The ScanDeNi® process could turn an existing under-performing activated sludge plant into an asset

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Abstract With tightening up of effluent discharge standards from wastewater treatment facilities, many plants are facing costly augmentations and in many cases completely new plants will have to be constructed. The ScanDeNi® process was developed in Sweden for increased nitrogen removal at the Västerås Sewage Treatment Plant (STP), 125,000 p.e. near Stockholm, and can be described as a modified contact stabilisation process with pre-denitrification and a selector stage for nitrification. The STP was upgraded at a cost of some 25 Mill. SEK (2.5 Mill. USD). It has been successfully in operation since 1998, exceeding all expectations. The process is showing the following major advantages.

- 25–35% less volume for the same Sludge Retention Time (SRT) and secondary sedimentation sludge load, compared to conventional pre-denitrification; or a 25–35% higher load can be applied within the same volume with the same removal efficiencies.
- The selector mechanism appears to be not limited to the nitrifying bacteria alone. Other microorganisms appear to be responsible for the reduction of surface active matter from the return activated sludge (RAS), as well as in the reject stream from sludge dewatering, resulting in an increase in α-values of approximately 50%.
- Due to the high α-values less aeration is required, resulting in significant operating cost savings.
- 'Automatic' creation of anaerobic conditions, enabling biological phosphorus removal.

Whilst rarely a concern in warmer climates, BNR plants in cold climates in winter often lose their capacity to nitrify. The Västerås STP has consistently maintained excellent effluent quality even with effluent temperatures as low as 7°C, and at an SRT of some 7–9 days, proving the effectiveness of the nitrifier selector. The ScanDeNi® process could offer excellent effluent discharge standards (T-N < 10 mg/L, T-P <0.5 mg/L) in smaller tank volumes and at a significantly lower operating cost, compared to conventional pre-denitrification systems.

Keywords Activated sludge upgrading; biological nutrient removal; contact stabilisation; increased α-value; reduced reactor volume; selector stage

Introduction

The reduction of ammonia and phosphorus from wastewater using biological processes is now widely practised. Whilst perhaps not all the mechanisms involved in these processes are fully understood, the application of proven design principles is providing the required results. The ScanDeNi® process was first developed in Sweden at the Västerås STP (150,000 e.p.), near Stockholm, and can be described as a modified or advanced contact stabilisation process with pre-denitrification and a selector stage for nitrification.

The original intention was to upgrade the existing STP to achieve nitrification and introduce wetlands to facilitate denitrification. The chosen area was situated some 21 km from the STP, requiring a large pumping station and two 800 mm pipelines to be laid in Lake Mälaren, resulting in an additional investment of some 100 Million SEK ($\approx$ 10 Million USD). A Project Group was selected in 1997, comprising some of the STP operating crew, a project manager and Scanvironment as the process consultant. Their task was to evaluate different options, to do the process design and to lead the procurement and implementation. The Project Group rapidly concluded that the wetlands option was not a realistic solution for the near future.

The Västerås STP

The original plant was built in the thirties for primary treatment only. In 1965 the STP was upgraded to include biological treatment using an activated sludge process. In 1972 tertiary treatment for P-removal was introduced. In the period from 1978 to 1984 the STP was rehabilitated and upgraded to handle larger capacities. Pre-precipitation with ferrous sulphate was introduced in 1994, unloading the biological stage, and taking the tertiary treatment out of operation as the phosphorus discharge limit now was achieved without it.

The activated sludge process (total reaction volume 12,600 m^3) comprises six parallel treatment modules each arranged in a horseshoe formation and each with a central distribution channel. Three of the modules are connected to older style secondary settlers with a combined surface area of 1,350 m^2. The other three units are connected to newer secondary settling tanks with a combined area of 1,260 m^2.

The latest set of discharge requirements was set at 15 mg/l for N_{tot} as an annual average with quarterly averages of 10 mg/l for BOD7 and 0.3 mg/l for P_{tot}, based on flow proportional samples. Mixed Liquor Suspended Solids (MLSS) concentrations in the activated sludge plant were originally very low at 1.5 g/l. Full-scale tests, however, did show that nitrification could be achieved at MLSS concentrations of 3.0 to 3.5 g/l. The existing reactor volumes were consequently quite adequate, provided that the higher MLSS concentrations could be used.

