PAPER 9

INNOVATIVE AND EFFICIENT WASTE WATER TECHNOLOGIES FOR TSAKANE WASTE WATER TREATMENT WORKS

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ABSTRACT
This paper is a case study for an innovative solution that is been implemented in Tsakane Waste Water Treat Works (WWTW). The objective of the project was to increase the capacity of the Tsakane WWTW from 10.8 Mℓ/d to 20 Mℓ/d. Tsakane WWTW required a capacity upgrade to meet the demands of a growing population. Over the years, the residential dwellings have increased and encroached the plant. The existing plant has a single BNR reactor, and ERWAT developed a cost effective plan that enabled the capacity of the existing plant to double. The project involved converting the existing BNR process to Hybrid Activated Sludge ("HYBACS").

The cost of the expansion was only R6 million per megalitre (Mℓ) of additional capacity provided. This represents a 40% reduction in Capital budget with reference to a benchmark cost of R10 million per Mℓ for conventional upgrade methods. Furthermore, the works have a potential 15% to 20% reduction on overall energy consumption, which have a positive variance on the operational budget.

Based on the historic designs, shortage of land, increase in population in the City of Ekurhuleni, the innovative designs and technologies are efficient. They are cheaper and require shorter turnaround time to install.

Keywords
Hybrid Activated Sludge, HYBACS, hydrolysis, Waste water capacity improvement, Environmental friendly, Energy efficiency, Lower capex and opex, Easy operation and maintenance

1. INTRODUCTION
The City of Ekurhuleni is Gauteng's third largest metro and home to more than 3.5 million residents. ERWAT is vital to the city's function, operating 19 wastewater treatment works (WWTWs) and employing some of the most experienced engineers, scientists and technicians.

Tsakane WWTW is towards the southern edge of Ekurheleni, between Brakpan and Nigel. The area has seen a rapid growth in residential population leading to pressure on the existing infrastructure. The current population in the Tsakane catchment is approximately 80,000.

The plant had a design capacity of 10.8 Mℓ/d ADWF and a PDWF of 21.6 Mℓ/d. This was proving to be insufficient for the growing population. The plant was given a Wastewater Risk Rating of 63.6% in the 2012 Green Drop report, with highlighted risks of design capacity and effluent quality. Accordingly ERWAT initiated a project in 2014 to upgrade the plant to 20 Mℓ/d.

ERWAT considered various options including the construction of a new module. We concluded that a HYBACS upgrade would be most suitable to meet ERWAT's main objectives: (1) Reliable compliance with Water Use Licence, (2) Low capital cost, (3) Small footprint, (4) Quick and simple off-line construction, (5) Simple to operate and maintain, and (6) Low operating costs.

2. THE HYBACS PROCESS BACKGROUND

2.1 History of HYBACS
HYBACS, denoting HYBrid ACtivated Sludge, is a variant on the activated sludge process which combines a high-rate attached growth reactor with a conventional activated sludge process. HYBACS is particularly cost-effective as an upgrade to an existing activated sludge process, where it can achieve a doubling in capacity and/or a significant enhancement in final effluent quality without the need for substantial investment in new assets. In the context of ERWAT, which has limited capital budget, the project is deemed to provide cost savings.

The process we now refer to as HYBACS was developed from a forerunner technology invented in South Korea during the 1980s and known as the Rotating Activated Bacillus Contactor (RABC) process (Kim _et al_, 2004). The first full-scale application was a 0.6 Mℓ/d industrial effluent treatment plant for Lotte Confectionary Co., built in 1999. This was followed by more than 20 installations on municipal wastewater treatment up to 110 000 Population Equivalent (PE) and industrial applications for the food & drink, livestock and landfill sectors, mostly within South Korea.

2.2 Configuration of HYBACS
HYBACS comprises two biological stages: a unique attached growth reactor referred to as a SMART™ unit, and an activated sludge tank. The subsequent process is clarification (or another solids separation technique) and, crucially, some or all of the return activated sludge (RAS) is recycled to the SMART unit. A typical HYBACS configuration is illustrated in Figure 1.

