Optimising Biological Treatment Plants to meet BAT: reduce operating costs and generate revenue

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Back in 2004 (Paper Technology, Vol.45, No.5, pp.39-41) Matt Smyth, then Senior Process Scientist, now Technical Director at Aqua Enviro (part of Suez Water Technologies & Solutions), wrote an article that highlighted some of the common operational problems that faced effluent treatment plants in the paper and board industry; how to investigate them; and potential solutions. Fourteen years on, Matt reflects on what has and what may change considering BREF (Best Available Techniques Reference Document), generating revenue from wastewater via anaerobic digestion and driving down energy consumption whilst minimising the likelihood of filamentous bulking problems in the activated sludge plant.

Introduction

The revised BREF brings in to force production based limits for a range of pollutants for the first time in the UK; these are Total Nitrogen, Total Phosphorus, Total Suspended Solids and COD (*Figure 1*). The main BAT Associated Emissions Levels (BATAEL's) for the UK sector are contained in BATC 45 (RCF mills with and without de-inking) and BATC 50 (paper and speciality mills). BAT10 also sets the requirements for final effluent monitoring.

Parameter	Yearly average (kg/t)
Chemical Oxygen Demand (COD)	0.9-3.0
Total Suspended Solids (TSS)	0.08-0.3
Total Nitrogen (TN)	0.01-0.1
Total Phosphorus (TP)	0.002-0.01

Figure 1. Example of new limits: Direct waste water discharge to receiving waters from the integrated production of paper and board from recycled fibres pulp produced with deinking on site.

The reality is that these levels with be challenging for some, but not all, sites.

In addition BAT conclusion No.8 details the monitoring of key process parameters and of emissions to water and air (*Figure 2*).

Parameter	Monitoring frequency
Water, flow, temperature and pH	Continuous
P and N content of the biomass, sludge volume index, excess ammonia and ortho-phosphate in the effluent, and microscopy checks of the biomass	Periodic
Volume, flow and CH_4 content of biogas produced in anaerobic wastewater treatment	Continuous
H_2S and CO_2 contents of the biogas produced in anaerobic wastewater treatment	Periodic

Figure 2. Monitoring key process parameters relevant for emissions to water.

Numerous sites will already have in place a monitoring regime that satisfies these requirements, but it's a good opportunity to revisit monitoring protocols and frequency to ensure that COD, TSS, TN and TP levels being discharged are as low as possible and that microscopy checks on the biomass are being used to optimise the plant (*Figure 3*). It's also an opportunity to review operating costs, typically >60% is accounted for by the aeration system and significant savings (up to 50%) can be made by operating with just enough micro-organisms in the process. This, however, may not be without risk and in the paper industry it may not be possible to realise this saving as the balance in the treatment plant could be upset and the settlement (measured by the sludge volume index) deteriorates, which puts final effluent quality (TSS, TCOS, TN and TP) at risk.

A site should understand this balance; the opportunity to reduce costs and operational carbon is high on the sustainability agenda.

We've also witnessed the arrival of anaerobic digestion in the sector; on paper this is highly attractive and can offer payback of one to three years, depending upon the size. The process is not without risk and scaling, particularly through calcite deposition, which is an ongoing issue that needs to be managed.

Managing nitrogen and phosphorus levels

Micro-organisms convert wastewater (measured by the Biochemical or Chemical Oxygen Demand test) into new biomass, carbon dioxide and water. They require nitrogen and phosphorus in a ratio, according to textbooks of 100:5:1 (BOD:N:P); in reality the amount needed is usually less, perhaps 100:2:0.2. Given that papermill effluents are usually comprised of predominantly carbohydrates (carbon, hydrogen and oxygen), they will be deficient in both nitrogen and phosphorus; macro-nutrients will therefore be added to the wastewater.

Different blends of nutrients are sourced from chemical suppliers and ideally should be tailored to the site's requirement; a first step in ensuring just enough is added and discharge levels are limited. Dosing should be automated, easy to maintain and calibrate and usually linked to flow, although this control method itself can create risk if the wastewater concentration is highly variable.