The resulting higher sludge load on the secondary clarification plant meant that this part of the process would be the 'bottle neck', with a risk for solids carry over. The possibility of using a minor dosage of polymer in the secondary clarifier, some 0.2–0.3 mg/l, however, has shown improved performance, and can be used for extra safety. The load on the biological processes, i.e. after pre-precipitation is shown in Table 1. The table shows that the pollutant concentrations in the pre-precipitated liquid are not very high. The soluble BOD is only approximately 20–30 mg/l, still sufficiently high however, to denitrify some nitrate-nitrogen.

The previous design conditions were based on a peak flow prognosis onto the biological process of 6,600 m^3/h. Based on an analysis of the operational data and the prognoses for future development in the city, the maximum daily flow was set to a more realistic 3,600 m^3/h. Excess flows (expected mainly in storms and snow-melting periods is resulting in a further dilution of the sewage anyway) would only be pre-precipitated and bypass the biological treatment process steps (a maximum of approximately 1% of the annual flow).

To ensure reliable nitrification, it is important to retain the biomass in the process. Only then nitrification down to temperatures as low as 6–8 degrees would be secure. This security is required, as starting up a plant at low temperatures is almost impossible, taking several months. The impact of the by-passed portion of the diluted pre-precipitated wastewater on the quality of the treated effluent would be minimal and not jeopardising the requirements of the discharge permit, which are based on monthly averages. The final design data was concluded as per Table 2 below.

Process design evaluations

Using contact stabilisation, i.e. aeration of the RAS before the contact with wastewater, is a 'classical' way of operating an activated sludge process with poorly operating secondary clarifiers, Figure 1. As the clarifiers were the limiting factor for effective treatment, and the use of an external carbon source imperative, a hybrid arrangement of contact stabilisation combined with a sludge anoxic zone was regarded as a promising option, Figure 2, with an excellent operational record from several other plants.

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The ScanDeNi® process

Applying sludge aeration as well as providing sludge anoxic conditions would mean that a large amount of biomass would lie 'idle'. The idea developed to use this stored but 'unproductive' biomass for nitrification of the reject from dewatering of digested sludge, which typically has very high ammonia concentrations (see Figure 3 below).

An ammonia rich stream is fed into a sludge aeration zone and mixed with RAS. Under these conditions the nitrifying microorganisms will have a competitive edge over other microorganisms and as a result are able to get maximum energy from the oxidation of ammonia (selection). The sludge aerobic zone is followed by a sludge anoxic zone where carbon is added (internal, typically a portion of the influent, or external). Denitrification is ensured and eventually, as soon as all nitrates are consumed, the 'automatic' creation of anaerobic conditions is established, enabling biological phosphorus removal. The process provides a number of advantages.

• It requires 25–35% less volume with the same SRT, or allows a 25–35% higher load

Table 1 Wastewater characteristics after pre-precipitation

Parameter		Average	Min.	Max
BOD$_7$	mg/l	55	15	100
NH$_4$	mg/l	20	16	24
P$_{tot}$	mg/l	2.5	0.5	4.0
Alkalinity, HCO$_3$	mg/l	190	150	215

Note! Some 75% of N$_{tot}$ is ammonia nitrogen

Table 2 Design criteria

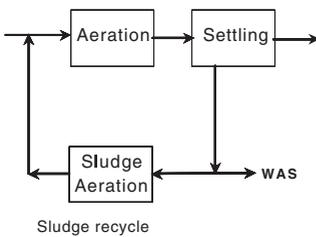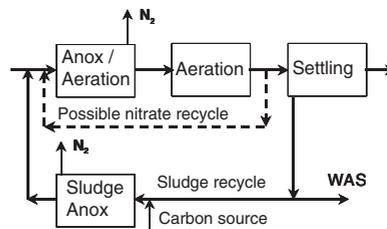|		1996	2010
Connected people	p.e.	110,000	127,000
Average dry weather flow	M^3/d	47,600	55,000
Normal maximum flow to bio-stage	M^3/h		3,600
Peak load to bio-stage	M^3/h	6,600*	4,800
BOD to bio-stage	kg/d	3,000	3,300
P$_{tot}$ to bio-stage	kg/d	120	125
N$_{tot}$ to bio-stage	kg/d	1,400	1,400
N$_{tot}$ in reject from dewatering /from ABB	kg/d	300	250/85

Figure 1 Contact stabilisation

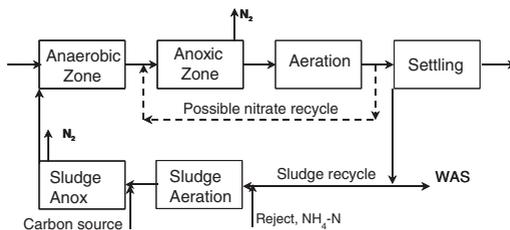**Figure 2** Contact stabilisation with sludge anox

Figure 3 The ScanDeNi process

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using the same reactor volumes without increasing the solids load onto the secondary clarifiers, when compared to a conventional pre-denitrification.