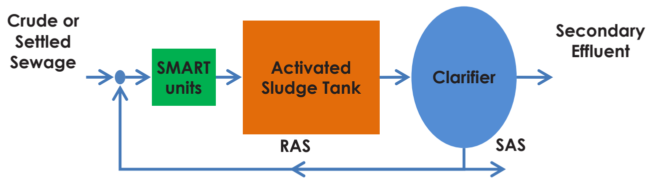

Figure 1: Typical HYBACS Configuration

The configuration can be adapted to achieve nitrogen and/or phosphorus removal by incorporating anoxic and anaerobic zones. In each case, the SMART units are located downstream of the point where incoming wastewater mixes with RAS, but upstream of the aeration tank or internal recycle. Maximising the Chemical Oxygen Demand (COD) concentration of the liquor passing through the SMART units optimises the overall performance of the process.

After evaluation of several technologies that were on offer during the procurement process, it was resolved that HYBACS is the best process to implement in Tsakane WWTW. The main reason being the technology had the ability to double capacity of the plant, and fulfilling the objective of the project. Twelve (12) SMART units and some retrofits of the existing infrastructure was constructed and the process capacity of the plant was doubled.

2.3 SMART Units
SMART units superficially resemble Rotating Biological Contactors (RBCs), having multiple circular disks of media mounted upon a horizontal shaft. The RBCs have circular disks that are partially or half submerged in the liquid and the microbes grow on the surface of the disks (Kadu et al, 2012).

In the case of the SMART units however, instead of impermeable disks which develop a biofilm with an active thickness of typically 200 microns, SMART units contain 50 mm thick reticulated mesh disks which fill naturally with porous attached biomass. The repeated immersion and drainage of the mesh as the shaft rotates ensures very efficient convection of substrates and oxygen throughout the biomass within the porous plates. In addition, the convection of the liquor, which contains the RAS, renews the biomass within the plates, sustaining a high biomass activity in the long term.

A standard SMART unit is 4.8 m long and 2.2 m wide, containing 30 mesh disks each 2.0 m in diameter, and serves a population equivalent of 5 PE to 10 000 PE depending upon the strength of the wastewater. The mesh rotates at between 2 rpm and 6 rpm (under Dissolved Oxygen (DO) control), driven by a 2.2 kW motor. SMART units contain about 10% of the total active biomass of HYBACS plants.

Figure 2: SMART Unit (cutaway to show mesh disks)

2.3.1 Function of the SMART Unit

The volume and retention time of the SMART unit is very small in comparison to the associated activated sludge tank; typically only 1% to 2%. Clearly, the SMART units are not merely serving as additional biological capacity, but are fundamentally altering the performance of the system. Research by Bluewater Bio and Infilco Degremont (Labban et al. 2013), has identified the following key features of the biochemistry of the SMART unit, which contribute to its performance:

- High biomass density
- Enriched population of aerobic heterotrophs within the biomass
- Absorption of particulate material onto attached biomass in the SMART unit
- Rapid enzymatic hydrolysis of particulate COD into soluble COD
- Absorption and assimilation of soluble COD

The mesh used within SMART units is unique and patented. It is fabricated from inert plastic fibres, formed into 50 mm thick sheets with a voidage of 96% (See Figure 3). In use, the mesh rapidly fills with attached biomass (See Figure 4). It is not a biofilm system so the specific surface area of the media is not a relevant parameter.

Figure 3: Clean mesh prior to use

Figure 4: Biomass within mesh

2.4 Hydrolysis of Particulate COD

It has been established that particulate COD and dissolved macromolecules must be hydrolysed into monomers and small oligomers before they can be assimilated and subsequently oxidised by bacteria (Banerji et al. 1967, Law 1980).

Further, over 75% of hydrolytic enzyme activity in an activated sludge process is associated with bacterial cell walls (Confer & Logan 1998, Li & Chróst 2006). The products of hydrolysis are released into the bulk solution for assimilation or further hydrolysis.