Measurement of nitrogen and phosphorus levels exiting the final sedimentation tanks (also referred to as secondary clarifiers) should show 'low' levels. How low, is a matter of opinion; historically where measured levels of ammonia-N or orthophos-

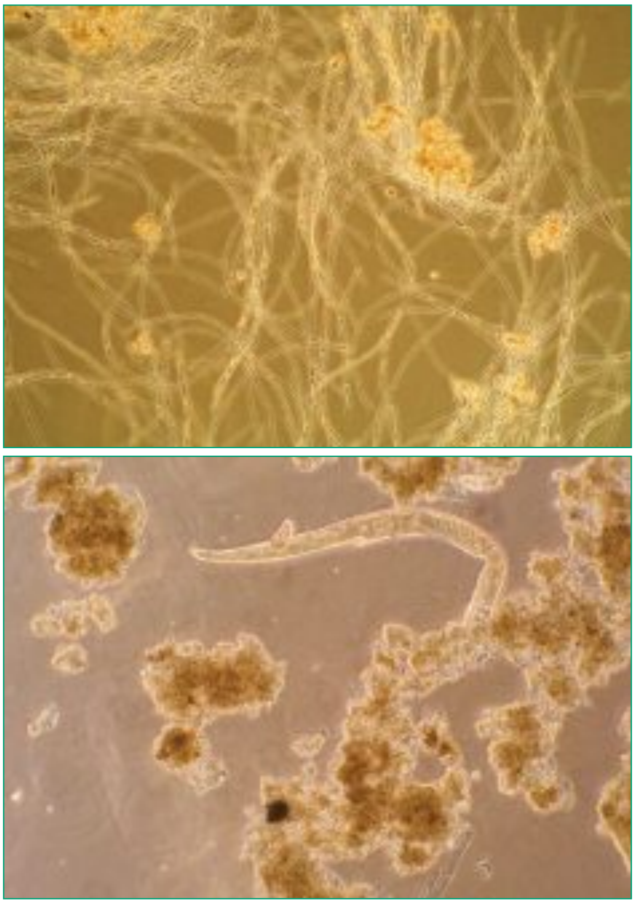

Figure 3. Filaments, which look like string, under the microscope (top left), a spilling blanket from the final clarifier (top right) and an ideal sludge with few filaments and a nematode worm (below).

phate-P drop below 1 or 0.5 mg/l a site will choose to increase the dose rate. Nutrient deficiency is a risk; too little and the competitive advantage in the aeration basin can swing towards filamentous organisms, that cause poor settlement.

In the drive towards lower discharge levels, a greater understanding of the fractions/forms of nitrogen (*Figure 4*) and phosphorus is required.

By way of example a site may contain forms of nitrogen that are unbiodegradable and these will pass through the biological treatment process; the site's discharge levels may therefore look 'high'. Or a site may see 'low' ammonia-N levels and increase the nutrient dose, but without also measuring nitrate-N levels, the process of nitrification (the conversion of ammonia to nitrite and then nitrate) may be taking place. Analysis and optimisation of nutrient dosing levels therefore requires more than ammonia analysis alone. The good news is that these different compounds can be measured and usually just require additional reagents for a spectrophotometer and time.

With BATAEL's and tighter production based limits coming into force it's the perfect time to review monitoring regimes, trigger levels and standard operating procedures for nutrient dosing. Fractionation of the wastewater will also help operators to understand and quantify what concentration levels for COD and Total Suspended Solids is possible for the current effluent treatment plant, which is an important step when developing investment scenarios.

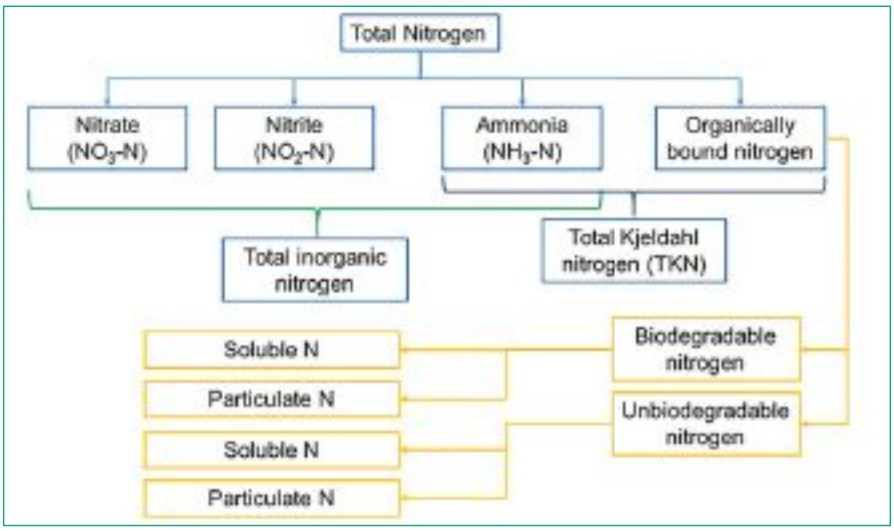

Figure 4. Nitrogen fractionation helps a site to understand how low it can go with discharge levels. The same approach can be adopted for total suspended solids, phosphorus and COD.

