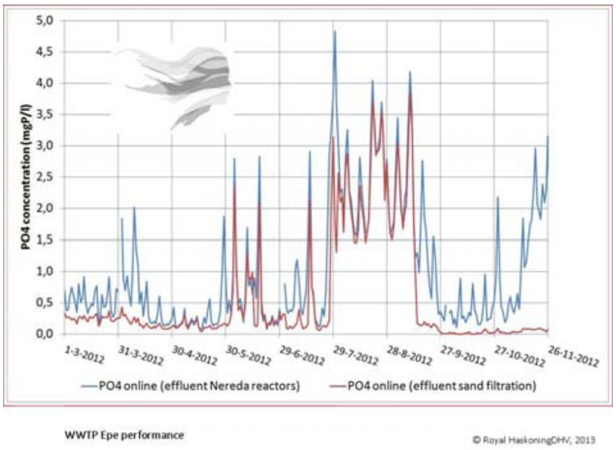

Figure 8: PO_4- P for both filtered and unfiltered effluent at Epe WWTP over 11 months

The extensive pilot test period on the Epe site has shown the robustness of Nereda® compared with conventional activated sludge systems, e.g. during pH upsets. Mainly due to the (illegal) industrial discharges the pH level of the influent sometimes peaked at pH 10-11 or dropped to pH 4-5. While the conventional system suffered major damage in operation for weeks in a row after such upsets, 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 upset occurrence.

Energy Consumption

The energy consumption during the start-up phase is shown in Figure 9. The energy consumption was reduced once the existing plant was taken off-line (mid February 2012). The plant overall energy consumption decreased from 3,500 kWh/d to 2,250 kWh/d, however, as the Nereda® Plant started receiving full plant load – the energy consumption in the Nereda® reactors due to aeration increased from 1,000 kWh/d to 1,250 kWh/d. 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.

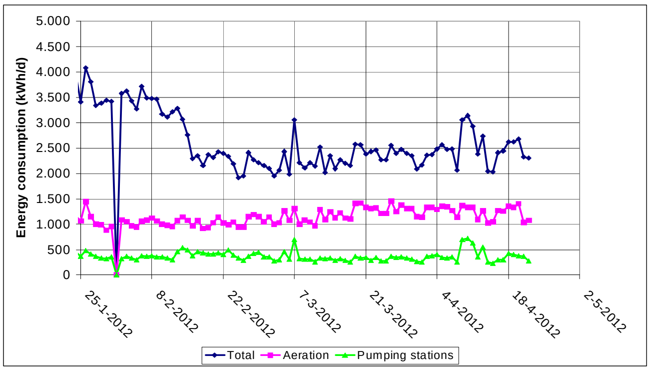

Figure 9: Energy Consumption at Epe WWTP

The energy usage during plant operation over the last 12months is summarised below.

Table 2: Epe WWTP – Plant Energy Usage from Jan 2012- Dec 2012

	Plant Energy Usage
Total energy use (inclusive Jan-Feb use of old existing facility)	909,300 kWh
Total Energy use of aeration blowers	419,000 kWh
Average use Jan-Feb with old plant still partly in use and Nereda® Plant in operation	3,295 kWh/d

[1] Higher than yearly target – due to metal salt dosing unit adjustment; currently steady at 0.3 P_{total}

Average use Mar-July (100% Nereda®):	2,465 kWh/d
Average Aug-Dec (100% Nereda®, optimised):	2,135 kWh/d

The plant is operating at 70% capacity and could meet license requirements with now only two-Nereda® reactors in operation. However, the third reactor was also brought online for the official plant opening ceremony in May 2012. The energy results post-optimisation, is for all three reactors at 70% plant ultimate design load.

In order to draw a comparison between real energy data from operating plants in South East Qld[2], the current energy consumption is 0.43 kWh/kL. The Epe plant doesn't have primary sedimentation and digisters. Whilst it is always difficult to compare energy usage between operational plants due to differences, in operating conditions, process selection, effluent requirements, equipment efficiencies, and economy of scale, it should be noted that Luggage Point WWTP and Oxley WWTP (QUU operated) which are an order of magnitude larger plants than Epe WWTP (220,000 -670,000 EP) achieves 0.4-0.5kWh/kL. Both plants have cogeneration facilities to achieve this. Compared to conventional operating plants, this is a significant improvement in energy foot-print and is one of the fundamental advantages of adopting the technology in Australia.

CONCLUSION

Nereda® Technology as proven by the performance from Epe WWTP has the potential to revolutionise biological nutrient removal in wastewater in Australia. Unlike Netherlands, lack of space is generally not a concern in Australia, however, the small footprint of the bioreactors means that Nereda® bioreactors can reduce initial capital investment. There is also a potential for retrofitting existing bioreactors to increase plant capacity and reduce plant operating costs. Nereda® offers substantial benefits through simplification of mechanical equipment, reduced tank volumes, plant footprint and hence, reduced capital investment.

The short-term drawback of Nereda® treatment process within Australia is the relatively long start-up phase (as can be observed during the commissioning period from Epe WWTP). Once there are a number of plants operational in Australia to utilise as the "sludge seed" factory the long granulation phase will be eliminated. This is evident in Europe where Epe WWTP and existing smaller industrial plants will become the seed sludge factory for the six plants under construction. Within Australia, this means that Nereda® reactors may first be considered for areas where an existing plant is being upgraded. For greenfield sites temporary measures need to be applied whilst the aerobic granules are being developed during the start-up phase, be it that experience shows good purification results already achieved long before full granulation is accomplished. Furthermore, the expectation is that the granulation period should be shorter in Australia due to relatively higher wastewater temperatures compared to the Netherlands.

Australia's regulatory bodies have pushed the envelope in terms of nutrient levels required for treated effluent to be discharged into waterways. Traditionally, the penalty for nutrient removal has been the added complexity in operation, equipment, controls and most of all, higher energy usage. One of the fundamental benefits of the Nereda® as observed over the 12months of operation at Epe WWTP is the energy savings. Considering that these are still the early days of

[2] Source: MBR Passing FAD or Future Presentation AWA technical meeting, QLD

operation, further optimisation, design learnings from Epe WWTP means that the energy consumption for Nereda® plants should reduce in the near future.

The carbon tax added to raising energy costs means that water authorities will need to take up innovative technologies that will not compromise effluent quality, and plant reliability. Nereda® Technology offers significant energy savings which will be of greater importance with Australia's commitment to reducing carbon emissions.

REFERENCES

D Sharland and S. Page, 2012, MBR Passing FAD or Future, AWA Technical Meeting Presentation Notes, QLD

A.Nor Anuar, Z Ujang, MCM van Loosedrecht and M.K. deKreuk, 2007 Settling Behaviour of aerobic granular sludge, Water Science & Technology Vol 56 No 7 pg 55-63, IWA Publishing.