- The sludge aeration zone, in the absence of organic matter, will act as a selector for nitrifying microorganisms. In this environment the nitrifying microorganisms will have a competing edge over other species. They are the ones using ammonia, not organic matter, as their energy source. This feature will result in:
  - higher nitrification rates due to a biomass containing more nitrifying micro-organisms and;
  - less sensitivity to peak loads, otherwise resulting in sludge carry-over, which is loss of biomass, in the effluent from the separation stage.

The cost estimation showed that the total costs associated with upgrading and rehabilitation would be some 25 Million SEK, saving some 5 Million SEK compared to previous calculations that included an SBR reactor for the treatment of the reject water.

Practical design

Each of the six units is laid out in a similar fashion with possible nitrate recycle for low concentration discharge during summertime. The locations 1 to 6 are monitoring points (Figure 4). In order to safeguard the operation of the facility, the plant was divided into two similarly equipped Blocks. Block A, consisting of three aeration units connected to new secondary clarifiers, would be regarded as the 'protected Block A' never to lose nitrification. Block A would be prevented from receiving flows in excess of 1,800 m^3/h eliminating the carry out of biomass in storm-flow conditions. Block B could receive flows up to 1,000 m^3/h per unit. In addition, in case of other threats to the system, e.g. expected toxic or inhibitory matter entering the facility, Block A could be isolated, thereby protecting the biomass allowing it to be used as a seed source for Block B if that were to be necessary.

Operational experience

Currently the nitrogen load onto the biological process steps is approximately 1,000 kg/d (N$_{tot}$) and the BOD load is approximately 5,000 kg/d, including glycol as an additional carbon source. The plant was designed for a MLSS concentration in the aerobic reactors of 3.3 g/l, a value based on the previous years' operational experience as being possible to manage with poorly operating clarifiers. The waste activated sludge (WAS) amounts to approximately 4,500 kg/d. The resulting SRT was then 12 days.

After one year's operation since the upgrade, a build up of Nocardia occurred in May 1999, resulting in a thick floating scum blanket all over the process plant. In order to rectify the problem the load was increased by reducing the MLSS concentration to 2.0 g/l in the aerobic reactor, giving a SRT of 7.5 d. In these conditions the sludge aeration SRT is 1.5 days at a MLSS of 4.5 g/l (total aerobic SRT is some 4.5 days). The Nocardia disappeared and excellent results were achieved in stable operation in spite of the low sludge age.

The operating crew decided to maintain the low MLSS concentrations throughout the winter of 1999/2000. It should be noted that the wastewater temperatures during that winter
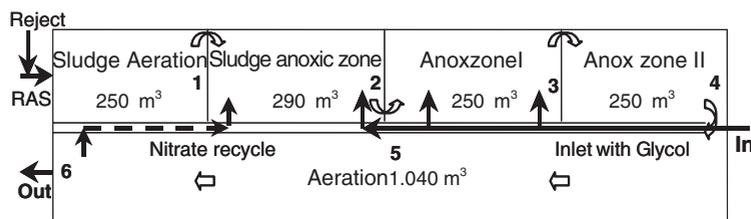

Figure 4 Schematic layout of process module

went down as low as 8–9 degrees Celsius. The STP performed very well under these conditions delivering effluent nitrogen levels well below 10 mg/l with NO_3-N at <6 mg/l and NH_4-N at <2 mg/l. (spiking on occasions to a maximum of 5 mg/l at peak load situations). Other effluent discharge requirements were also met reliably with T-P at concentrations < 0.2 mg/l and BOD and Suspended Solids concentrations at < 5 mg/l.

The results show very stable operation at very low temperatures. This is in contradiction to 'the literature', where it is often expressed that such operation should not be possible. It is important to note that there is a significant difference between establishing nitrification and maintaining nitrification. A fact on show in many plants in Scandinavia.

Low energy consumption

Immediately after start-up of the augmented plant, the energy consumption was recorded as being remarkably low. The air consumption, 3,000–3,500 m^3/h, was only about 50% of the expected level. Further operation of the STP indicated that the low air consumption was indeed a feature enjoyed on a continuous basis. The initial explanation was centred on a supposedly higher alpha-value than the 0.7 used in the design oxygen calculations.