Driving down the cost of aeration

For paper mill effluents that have a low influent nitrogen concentration, oxygen is required to:

- Convert BOD (or readily biodegradable COD) into new biomass, and
- Meet the breathing requirement of the micro-organisms, termed the endogenous respiration rate

To remove the pollutants from the wastewater sufficient micro-organisms are required and it is the operator's role to control the quantity; this is measured by the term, sludge age. The sludge age is easy to determine – simply calculate the mass of organisms in the aeration basin (volume multiplied by concentration) and divide by the mass wasted/removed (volume multiplied by concentration) each day, to provide a measure of anywhere between 3 and 30 days. In this example the site at thirty days is holding ten times as much biomass than the site at three days; accordingly the breathing requirement and cost of providing oxygen to meet the endogenous respiration is tenfold. And so, the question is asked:

'*What is the right sludge age for my plant?'*

In terms of treatment and meeting consent, three days is enough for mill effluents. Operators only require longer when there is a need to biologically remove nitrogen; this is common practice in the domestic wastewater industry. However, there are many sites that choose to operate at longer sludge ages and often this is because they have found and proven that sludge settlement rates and overall robustness of the plant is improved. It's therefore an advantage if a site has the flexibility and capacity to vary its sludge age – some do and some do not. Where the flexibility is not present this can be where a site turns to chemical dosing to aid settlement rates, which can be effective, but only against certain bacteria (Type 021N and *Thiothrix*). Chemical dosing, with polymer or hypochlorite, should be tested rigorously at bench scale with jar testing, settlement tests, final effluent analysis and microscopy to minimise the risks of over dosing and to get the optimum (*Figure 5*).

In assessing energy consumption and the optimum operating mixed liquor suspended solids concentration (determined by the sludge), temperature in the activated sludge plant must also be understood. The rate at which the aerobic bacteria breathe doubles for every 10°C rise, up to approximately 30°C. Plants operating at >30°C may therefore find that 80% of the oxygen they are providing and paying for is simply meeting the breathing requirements of the bugs, especially if the sludge age is long.

With BATAEL's, it's the perfect time to review your sludge age, how this affects settlement rates and the cost of aeration; there may be significant savings.

The opportunity for anaerobic digestion

Anaerobic digestion is the conversion of organics into biogas (largely methane and carbon dioxide) in the absence of oxygen. The methane produced from the mill effluent is a source of renewable energy and the biogas produced may be eligible for fiscal incentives, which include the Renewable Heat Incentive and the Feed-in-Tariff. The value of the biogas or the electricity produced through a combined heat and power engine can be used to displace energy used by the site or exported to grid.

One of the main costs associated with digestion is the heat required to achieve mesophilic temperatures, 30-40°C. Often papermill effluent will fall within this range and so the cost is largely avoided. In terms of revenue potential, each tonne of COD converted to methane produces 350m^3 at standard temperature and pressure, equivalent to 3.49MWh. A site producing 10 tonnes of COD a day could in theory produce up to 35MWh a day. How much is actually produced will depend upon the nature of the COD; here fractionation (as with nitrogen and phosphorus) and biochemical methane potential testing is required to estimate accurately. Typically, a site may hope to remove 70-80% of the COD load by AD, which means that a downstream aerobic treatment plant is required to 'polish' the effluent to meet its consent to watercourse. A mill embarking on a digestion project should therefore consider replacing or upgrading the aerobic treatment plant to cope with generally lower levels of pollutants, but also design in the flexibility to take additional load when the anaerobic digestion plant is offline or '*unwell'*. Far too often, across all industries, the ability to bring online or take offline unit treatment processes is removed at the value engineering stage and this restricts the operators' options in difficult times.

