STANDBY PAPER 1

LOW-COST UPGRADES FOR ACTIVATED SLUDGE PLANTS

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ABSTRACT

For over a century, activated sludge plants have been designed and operated as suspended growth systems, but there is an inherent flaw in this approach. Bacteria regulate their metabolism according to their environment and restrict the expression of hydrolytic enzymes when COD concentrations are low; this limits the rate at which COD can be assimilated and oxidised, resulting in inefficient use of large reactor tanks. Conversely, retaining bacteria in an environment with a high COD concentration promotes enzyme production by a process called catabolite activation and leads to intensification of activated sludge processes.

A novel hybrid activated sludge process was introduced to South Africa in 2010 and a further three plants have been constructed since then. The process creates an environment where biomass can attach at the start of the activated sludge stage, receiving a consistent high concentration of COD as well as oxygen, and triggering the rapid synthesis of hydrolytic enzymes. Incoming COD is quickly hydrolysed, releasing small molecules which are assimilated into the mixed liquor and carried into the main reactor. By accelerating hydrolysis in this way, the process can operate at double the loading rate of a conventional activated sludge plant as well as creating ideal conditions for biological nutrient uptake and the development of a highly settleable sludge.

This paper presents data from ERWAT's wastewater treatment plant at Tsakane, which has been using this technology since 2018. Additional data are presented from other plants operating globally at a range of scales from 3 to 230 MLD on both municipal and industrial wastewaters. We will explain the process by which an existing plant may be upgraded to use this technology whilst it remains in operation, through offline construction techniques. The presentation will also describe the typical operation and maintenance tasks associated with the technology and compare it to a conventional activated sludge plant. Finally we will illustrate the typical costs for an upgrade and funding mechanisms which may be available.

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.

Prior to the 2018 upgrade, the plant had a design capacity of 10.8 MLD (ADWF) and a PDWF of 21.6 MLD. 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 before selecting a Hybrid Activated Sludge (HYBACS®) upgrade of the existing plant as the solution. The main factors influencing ERWAT's decision were:

- Reliable compliance with Water Use Licence
- Low capital and operating costs
- Ability to construct the upgrade quickly and without affecting operation of the existing plant
- Simple to operate and maintain and a small footprint

The HYBACS Process

HYBACS 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.

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).

In 2007 Bluewater Bio acquired the technology and commissioned researchers at Cranfield University to undertake extensive research to understand the biological mechanisms underlying its high performance (Hassard *et al*, 2018, Hassard *et al*, 2020). Bluewater Bio have since completed several HYBACS upgrades in Europe and the Middle East, serving population equivalents from a few thousand to 700,000. Tsakane WwTW is the 4th HYBACS upgrade to be completed in South Africa.

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, the return activated sludge (RAS) is recycled to the SMART unit. A typical HYBACS configuration is illustrated in Figure 1.

The configuration can be adapted to achieve nitrogen and/or phosphorus removal by incorporating anoxic and anaerobic zones. In each case, the

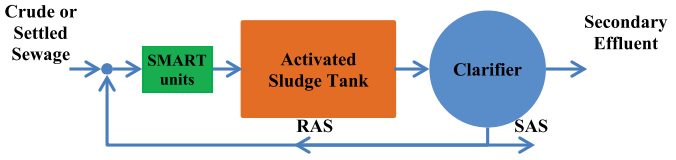


FIGURE 1: *Typical HYBACS Configuration*

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 COD concentration of the liquor passing through the SMART units optimises the overall performance of the process (Hassard *et al*, 2020).

HYBACS is best applied as an upgrade to an existing activated sludge process. By adding an appropriate number of SMART units, the load to an existing aeration tank may be increased by up to 150%. This was proven at an activated sludge plant in the Middle East which was upgraded in 2013 from 40 Ml/d to 100 Ml/d using HYBACS. Generally, the existing assets can be retained in a HYBACS upgrade, helping to minimise the costs and duration of construction.

SMART Units

SMART units superficially resemble rotating biological contactors (RBC), having circular disks of media mounted upon a horizontal shaft. However, instead of impermeable disks which develop a biofilm with an active thickness of typically 200 microns, SMART units contain 50mm 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 SMART unit is 4.8m long and 2.2m wide, containing 30 mesh disks each 2.0m diameter, and serves a population equivalent of 5-10,000 PE depending upon the strength of the wastewater. The mesh rotates at 6 rpm driven by a 2.2kW motor. SMART units contain about 10% of the total active biomass of HYBACS plants.

