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Advancements in the application of aerobic granular biomass technology for sustainable treatment of wastewater

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Abstract

Aerobic granular sludge technology can be regarded as the future standard for industrial and municipal wastewater treatment. As a consequence, a growing number of institutes and universities focus their scientific research on this new technology. Recently, after extensive Dutch research and development effort, an aerobic granular biomass technology has become available to the market. Full scale installations for both industrial and municipal applications are already on stream, under construction or in design. The technology is distinguished by the name 'Nereda®' and based on the specific characteristics of aerobic granular sludge. It can be considered as the first mature aerobic granular sludge technology applied at full scale. It improves on traditional activated sludge systems by a significantly lower use of energy and chemicals, its compactness and its favorable capital and operational costs.

Key words: aerobic granular biomass, innovative biotechnology, Nereda, sustainability

DEVELOPMENT OF AEROBIC GRANULAR BIOMASS

For more than a century the conventional activated sludge process (CAS) is the standard for wastewater treatment. It is capable of extensive biological nitrogen and phosphorous removal (BNR) with a high operational flexibility. Because of the poor sludge settling properties CAS systems require a relatively large footprint. Especially in countries with combined sewerage systems the footprint for secondary clarifiers need to be large. In order to provide a solution that overcomes this drawback, many institutes and university focus their scientific research on the fundamentals of aerobic granular biomass to work on the replacement of activated sludge.

Recently, as outcome of extensive Dutch research and development efforts, a new technology became available and was implemented at pilot and then full scale. This Nereda® technology is based on the specific characteristics of aerobic granular biomass. It is considered to be the first mature aerobic granular biomass technology that is applied in full practice. It distinguishes itself from traditional activated sludge systems by a significant lower use of energy and chemicals, its compactness and its lower investment and operational costs.

A team led by the 2012 winner of the prestigious Lee Kuan Yew Water Prize, Prof. Mark van Loosdrecht of the Delft University of Technology was the first to develop a feasible method to obtain stable aerobic granulation during the wastewater treatment process. Consulting engineer Royal Haskoning DHV collaborated closely with Delft University of Technology for more than a decade to translate results from lab scale to pilot and full scale installations. This required the adaptation from controlled conditions and artificial feed in a lab to fluctuations in temperature, diurnal flow patterns and real wastewater as feed source in full scale practice. It was a necessary step to mature the innovative technology into an applicable system.

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In addition to close collaboration with research institutes, municipal and industrial launching customers in several countries, a unique public-private partnership (PPP) proved instrumental in the scale-up of the technology for larger municipal applications. This PPP comprised the Dutch Foundation for Applied Water Research (STOWA), Delft University of Technology, Royal HaskoningDHV and six Dutch District Water Boards. At five municipal WWTPs in the Netherlands intensive pilot research was executed, focusing on granulation and nutrient removal. The development program was further supported by fundamental research at the University of Delft and was subsidized by several national and international innovation programs.

NEREDA® TECHNOLOGY

Since aerobic granular biomass was born in the laboratory of Delft University of Technology, fundamental research has been booming ever since and gave insights into the granulation process, although not even to date all mechanisms are fully understood. It is clear that stable granulation can be obtained if sufficiently high sedimentation selection pressure is applied in combination with selection of slow growing bacteria that produce biopolymers that constitute the granules' physical matrix. Such crucial process and operational conditions can be best achieved using a batch wise operated system.

The Nereda technology uses an optimized sequencing batch reactor (SBR) cycle (see Figure 1) in which fill and draw are efficiently combined in a first process step. During this feed step, the influent is distributed at the bottom of the reactor and effluent is simultaneously displaced from the reactor at the top. The granular biomass properties enable high specific hydraulic loadings. After feeding, the aeration is started and in this second step a wide range of biological purification processes takes place. The supplied oxygen will only penetrate into the outside layer of the granule, as it is consumed by autotrophic- and heterotrophic organisms in that zone. The inside layer of the granule is anoxic and anaerobic. Subsequently, efficient simultaneous nutrient removal is achieved without the need for separate oxygen rich and oxygen depleted reactor compartments: e.g. transport of nitrate or nitrite takes place by diffusion, not by pumping. In the last step of the cycle the granular biomass is allowed to settle. Since granules have excellent settling properties, short settling times can be applied, resulting in less 'downtime'.