The '*health*' of a digester is defined by the temperature, the pH, the level of volatile fatty acids and alkalinity present as well as biogas quality and volume; indeed the monitoring requirements of operation are numerous and should be fully accounted for. In addition, the digester needs to hold anaerobic micro-or-

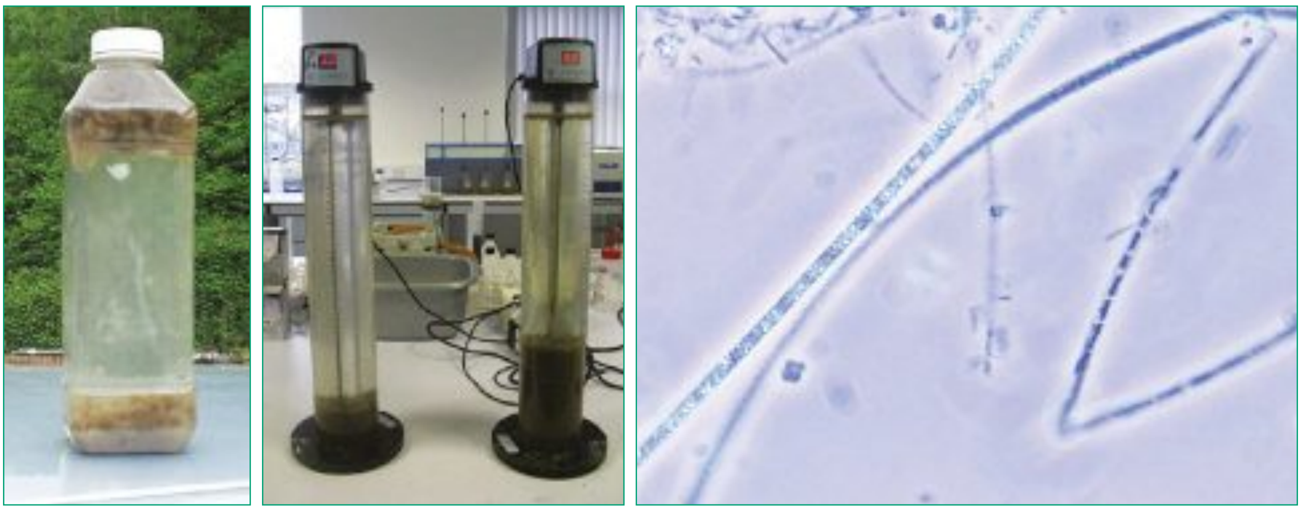

Figure 5. Rising sludge (left) indicative of denitrification or overdosing polymer, the Stirred Sludge Volume Index test (middle) and Thiothrix filament with i) Sulphur inclusions and ii) snapped following hypochlorite dosing.

