Minworth STW

the first UK Anammox® plant to yield an environmentally friendly and budget beating biological phosphorous solution

by Chris Shorrock, Willie Driessen, Paul Snelson and Manjit Chadha

Minworth is Severn Trent Water's largest sewage works and the second largest in the UK. It serves a population equivalent of 1.7 million within Birmingham and the Black Country. The AMP5 phase of investment is to deliver an Urban Waste Water Treatment Directive output of 1mg/l total phosphorous, or 80% removal, by September 2014. This action will guard against eutrophication in the River Tame. The phosphorous concentration in the effluent currently exceeds the new requirement, so to do nothing is not an option.

Anammox® plant under test - Courtesy of Costain

Selecting the Anammox® innovation for Minworth STW

Two approaches were considered for the removal of phosphorous:

(i) biological treatment.
(ii) chemical precipitation using iron.

The whole life cost of iron dosing was prohibitively high, despite relatively low capital cost. Chemical precipitation also raised significant concerns regarding chemical supply as the solution would require three tanker deliveries per day. The preferred approach was biological treatment and Severn Trent Water has successfully conducted pilot trials to confirm that the sewage characteristics are suitable.

In July 2008 Severn Trent Water proposed process modifications in order to meet the new phosphorous removal requirements, as shown in Figure 1 (below).

The proposal included construction of a new 54ML unaerated tank with a project cost of £34m, which did not meet the final AMP5 business plan which required efficiencies of 20%, giving an available budget of £27m.

Severn Trent Water then decided to investigate alternative process designs with the aim of beating the budget without compromising environmental impact, quality or operating cost.

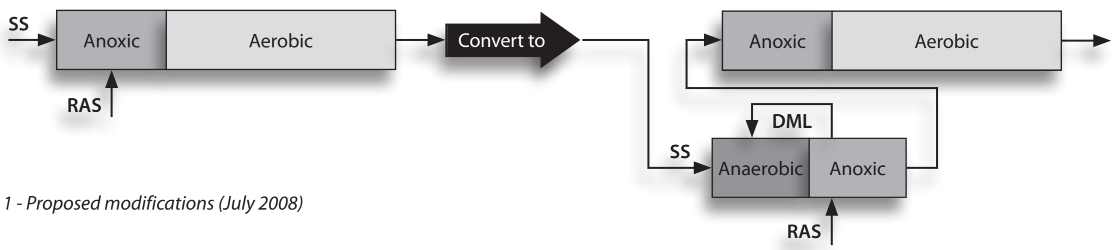

Figure 1 - Proposed modifications (July 2008)

Reference: Minworth STW

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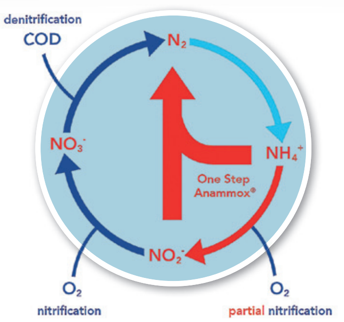
Nitrogen Cycle



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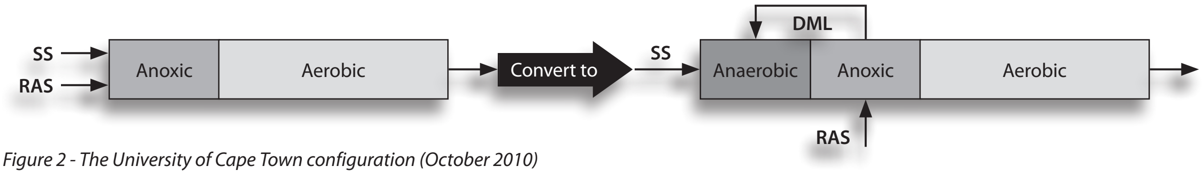


Figure 2 - The University of Cape Town configuration (October 2010)

Nineteen technically viable options were considered in detail. Each was rated with respect to whole life cost, risk and operability. In October 2010 the clear winner was conversion of the existing activated sludge lanes to the University of Cape Town (UCT) configuration, as shown in Figure 2 (above).

For each of the existing 24 (No.) treatment lanes, the UCT configuration requires the conversion of the anoxic zone to anaerobic operation plus the introduction of a new anoxic zone. Overall this equates to a reduction in aerobic capacity of 33ML.

This is partly mitigated by increasing the working water depth by 300mm to give an additional 18ML aerobic capacity. The increased head on the blowers due to the raised TWL would reduce the output, but the output would be adequate for the aeration requirements (as these will be less than the requirements for the tightening of the ammonia consent). There would also be some improvement in oxygen transfer efficiency (OTE) due to the increased diffuser submergence. The increased water depth also maximises the anaerobic and anoxic volumes.