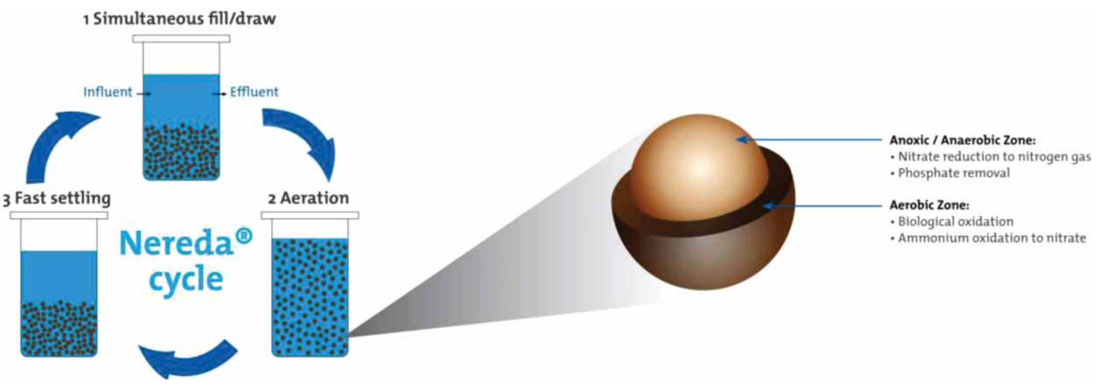

Figure 1 | Schematic view of the Nereda® cycle.

RESEARCH PROGRAM

Since 2003, at five locations pilot research was executed with municipal waste water. The pilot plants (see Figure 2) with a capacity of 5 m^3/h consist of one or two parallel reactors with height and

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Figure 2 | Pilot-scale unit.

diameter of 6 and 0.6 m respectively, equipped with extensive online monitoring (NH_4, NO_x, PO_4) and process control features.

At the start of the development program, granulation was the most important research focus. Figure 3 (left) shows some typical characteristics of the aerobic granules. With decreasing SVI in time, the SVI_5 equals more and more the SVI30. With mature granules even the SVI_2 equals the SVI_{30} and generally amounts 30–60 mL/g. Sludge concentrations higher than 10–15 kg MLSS/m^3 are achievable, but for design purposes in municipal applications a value of 8 kg/m^3 is typically chosen. The photograph in Figure 3 (right) demonstrates clearly the superb settling characteristics of aerobic granules (left) after only 5 minutes in comparison with activated sludge (right) both samples containing 4 g/L.

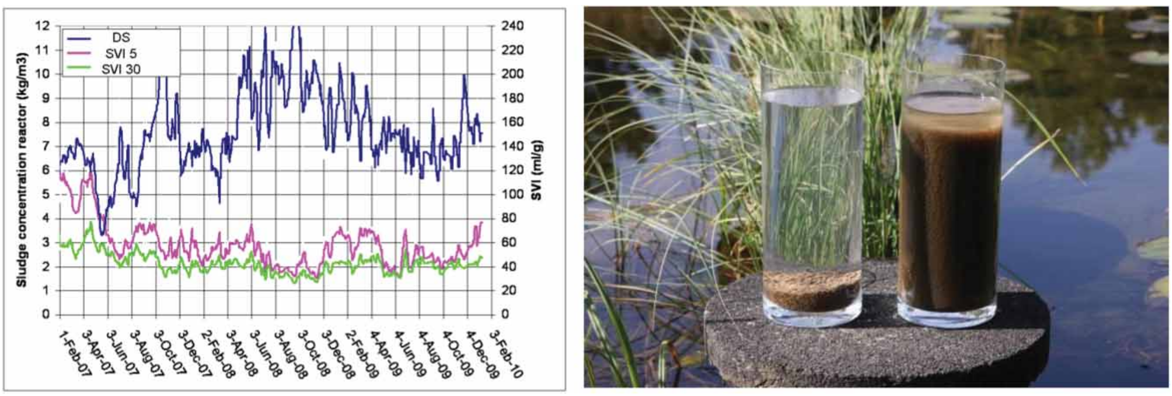

Figure 3 | Characteristics and photograph of granules.

After granulation was shown and proven at pilot scale, optimization of nitrogen and phosphorous removal became the main research topic. For several projects the ambitions with respect to nutrient removal rates were set higher, to meet more stringent effluent discharge limits like TN < 5 mg/L and TP < 0.5 mg/L. Moreover, these limits are to be achieved at specific Dutch circumstances, implying

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low process temperatures (<10 °C) and higher RWF/DWF ratios. During the severe winters of 2008–2009 and 2009–2010 the research projects showed the great possibilities of the Nereda® technology even under these harsh conditions. At average MLSS-concentrations of 8 kg/m^3 BNR without addition of chemicals still resulted in very good system performance.