Hydrolysis is the rate-limiting step in the activated sludge process. HYBACS works by creating the conditions in the SMART unit which cause naturally-occurring bacteria to produce much higher concentrations of the enzymes responsible for hydrolysis (Hassard et al. 2018). Thus HYBACS overcomes this bottleneck and enables more flow and load to be treated within a given reactor volume.

The products of hydrolysis create a high concentration of readily-degradable and soluble COD. This accelerates the rates of diffusion within the activated sludge flocs, promoting the growth of larger, denser flocs which settle more quickly than conventional activated sludge. Thus HYBACS can operate with higher clarifier loading rates, enabling more flow to be settled in existing clarifiers.

The enhanced hydrolysis also promotes effective biological nutrient removal, due to the availability of readily-degradable carbon.

3. IMPLEMENTING HYBACS AT TSAKANE WWTW

Tsakane WWTW was originally built in 1975 as a carbonaceous activated sludge plant for a flow of 2.5 Mℓ/d. This was replaced in 1986 by a single BNR module in the AAO configuration, with a capacity of 10.8 Mℓ/d. Until the recent upgrade, the treatment process comprised:

- Inlet screening and grit removal (designed for ADWF of 21.6 Mℓ/d)
- One primary settlement tank, 17 m in diameter
- One BNR reactor comprising:
  - Anaerobic zone: 900 m^3 with 3 submersible mixers, 1 kW each
  - Anoxic zone: 1 200 m^3 with 2 submersible mixers, 2 kW each
  - Aerobic zone: 4 600 m^3 with 8 surface aerators, 30 kW each
- Two final settlement tanks, 25 m in diameter
- Final effluent disinfection (chlorine)
- Four aerobic sludge digesters, each 1 635 m^3 in volume with a 37 kW surface aerator
- Gravity sludge thickener and sludge drying beds

Figure 5: Aerial Photo of Tsakane WWTW (2015)

The flows and loads used for design purposes are presented in Table 1.

Table 1: Design Flows & Loads for Tsakane WWTW

Parameter	Design Value
Average flow (MLD)	20
COD concentration (mg/l)	500
SS concentration (mg/l)	173
NH_3-N concentration (mg/l)	29
Ortho-phosphorus concentration (mg/l)	3.4

To achieve the upgrade in capacity from 10.8 Mℓ/d to 20 Mℓ/d involved the following modifications:

- New steel baffle wall in the BNR reactor to enlarge the anaerobic zone from 900 m^3 to 1 600 m^3 and to raise the upstream water level by 155 mm.
- Installation of 12 SMART units and associated steel channels on vacant land beside the BNR reactor.
- New steel baffle wall in the BNR reactor to enlarge the anoxic zone from 1 200 m^3 to 1 812 m^3.
- Convert 2 cells of the aerobic digester into additional aeration capacity, to offset the 1 312 m^3 lost as additional anaerobic / anoxic volume. Aeration zone increased from 4 600 m^3 to 7 060 m^3.
- Overhaul and retain the existing surface aerators on the main aeration reactor.

One of ERWAT's objectives during the planning of the project was to minimise the disruption to the operation of the existing works caused by construction activities. The layout of the SMART units was designed in accordance with best-practice principles of Design for Manufacture and Assembly (DfMA). This approach uses factory-built components which are designed, from the beginning, to be manufactured and assembled off-site, leaving the absolute minimum of work to be done on site.

The 12 SMART units were arranged in two rows of six with the flow entering and leaving via gravity in stainless steel channels. Access walkways were built on top of the channels to provide good access for inspection and maintenance. The entire assembly of SMART units and steel channels was fabricated, assembled and tested in a Gauteng workshop before disassembling into sections for transport. The sections were then reassembled on a simple, flat concrete slab at Tsakane WWTW; the site work took only 3 weeks.

There are many benefits of the DfMA approach. Offsite benefits include:

- All manufacturing processes take place in a workshop with all tools, lifting facilities, welfare facilities and materials readily available.
- The clean, controlled environment of the workshop enables a better quality of finish for welding, coating, painting and similar processes.
- Quality control is better and any snags can be remedied properly before the equipment reaches site.
- Any surplus materials and offcuts can be recycled more easily, reducing cost and wastage.