By adding the innovative Anammox® treatment plant to remove 90% of the ammonia from the sludge liquors, the remaining 15ML short fall of aerobic capacity is satisfied. Although the sludge liquors equate to less than 1% of the flow to treatment they contain 15% of the ammonia load to treatment (4,000kgNH_4-N/d). A conventional treatment approach would not be accommodated in the existing structures and would require chemical addition for denitrification to nitrogen gas.

Anammox® at Minworth will be the first UK installation and the largest sludge liquor application in the world. The process has a low whole life cost (WLC) when compared to alternative de-ammonification processes, as it has a smaller footprint and uses less air and chemicals. There are currently fourteen reference sites around the world (see Figure 3 below) with a total installed capacity to treat over 50,000kgN per day. The first full scale plant, commissioned in 2002, has now been in operation for nearly ten years.

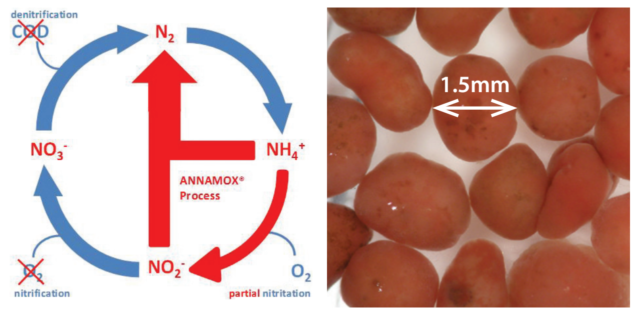
Stream type	Country	Design Capacity (kg N/d)
Sludge liquor WwTW	The Netherlands	700
Semiconductor Industry	Japan	220
Tannery	The Netherlands	325
Sludge liquor WwTW	Switzerland	60
Sludge liquor WwTW	The Netherlands	1,200
Yeast factory	China	1,000
Fermentation industry	China	11,000
Fermentation industry	China	9,000
Yeast industry	China	7,000
Fermentation industry	Poland	1,200
Sludge liquor WwTW	The Netherlands	660
Sludge liquor WwTW	UK	4,000
Winery	China	900
Rendering plant	The Netherlands	3,000

Figure 3 – Anammox® full scale references

Anammox® technology

Anammox® (***AN***aerobic ***AMM***onium ***OX***idation) is patented technology supplied by Paques bv. It utilizes an innovative biological reactor which shortcuts the nitrogen cycle to efficiently convert influent ammonium to nitrogen gas with nitrite as the electron acceptor. This neatly reduces the power demand by 60% and avoids the need for denitrification chemicals such as methanol.

The reaction is executed by two different bacteria, which coexist in the reactor: *nitrosomonas* bacteria oxidise approximately half of the ammonium (NH_4^+) to nitrite (NO_2^-); Anammox bacteria then convert the ammonium and nitrite into nitrogen gas.



(Left) Nitrogen cycle shortcut & (right) Anammox® granules
Courtesy of Paques bv

Anammox reactions in the world's oceans are responsible for 30% - 50% of the nitrogen in the air we breathe. The red-coloured Anammox bacteria have a relatively slow doubling time of 10 days, so biomass retention is very important. Anammox bacteria have a natural ability to form granules with a high specific gravity, which are readily separated from other solids material by special biomass separators. Granular sludge type reactors allow for highly concentrated biomass retention, hence a very compact reactor footprint.

A third advantage of granules is that they are relatively easy to mix. The slow growth rate of Anammox bacteria has the advantage that

Anammox® plant aerial view - Courtesy of Costain there is minimal production of excess sludge. In fact the excess granular sludge can provide a revenue stream as seed sludge for other Anammox® processes requiring start-up.

At Minworth the existing blowers and diffusers will be optimised for the reduced air demand and the Anammox® plant will be operated at 30°C. The hot water ring main in the CHP plant will be extended to provide heat to the digesters as well as the Anammox® plant. On average there is an excess of heat generated by the CHP plant and Anammox® provides an alternative to a heat dump. In order to minimise the CHP heat demand, the Anammox® effluent will pre-heat the incoming liquors such that only a further 3°C rise is required. This takes into account the fact that the exothermic Anammox® reaction will provide a small rise in temperature.

There is great potential for Anammox® to be adopted where there is a need to remove a relatively high ammonium concentration (>200 mgNH_4-N/l) and a relatively low COD concentration. Industries where these conditions are found include:

- Municipal wastewater treatment (especially post-digestion sludge liquors).
- Solids waste treatment (especially liquors from landfill, composting and digestion).
- Food processing.
- Semi-conductor.
- Tannery.
- Fertiliser industry.
- Metallurgical industries.