Furthermore the pilot tests showed a striking robustness and reliability of the technology. While an in parallel operating activated sludge system suffered from chemical spills in the received sewage, the Nereda® system could handle these toxic loads very well. This confirmed the results of various laboratory experiences, which showed that the stability and robustness of aerobic granular biomass outperforms those of activated sludge. The stable biopolymer matrix of the compact granule seems to protect the biomass to a certain extent during process against short term toxic loads. The high concentration of biomass and the latent available and diverse micro-biological population makes the process less sensitive to and quicker to recover from severe process upsets.

FULL-SCALE RESULTS

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. While the PPP was working on the scale-up for larger municipal applications, the technology was further valorized in other industrial applications. For example, in 2006 the first green field industrial application came on stream for the treatment of 250 m^3/day wastewater from a small food industry. When in 2009 this company decided to relocate their production facility, key equipment was shipped to another location and retrofitted on-site into a Nereda® treatment plant (Figure 4) with twice the original treatment capacity (COD removal of 500 kg/day). Seeded with normal activated sludge, full granulation of the biomass was obtained within 3 months. The influent COD currently ranges from 1,000 to 8,000 mg/L and the unit is fully loaded with daily peaks up to two times design capacity. With biomass concentrations maintained at as much as 10–20 g/L, sludge volume indices after 5 minutes that amount to only 20–30 mL/g, at process temperature of approx. 40 °C and absorbing large feed fluctuations, the unit consistently meets the treatment requirements with COD reductions of approx. 95% (Figure 5).

Figure 4 | Nereda® installation – food industry.

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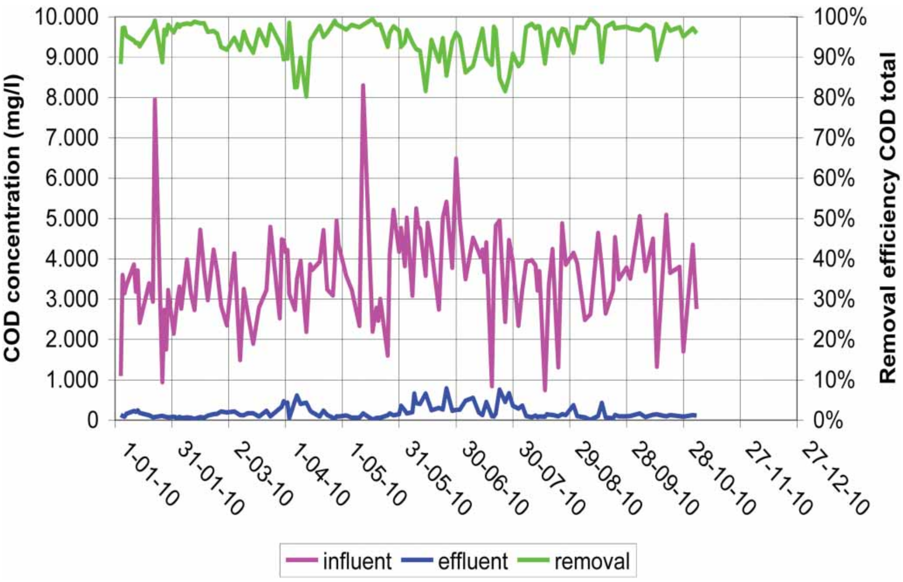

Figure 5 | Feed and effluent characteristics.

Larger scale municipal application was initiated in 2008 when in South Africa a first demonstration installation (Figure 6) was started-up for treatment of municipal waste water at Gansbaai STP. The treatment facility is designed for 4,000 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 1), 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.

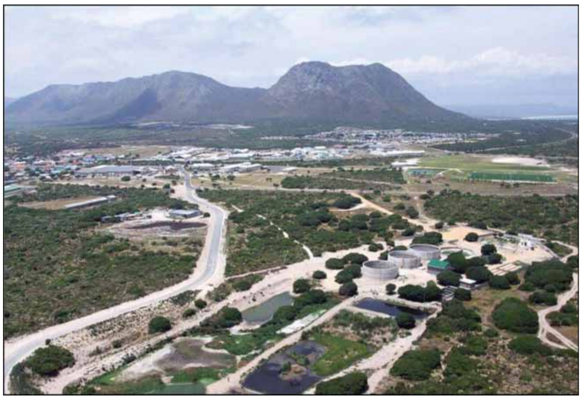

Figure 6 | Demonstration installation South Africa.