The SMART unit is structurally different to a rotating biological contactor (RBC). It includes structural end-plates and interlinking beams to create a rigid cylindrical cage, which is inherently much stronger than the shaft of an RBC.

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 1-2%. Clearly the SMART units are not merely serving as additional biological capacity, but are fundamentally altering the performance of the system.



FIGURE 2: *SMART Unit (exploded view to show mesh disks beneath cover)*



FIGURE 3: *Clean mesh prior to use*



FIGURE 4: *Biomass within mesh*

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
- Adsorption 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 50mm thick sheets with a voidage of 96% (Figure 3). In use, the mesh rapidly fills with attached biomass (Figure 4). It is not a biofilm system so the specific surface area of the media is not a relevant parameter.

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. These conditions also favour selection of floc-forming organisms over filamentous bacteria and reduce the risk of filamentous bulking (Palmer *et al*, 2020). 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.

There are no known direct competitors to the HYBACS process, using the same principle of accelerated hydrolysis. The closest similarities are

with high-rate MBBR used in the first zone of an aeration tank, where the biomass attached to the MBBR media is in a region with somewhat elevated COD concentration and catabolite activation may occur to a degree. Such configurations are effective at increasing capacity of a plant by up to around 50% but are often problematic due to excessive biomass growth on the MBBR carriers leading to accumulation of inert solids, especially where media with protected surfaces are used (Dezotti, 2016, Zhang & Bishop, 1994).

Implementing HYBACS at Tsakane WWTW

Tsakane WWTW was originally built in 1986 as a single BNR module in the AAO configuration, with a capacity of 10.8 Ml/d. Prior to the upgrade, the treatment process comprised:

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

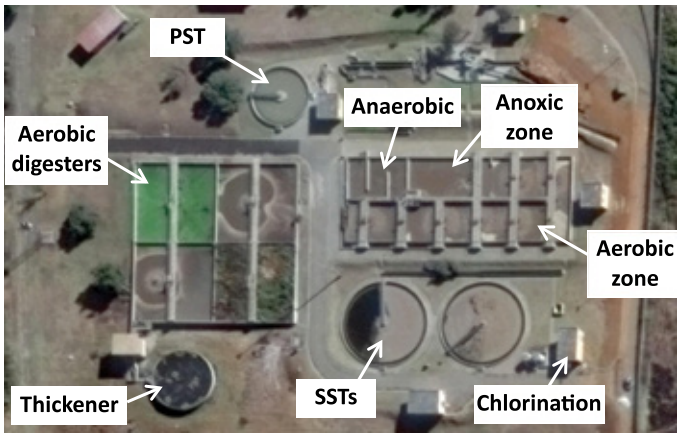


FIGURE 5: *Aerial Photo of Tsakane WWTW (2015)*

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

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.



FIGURE 7: *SMART units installed at Tsakane WwTW*

REVIEWING THE SUCCESS OF THE PROJECT

Final Effluent Quality

The HYBACS upgrade was designed to achieve the Water Use Licence criteria set out in Table 1, though the limit for ammonia has recently been tightened to 1.5 mg/l.

TABLE 1: *Summary of Design Requirements & Actual Performance*

Parameter	Water Use Licence	Average during 2026
COD (mg/l)	75	28.3
NH_3-N (mg/l)	6	5.96
Ortho-phosphate (mg/l)	0.9	0.33*

Note: * The limit of detection for the method used was 0.1 mg/l. All values less than 0.1 mg/l were recorded as 0.1 mg/l.

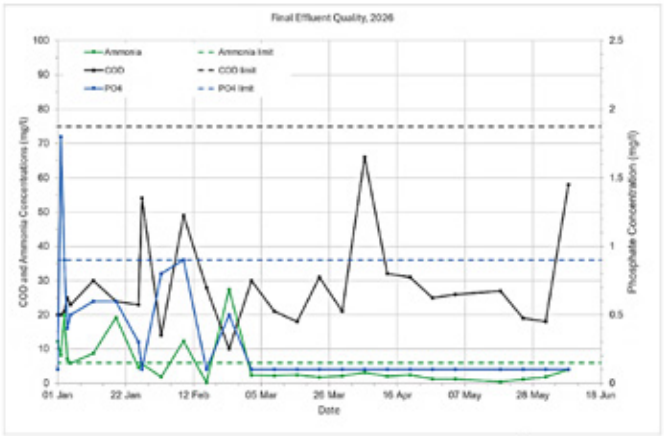


FIGURE 8: *Final Effluent COD, TSS and OP Concentrations*

Compliance with the design objectives and Water Use Licence for the various quality parameters has been good. Ortho-phosphate removal has generally been excellent, with <0.1 mg/l OP in the final effluent for most of the time.