The direct benefits of DfMA on site work include:

- Major reductions in time and resources on site, resulting in savings in site costs (welfare, offices, transport).
- Many items of equipment can be manufactured offsite simultaneously, reducing the overall project programme and reducing the impact upon site operations.
- Less risk to the construction programme since DfMA is not liable to delays by weather.
- Equipment is typically installed onto flat slabs, meaning that civil works are simple and involve minimal health and safety risks.

Figure 6: Fabricating the Steel Channel Sections in a Gauteng Workshop

Figure 7: SMART units installed at Tsakane WWTW

4. REVIEWING THE SUCCESS OF THE PROJECT

4.1 Final Effluent Quality

The HYBACS upgrade reached practical completion at the end of 2017, though residual snags and mechanical breakdowns elsewhere on the plant affected performance until February 2018. From then until the time of writing, the performance of the HYBACS upgrade has been very good with an overall compliance on nutrient limits of 99%. The HYBACS upgrade was designed to achieve the Water Use Licence criteria set out in Table 2. For comparison purposes, we have included the average final effluent quality recorded during the two months to mid-April.

Table 2: Summary of Final Effluent Quality Requirements & Actual Performance

Parameter	Water Use Licence	Average during Feb. – April 2018
COD (mg/ℓ)	75	27.8
SS (mg/ℓ)	30	10.6*
NH_3-N (mg/ℓ)	7	0.47
Oxidised nitrogen (mg/ℓ)	9	3.5
Ortho-phosphate (mg/ℓ)	0.9	0.24

*Note: * The limit of detection for the method used was 10 mg/l. All values less than 10 mg/l were recorded as 10 mg/l.*