Table 1 | Influent and effluent data municipal demonstration installation South Africa (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

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Building on the experience and the excellent results of all installations, the step to a larger municipal Nereda® application was easily made when, at the end of 2011, the first municipal full-scale installation at STP Epe, The Netherlands, came online. This plant was inaugurated 8 May 2012, is owned by District Water Board Veluwe, has a design capacity of 59,000 P.E. and treats up to 1,500 m^3/h municipal wastewater with a high contribution of industrial waste from slaughterhouses. It is meeting challenging effluent requirements of TN <5 mg/L and TP <0.3 mg/L under Dutch climate and hydraulic conditions. Prime reasons for Water Board Veluwe to select this innovative technology for the replacement of their old STP were the low investment costs, the small footprint and in particular the energy-efficiency.

To minimize the start-up and granulation phase, a smart project planning was developed in which, in parallel to finalizing the plant construction and commissioning, the granulation process already was initiated in one reactor. Figure 7 shows how during start-up the wastewater feed was gradually increased from the old to the new treatment plant. After approx. 4 months all wastewater was treated by the new treatment plant and the old plant was decommissioned. Figure 7 also shows that during aforementioned period the biomass level grew steadily and that the number of reactors in use has been increased while the biomass level continued to grow.

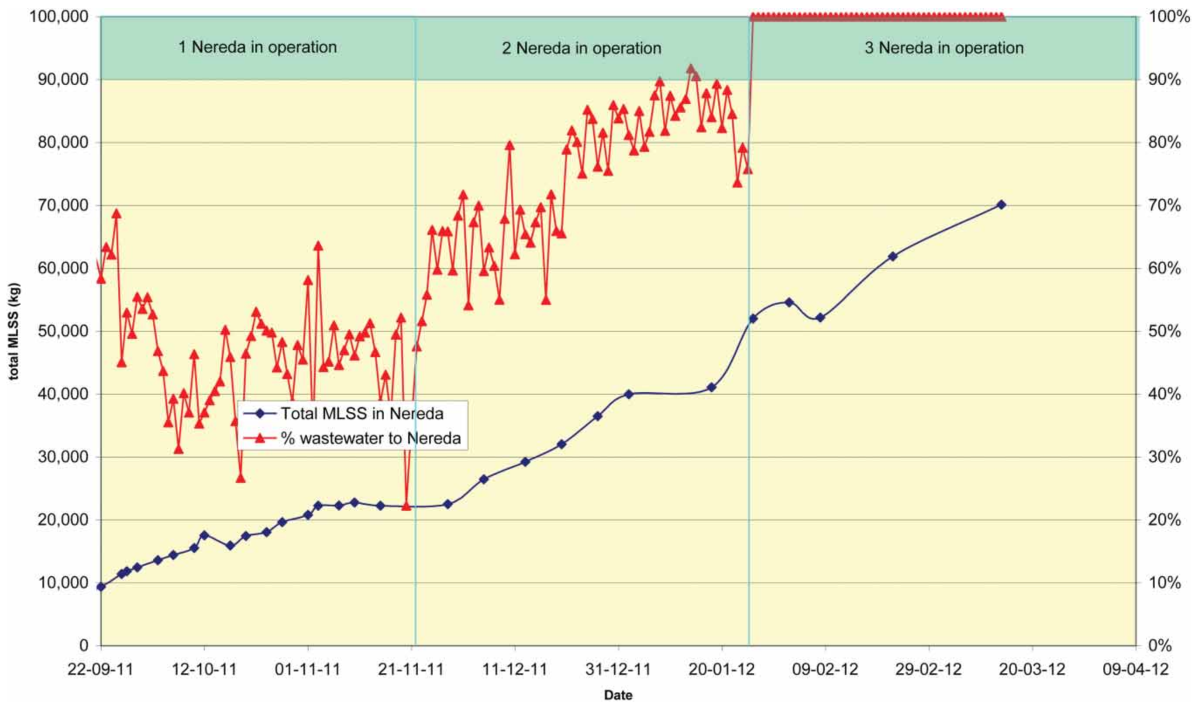

Figure 7 | Start-up of Nereda® STP Epe.

The produced water quality, during the start-up, as measured by the on-line plant data prior to sand filtration polishing, is presented in Figure 8. Though from start-up to treatment of 100% of the incoming raw feed took approx. 4 months, as a result of the selected strategy, already a few days after beginning of the start-up the plant produced a remarkable good effluent quality. Even at the severe winter conditions in mid February the BNR performance was very good and already met the discharge limits as set for the summer average. This illustrates that the longer start-up time for the growth of granular biomass does not necessarily mean that it takes also longer before sufficient 'treatment power' is obtained. Further, by seeding with granular biomass, duration of start-up can be significantly reduced.