During the period from December 2025 until March 2026, the primary settlement tank desludge pipe was blocked, causing septic conditions in the tank and the release of high concentrations of nitrogen and phosphorus through anaerobic fermentation. This likely caused the somewhat elevated final effluent ammonia and OP concentrations witnessed during this period. There have also been breakdowns of certain surface aeration equipment

resulting in occasional increases in effluent ammonia concentrations. These examples demonstrate the need for good maintenance throughout the treatment stream.

Microscopy

Samples of mixed liquor are regularly taken and assessed in ERWAT's Laboratory using bright-field and phase-contrast microscopy using an Olympus BX43 microscope with x4, x10 and x40 objectives and SC30 camera. The Shannon-Wiener Diversity index was calculated (Shannon, 1948) and Jenkins' Filamentous Index (FI) was estimated.

Regular monitoring confirms that the HYBACS process produces a large, dense floc with a high proportion of ciliate species and few filaments. Typically the HYBACS plant at Tsakane gives a Shannon-Wiener Diversity Index of between 1.2 and 1.7 and a Filamentous Index of 2-3, indicating a healthy and diverse mixed liquor.

Analysis of Project Capital Costs

ERWAT has applied best practices of proven innovation to deliver a cost-effective, robust and appropriate upgrade at Tsakane WWTW, using the HYBACS® process. The project was delivered at a cost of less than R6 million per Ml of additional capacity, representing a saving of at least 40% compared to a conventional upgrade.

Whilst the Tsakane project was funded in the conventional way by ERWAT, other HYBACS upgrades have leveraged the United Kingdom's Export Finance (UKEF). The UKEF offer typically comprises a long-term government-to-government loan on highly favourable rates and is available to projects with a minimum content sourced from UK suppliers. The UK government prioritises loans in the environmental sector facilitated through companies such as Bluewater Bio who have the appropriate experience and accreditation to ensure compliance with international banking best practices.

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. 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.

Whilst meter readings are not available, we have estimated the power savings compared to a conventional BNR process to be approximately 15-20%. 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.

Other HYBACS Installations

Tubli WwTW is the largest wastewater treatment plant in the Kingdom of Bahrain. Two HYBACS upgrades were carried out in 2013 and 2021 with a combined capacity of 230 MLD (ADWF). The HYBACS plants operate at a typical aerobic sludge age of only 3.8 days at wastewater temperatures of 23 - 36°C.

The HYBACS plant receives screened and degritted crude sewage and comprises 84 SMART units and 4 aeration lanes, each with 2,500m^3 anoxic and 10,000m^3 aerated volume and an internal recycle pump operating at 1.5Q.

The treatment objectives are 60 mg/l COD, 15 mg/l TSS, 3 mg/l ammonia and 10 mg/l total nitrogen assessed on a monthly average basis. The secondary effluent is consistently fully nitrified and with a low TSS and COD concentration. The total nitrogen concentration is consistently within required limits though could be reduced further by increasing the capacity of the internal recycle pumps.

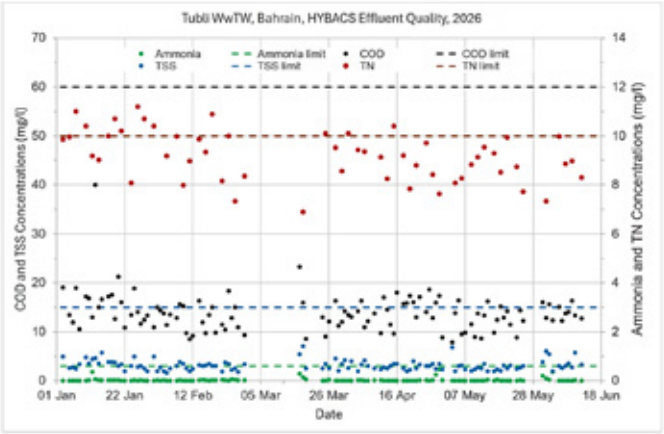


FIGURE 9: *HYBACS Effluent Quality, Tubli WwTW, Bahrain*

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 R 6 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 quickly and efficiently, 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.

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