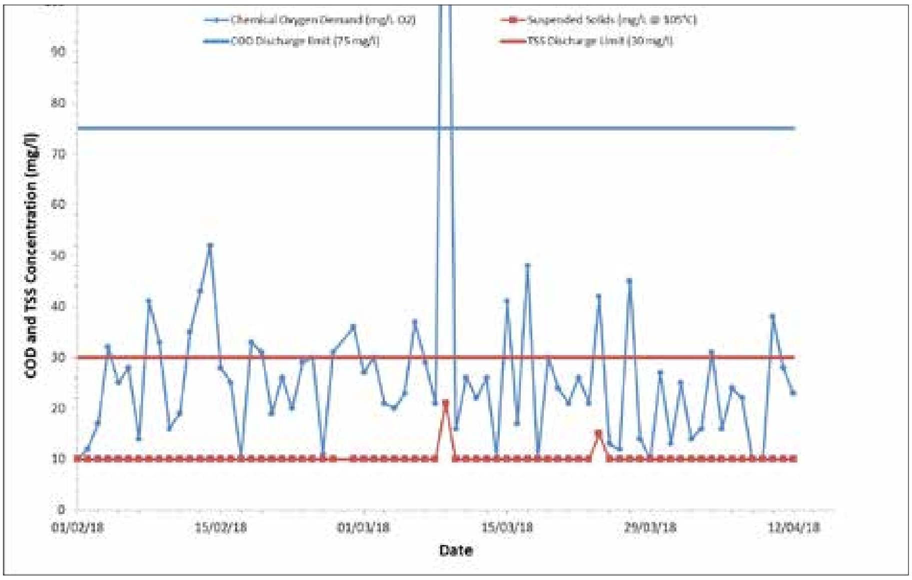

Figure 8: Final Effluent COD and TSS Concentrations

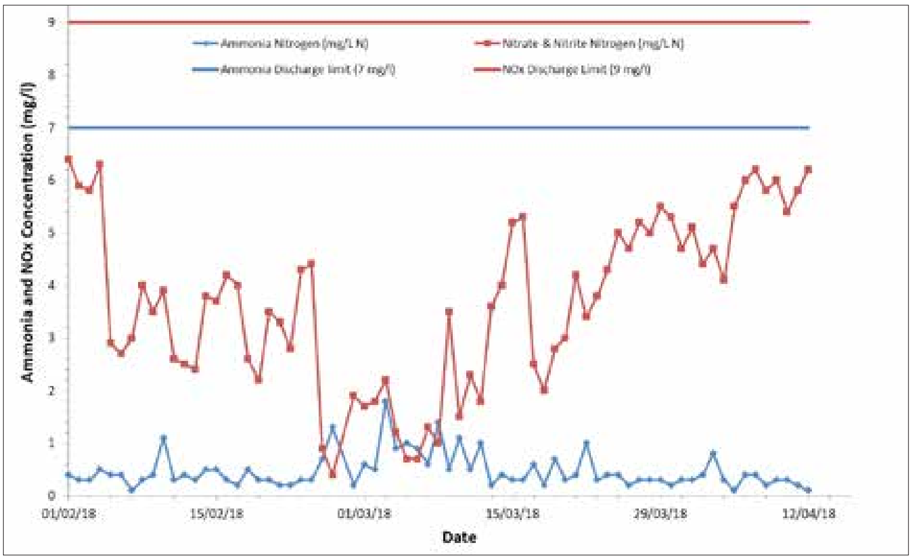

Figure 9: Final Effluent Ammonia and Oxidised Nitrogen Concentrations

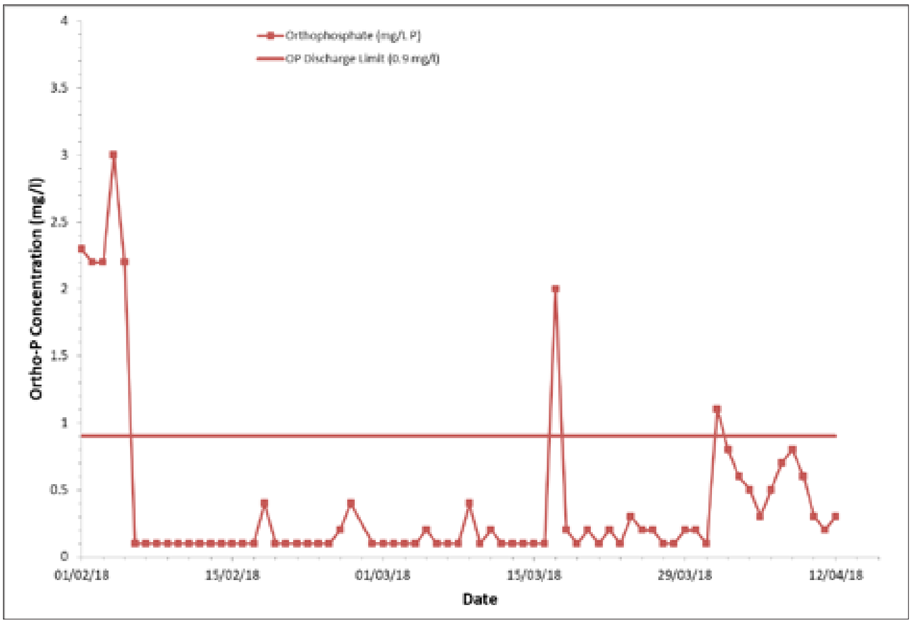

Figure 10: Final Effluent Ortho-Phosphate Concentrations

Figures 8, 9 and 10 show the compliance with the Water Use Licence to date for the various quality parameters. The COD, TSS, ammonia and oxidised nitrogen concentrations have remained 100% within limits, apart from one COD reading of 170 mg/ℓ which ERWAT believe to be an erroneous value. Ortho-phosphate removal has generally been excellent, with <0.1 mg/ℓ OP in the final effluent for most of the time. There have, however, been occasions where concentrations have risen and, on 2 samples out of 65, the limit of 0.9 mg/ℓ has been breached. One breach is likely to be a sampling error and the other is likely due to mechanical breakdown of one of the two duty nitrate recycle pumps on 29/03/18; ERWAT is working with our suppliers to address these matters and achieve 100% compliance.