A thorough study was carried out in July 1999 to measure the alpha-values in the various sections of the biological reactors and to verify the mass balances for the overall process. A 'plug of water' was followed through process module no 3, in an effort to sample the same water after each process stage. All flows were checked regularly and the detention time in each stage recalculated to, as accurately as possible, follow the water through the different process stages. Nitrification, denitrification and respiration rate tests and analysis of COD, SS, nitrate and ammonia were carried out to enable mass balance analysis.

The alpha-value measurement was carried out in a special test unit, connected to a computer. The computer was programmed to calculate the Oxygen Uptake Rate (OUR), first in clean water, then in the different samples. The ratio between the OUR in a sample and the clean water OUR is the alpha-value. Each test started with a period of blowing in nitrogen gas to remove all oxygen. The alpha-values for the monitoring points shown in Figure 4 are presented below in Table 3, and the results were very logical.

The design of the aeration equipment was based on an assumed alpha-value of 0.7. Normally an alpha-value of 0.8 had been used for municipal wastewaters. The more conservative figures were adopted based on recent experiences in Sweden with STP's having problems with oxygenation caused by low alpha-values. Tests indicated that the probable reason for the problems experienced in these facilities was associated with surface active substances like tensides to a large extent generated by 'environmental friendly' washing powders and car-washing products during the winter time. Although no such problems had been observed in the Västerås STP, the lower design value was chosen as a safety precaution. As can be seen, the assumption was not incorrect as the alpha-value on the pre-precipitated water was measured to be 0.67. The reduction of the alpha-value caused by

Table 3 Alpha values

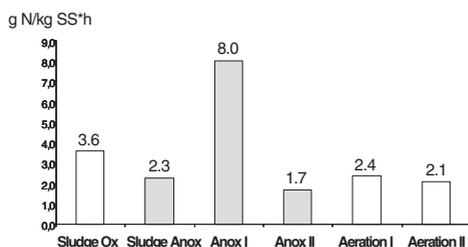| Sampling points:		Alpha-value
	Pre-precipitated wastewater	0.67
0.	Pre-precipitated wastewater with glycol	0.37
RS.	Return sludge	1.00
1.	After Sludge Aeration	1.07
2.	After Sludge Anoxic conditions	1.03
3.	After Anoxic Reactor I	0.99
4.	After Anoxic Reactor II	0.96
5.	Aerobic Reactor, mid-point	0.99
6.	Outlet to Secondary Clarifiers	1.00

g N/kg SS*h

Figure 5 Nitrification and denitrification rates
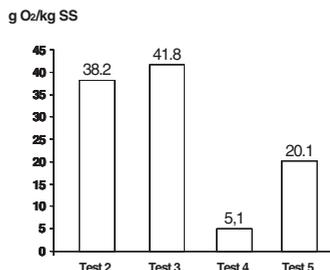
g O₂/kg SS

Figure 6 Respiration rates

the glycol is of course no problem as it is very easily degradable and the necessary carbon source crucial for denitrification. The considerably improved alpha-values in the process, however, were unexpected. The lower air consumption is further accentuated by the benefits provided by the higher specific oxygen transfer at the lower diffuser capacity. The combined effect is an almost 50% reduction of the initially anticipated energy consumption.

The nitrification rate in the sludge aeration was high, Figure 5, as well as the denitrification rate in Anox I. Oxygen was still available in the Sludge Anox and the carbon source was used up before Anox II, explaining the lower values. The respiration rates for inlet after pre-precipitation, plus sludge and glycol, Test 2 and 3; sludge only, Test 4 as well as inlet plus sludge, Test 5, are shown in Figure 6.

Conclusion
An often-neglected component of plant design is the internal housekeeping within the facility. Major efficiency gains can be achieved, for instance, by managing the return of the high strength effluents from sludge thickening and dewatering. The ScanDeNi® process's control system ensures that the return of high strength return streams are managed such that they do not add to the plant influent at times when loads are high but instead are used to the benefit of the process when most appropriate.

The process is especially suitable if an anaerobic digestion plant is present. On the other hand, internal re-circulation with high ammonia and low organic content may also be employed. This is a feature of the augmentation of the Norrköping STP (175,000 e.p.) south of Stockholm, currently in progress. The cost of upgrading is being reduced from an expected 80 Mill. SEK to some 30 Mill. SEK. In addition, significant but not yet quantified operating cost savings associated with improved oxygen transfer are also expected.

For a sewage treatment plant with a low ammonia and total nitrogen (and phosphorus) discharge consent, the ScanDeNi® process could be added at a relatively minor cost, potentially turning an existing, overloaded and under-performing activated sludge plant into an efficient asset.

Acknowledgements

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