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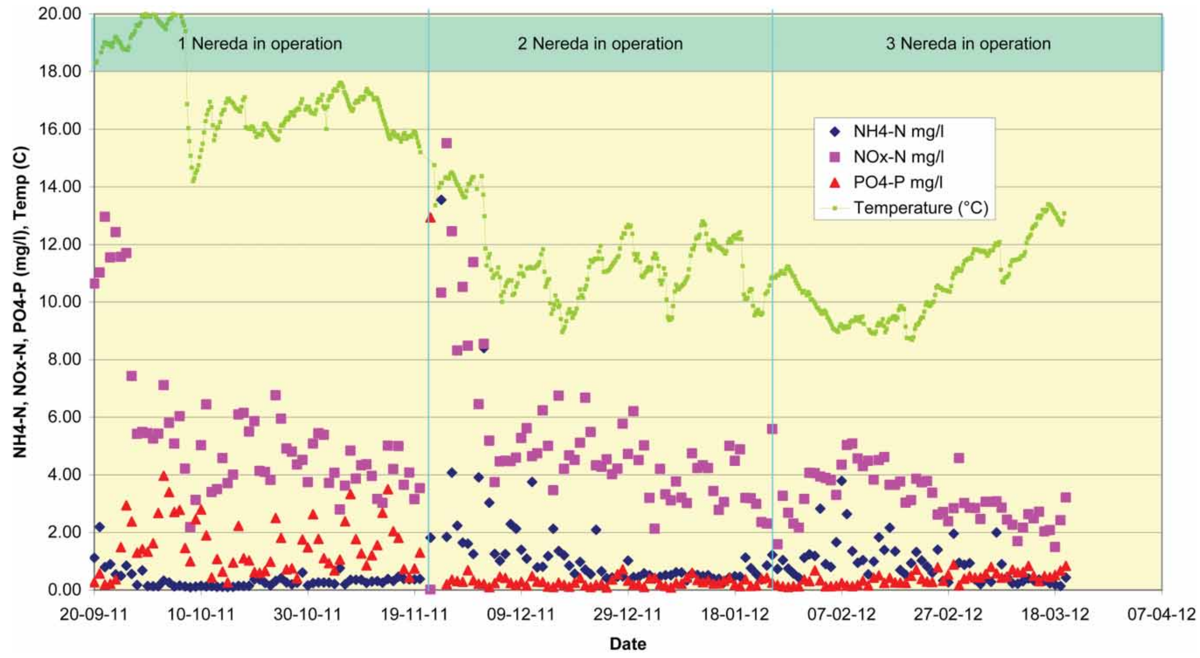

Figure 8 | BNR performance during start-up.

Figure 9 | Epe STP and effluent sample (right).

THE EMERGING NEW STANDARD?

Feedback and lessons learned from the first Nereda® installations clearly confirm the added-value of this modern technology. Especially the full-scale demo installation in South Africa and a growing amount of industrial applications demonstrate the reliability of the process also under harsh conditions.

With full scale plants running now and many projects in the pipeline, strong interest in the new technology is aroused in many countries in Europe, Asia, Australia and the Americas. For example, currently the municipal treatment plants for Municipality Stellenbosch in South Africa and STP Dinxerplo in The Netherlands for District Water Board Rijn and IJssel and STP Vroomshoop for District water Board Regge en Dinkel are under construction, while many others and projects for food, beverage and chemical industries are being prepared by Royal HaskoningDHV themselves or their licensees. Recently, a construction consortium and their consultant applied Nereda® for their winning quotation for the extension of one of the largest Dutch wastewater treatment works (400.000 P.E.).

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Here Nereda will be applied in parallel to the existing conventional plant and could also be operated in a hybrid process tie-in mode to improve the process performance of the existing activated sludge process.

While research in aerobic granular biomass technology is booming world-wide, BNR experts identify the technology as the first real process breakthrough in decades for generic biological purification of municipal and industrial wastewater.

With the technology now being scaled-up and applied in various wastewater markets and countries, Nereda is often used as a showcase for affordable and sustainable wastewater treatment to meet the world's sanitation needs and water pollution challenges. The near future will show whether or not this emerging technology will indeed become the new 'world standard' for aerobic wastewater treatment.

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