The graph of ammonia and oxidised nitrogen concentrations (Figure 9) is particularly interesting because it shows the effect of adjusting the dissolved oxygen (DO) setpoint in the aeration lane. In early March 2018, the DO concentration was kept below 1 mg/ℓ, resulting in less DO carried back to the anoxic zone in the nitrate recycleand better denitrification. The effluent nitrate concentration during this period was less than 2 mg/ℓ while the ammonia concentration remained at approximately 1 mg/ℓ.

In mid-March, the aerators were left on in manual control and the DO concentration was typically 3 mg/ℓ. This resulted in better nitrification and the effluent ammonia concentration fell to <0.5 mg/ℓ, but the high DO had an adverse effect upon denitrification and the nitrate concentration increased to 4 mg/ℓ to 6 mg/ℓ. This demonstrates the importance of good aeration control to optimise nitrogen removal. Operating the plant at low DO concentrations also minimises the power consumption because the oxygen transfer efficiency is approximately 40% better at 1 mg/ℓ DO than at 3 mg/ℓ.

4.2 Analysis of Project Capital Costs

ERWAT managed the project directly using its project managers and placed subcontracts with the following services providers to deliver the project:

- Headstream Water: principal designers, supply and installation of SMART units, commissioning and servicing of SMART units
- Veolia/Gohitile JV: civil construction, M&E replacement of RAS pumps, nitrate recycle pumps and surface aerators

The total cost of the project in its entirety costed ERWAT just over R57 million. Based on the assumption of R10 million/Mℓ for conventional plant. We can therefore conclude that the HYBACS plant will cost R6m/Ml. This is about 40% saving on capital required to increase the Tsakane plant to double capacity.

4.3 Operation and Maintenance of the HYBACS Plant

The SMART units are very simple machines with a variable speed motor and two bearings (equipped with auto-greasers) per unit. There are no routine operating tasks.

The operation and maintenance of the rest of the plant is the same as for a conventional activated sludge process: surface aerators, pumps, mixers, scrapers and instruments for flow, level and DO measurements. ERWAT's existing operation and maintenance staff are already fully trained and experienced in equipment of this type, so the adoption of the HYBACS process has been simple for them.

It is too early to fully assess the savings in operating costs following the upgrade. Bluewater Bio, the suppliers of the HYBACS process, have estimated the power savings to be approximately 15% to 20%. This is achieved by operating the plant at a shorter sludge age than a conventional activated sludge process, so there is a reduced demand for endogenous respiration. ERWAT will be monitoring and optimising the operating costs at Tsakane WWTW as part of our ongoing management systems.

5. CONCLUSIONS

ERWAT has applied best practices of proven innovation, design for manufacture and assembly and effective project management techniques to deliver a cost-effective, robust and appropriate upgrade at Tsakane WWTW, using the HYBACS process. The project was delivered at a cost of only R6 million per Mℓ of additional capacity, which represents a saving of 40% on conventional upgrade methods. Much of the capital cost saving is attributed to the fact that existing reactors and settling tanks can be retained as part of the HYBACS process, though their treatment capacity has been enhanced.

The upgrade at Tsakane WWTW was delivered in a efficient manner, using DfMA to shorten the project programme, reduce costs and reduce risks. This approach also minimised the disruption to routine operation caused by construction works. DfMA also reduces health and safety risks during construction and the project was successfully delivered without injuries or accidents.

Results to date indicate that the HYBACS plant is performing very well, comfortably within the limits of the Water Use Licence. We have identified that there is scope to "tune" the plant performance by adjusting operator setpoints to improve the final effluent quality even further, whilst also reducing operating costs.

HYBACS is a simple process to operate and maintain. The regular operational tasks are the same as a conventional activated sludge process and so ERWAT's skilled staff have no difficulties with operation and maintenance.

The new works was designed and built at a lower cost, this is in comparison to the conventional treatment plant that have the same treatment capabilities.

6. ACKNOWLEDGEMENTS

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