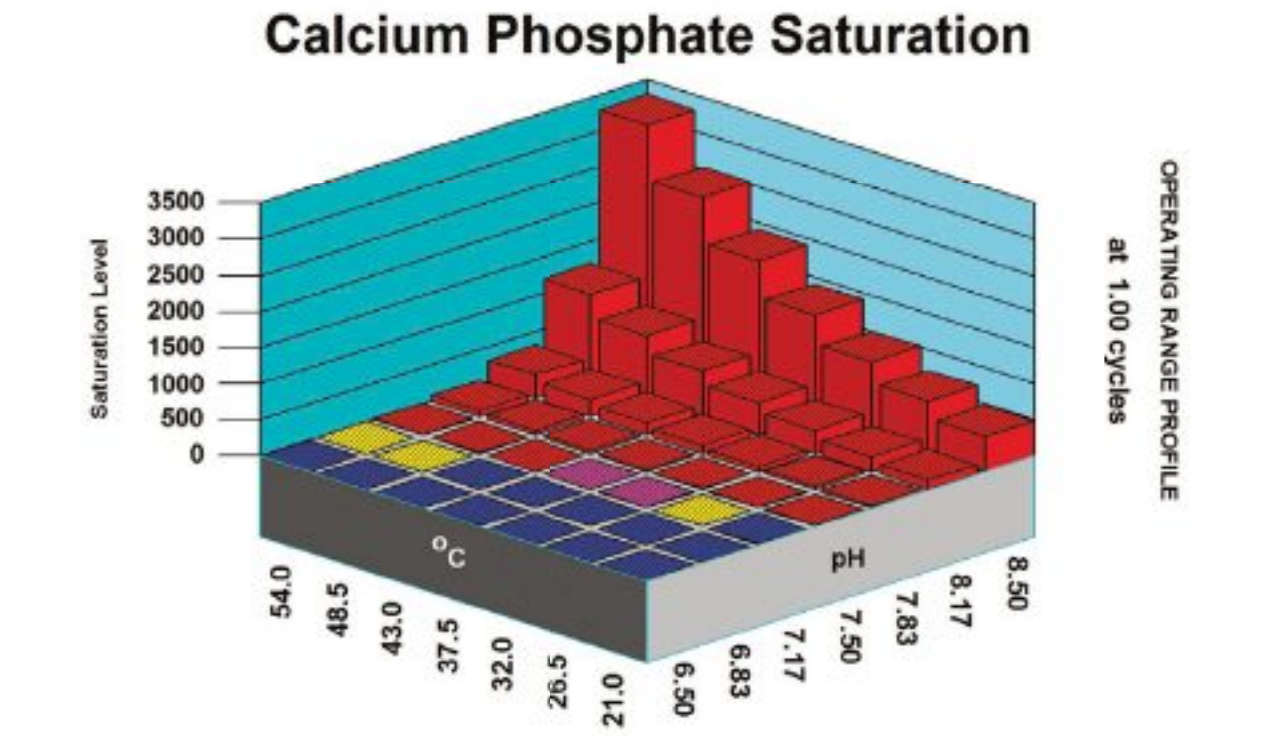

Figure 6. French Creek Analysis output graph illustrating the scale potential of Calcium Phosphate, solubility reduces with increasing temperature and pH. Red warns of a problem, treatment or other remedial action is required. Magenta indicates a problem is likely, take corrective action. Yellow warns to check measurements, trouble is near. Green indicates a mild problem. Blue signifies a safe range.

ganisms and methane formers, termed methanogens. These micro-organisms form caviar like granules, which settle rapidly and retaining them is crucial to long term, successful performance. Where granules lose the ability to settle or are replaced by inorganic precipitates this becomes problematic as the methanogen population drops too low, COD removal rates and biogas production reduces and the load to be 'polished' by the aerobic treatment plant increases. Disruption events including shutdowns and product changes can be challenging to manage; digesters work best when the feed is consistent.

Scaling, however, is now known to be a significant issue. It occurs when the pH rises and this is largely inevitable in digesting mill effluents where the pH is generally '*low*' and dissolved salts (e.g. calcium, magnesium) are present. In the digestion process the pH increases to pH 7-8 as intermediate compounds, termed volatile fatty acids, are converted to methane and alkalinity is returned to the system. The potential for calcium to precipitate increases with increasing pH and increasing temperature, the result being that calcium carbonate and other precipitates are deposited upon and grow within the granules. Testing the organic (or volatile) solids content of the biomass will quantify the extent of the problem. This phenomenon is also seen in activated sludge plants, but the impact is more pronounced in digesters where the sludge yield (the amount of new biomass created from the feed) is lower.

Managing scaling is challenging. Anti-scalants are an option, but themselves may cause issues, and sites may choose simply to replace the digester contents over a period of time. Replacement seed can be sourced from digesters treating wastewater from an industry that does not have such high levels of dissolved salts (e.g. brewing). Scaling should not, however, come as a surprise, and the first stage is to understand the risk of occurrence. Various software packages can predict the pH and temperature when precipitation (Calcium Phosphate shown in *Figure 6*, similar outputs for Calcite can be modelled) will occur, including French Creek Modelling.

For any model, assumptions will need to be made, but these are minimised where the data input is representative of the site's true wastewater characteristics over a production cycle. Given the costs associated with reseeding, potentially £2000 per tanker load, it's worth understanding scaling and fully investigating mitigation measures.

Conclusions

With BATAEL's and tighter production based emission limits on the horizon now is the time to review your effluent treatment plant performance; there may be significant savings and also the potential to generate income through anaerobic digestion.

Matt is Technical Director at Aqua Enviro (part of Suez Water Technologies & Solutions) and has been working in wastewater treatment and anaerobic digestion for nineteen years. He has trained over 1,000 people on wastewater, aerobic and anaerobic treatment including, in January 2018, Environment Agency Officers regulating the paper and pulp industry.

Matt will be delivering in June 2018, in conjunction with PITA, a similar, tailored course for all those operating aerobic and anaerobic treatment plants. For details contact the PITA Office: **info@pita.co.uk** or **Tel: 0300 3020 150**.