Project drivers and benefits

The driver for this project is environmental sustainability. The effluent phosphorous content must be reduced in order to guard against eutrophication in the River Tame. Phosphate nutrients have the potential to promote phytoplankton growth resulting in algal blooms, which can deplete the oxygen content in the water, leaving none for aquatic organisms such as fish. Some algae even produce toxins that are harmful to higher forms of life causing problems along the food chain.

The installation of Anammox® into one of the existing liquor treatment reactors at Minworth allows biological phosphorous removal to be carried out in the existing activated sludge lanes.

All Minworth liquor flows can be treated in one existing tank, allowing the second tank to be used for flow and load balancing to ensure optimum operation. Through the use of the existing structures, the solution not only reduces the capital cost but minimizes the embodied carbon footprint.

New construction is limited to pump stations and pipe routes only. Less construction also means less disruption to neighbours. Large areas of the site have naturalized into rough grasslands, scrub woodland and wetland. These habitats are home to great diversity of plants and animals and will not be disturbed by the need to expand.

Compared to the original £34m budget the final solution has reduced CAPEX by 60%. It is important to note that this is not at the expense of operating cost or carbon footprint. The OPEX saving is 40% mostly due to power savings which equate to operational carbon footprint savings.

The direct impact of installing Anammox® is a saving of £12.8m. Further rationalization of the design includes:

- ***A saving of £4.1m:*** Modelling the impact of the uneven distribution to show that it does not need to be replaced.
- ***A saving of £1.3m:*** Demonstrating that it is not necessary to include for a swing zone (swing zones normally used as

aerated zones but capable of conversion to anoxic zones to provide mitigation against loss of the sidestream liquor treatment process, and greater operational flexibility).

- ***A saving of £1.5m:*** Optimising the movement of existing diffusers where they are no longer required.
- ***A saving of £0.4m:*** Optimising the provision of back-up chemical dosing.
- ***A saving of £0.6m:*** Working with the supply chain to identify procurement efficiency.

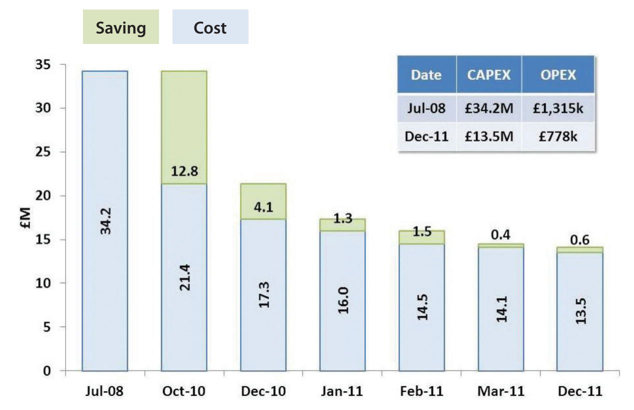
New build has been avoided by utilizing the existing assets and as a result the business rates have increased by only £5k and an 80% reduction in write-off has been identified.

Anammox® directly contributes a 5% reduction in overall activated sludge lane air demand in a solution total reduction of 18%. This is a significant reduction in power usage equating to an approximate operational carbon footprint saving of 158 teCO_2e each year.

In order to safeguard against over-aeration the process will operate at an elevated temperature of 30°C. Rather than add to power use on site, the Anammox® reactor will makes use of surplus CHP heat generated by the digestion plant. The average heat demand is 0.8MW which is minimal due to two innovations which reduce the duty:

- The cold washwater is separated from the filtrate within the dewatering belts to maximize the temperature to the reactor and minimize the flow.
- The Anammox® process is exothermic. The effluent stream exchanges approximately 3MW of heat with the incoming filtrate stream to pre-heat it.

Anammox® at Minworth will be delivered to Severn Trent Water by Costain-MWH as part of the e5 programme. The e5 programme



Savings through innovation and reducing project costs over time

team is a collaborative grouping of Severn Trent Water, Costain Ltd, MWH Treatment Ltd, Mott Macdonald Bentley Ltd and North Midland Construction plc working together to deliver eleven major wastewater projects within the AMP5 Capital Programme.

At the time of writing (July 2012) the Minworth Anammox® plant is nearing construction completion. Seeding is planned for September 2012 and after maturation, the plant is scheduled to be complete by March 2013.

The Editor & Publishers would like to thank the following for providing the above article for publication:

Chris Shorrock, Principal Process Engineer with MWH and the technical lead for this project. Willie Driessen, Regional Manager with Paques bv, Paul Snelson, Senior Project Manager with Costain and Manjit Chadha Programme Manger with Severn Trent Water.

Anammox® plant being installed - Courtesy of Costain