Activated sludge optimization using ATP in pulp and paper Industry
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ABSTRACT

The activated sludge process is an old technology, but still the most commonly used one for treatment of wastewater. Despite the wide spread usage the technology still suffers from instability (Tandoi et al. 2006) and high operating cost. Activated sludge processes often carry a large solids inventory. Managing the total inventory without interference is the key component of the optimization process described in this paper. Use of nutrients is common in pulp and paper effluent treatment. Feeding enough nutrients to support the biomass growth is a delicate balance. Overfeeding or underfeeding of nutrients can result in higher costs. Detrimental substances and toxic components in effluents entering a biological treatment system can cause severe, long lasting disturbances (Hynninen & Ingman 1998; Bergeron & Pelletier 2004). A LumiKem test kit is used to measure biological activity with adenosine triphosphate (ATP) in a pulp and paper mill. ATP data are integrated with other standardized mill parameters. Measurements of active volatile suspended solids based on ATP can be used to quantify the living biomass in the activated sludge process and to ensure that sufficient biomass is present in order to degrade the wastewater constituents entering the process. Information about active biomass will assist in optimizing sludge inventories and feeding of nutrients allowing the living biomass to re-populate to create optimal efficiency. ATP measurements can also be used to alert operators if any components toxic to bacteria are present in wastewater. The bio stress index represents the stress level experienced by the microbiological population. This parameter is very useful in monitoring toxicity in and around bioreactors. Results from the wastewater process optimization and ATP measurements showed that treatment cost could be reduced by approximately 20–30% with fewer disturbances and sustained biological activity compared to the reference period. This was mainly achieved by the removal of detrimental substances and optimized nutrient dosage.

Key words | activated sludge, ATP, biological activity, pulp and paper, toxic

INTRODUCTION

Water is an essential raw material for the manufacturing of pulp and paper. Environmental protection and water management has been in focus for many years, especially in areas where clean water is scarce. As forest industries are big water users, recycling of water is of uttermost important for these industries.

The pulp and paper industry have however reduced their water consumption dramatically over the years. In modern mills, water systems are to a high degree closed and a major part of the water is recycled. As a rule of thumb, water is recycled 50 times inside the mill before being discharged into natural water bodies. A modern Kraft mill uses 20–80 m³ water per tonne of bleached pulp produced compared to on average 250 m³ per tonne some 20 years ago. Recycling of water as well as proper effluent treatment has considerably reduced the environmental impact and discharges from pulp and paper production.

The main discharge into water from pulp mills is dissolved organic matter from wood. It differs thus greatly from other types of wastewater in which as much as 40–70% of the organic material (chemical oxygen demand (COD)) is associated with suspended solids (Fettig et al. 1988). A major part of the wastewater originates from stock preparation, black liquor evaporation, screening room and bleaching section.
In paper mills, the wastewater originates as much from the pulping as from the actual papermaking process. Although the wastewater is generated from different raw materials, manufacturing processes, product grades and separation units, effluents from unintegrated paper mills are similar in composition.

Biological effluent treatment has for long been state of the art, but wastewater treatment plants are complex environments with many parameters to keep track on. The activated sludge process is the most widely used biological treatment method within this industry worldwide (Tandoi et al. 2006). It is a process that provides excellent treatment results and low effluent concentrations of organic matter, suspended solids and nutrients, if operated under stable and favorable conditions. The main drawback of the process is the relatively high sensitivity toward variations and disturbances (Jenkins et al. 1993).

The wastewater may contain many different chemical substances, which can inhibit the growth of micro-organisms and cause various troubles during the biological treatment process. These harmful substances can, depending on their physical and chemical properties, either be hard to degrade or recalcitrant and remain toxic during most or even the entire wastewater treatment process (Schalk et al. 1998).

Several surface active compounds, originating from the wood raw material including lignins and wood extractives, such as resin and fatty acids, di- and triglycerides, steryl esters and sterols are toxic to biological treatment processes (Hyninnen & Ingman 1998; Bergeron & Pelletier 2004). Most of the compounds remain bound to fibers and solids in the pulp and papermaking process but some are eventually carried over to the biological wastewater treatment plant.

Efficient end-of-pipe treatment remains a challenging task and control of the wastewater treatment process is extremely important, especially for industries where extensive amounts of water are being discharged into recipients.

The focus on the environmental impacts of pulp and paper mill effluent have in recent years shifted from waste and broad terms such as color, suspended solids and organic matter to more specific terms such as sterols and ‘endocrine disruptors’. The interest in specialized effluent treatment methods is growing as mills will have to monitor their emissions in much more detail in the future.

As wastewater characteristics differ from one mill to another so do the treatment procedures. Primary treatment, with chemical coagulation, removes particulate matter but cannot fully remove dissolved organic material from the wastewater. Biological, so-called secondary, treatment has therefore become ‘state of the art’ for mills with high pollutant concentration. Chemical/physical tertiary treatment may be added to meet the regulatory standard for discharge of wastewater.

Upsets in anaerobic and aerobic biological wastewater treatment plants are costly and difficult to predict and control. Standard measurements such as flow, biochemical oxygen demand (BOD), total suspended solids (TSS), etc. give an indication of wastewater quality and plant performance, but disturbances due to effluent toxicity and/or change of production processes are not detected in due time.

Microscopic observations may provide a good indication of biomass physiology but not of bioreactor health. Advanced measurements on living biomass throughout the process are needed to control the biological processes.

An integrated pulp and paper mill wanted to study the variation of incoming organic load and the impact on the bacteria in the activated sludge treatment plant. The mill was also seeking new ways to stabilize and improve the wastewater treatment process operation.

The main aim of the present paper is to verify the potential application of the ATP measurements as a tool to optimize and control biological wastewater treatment plants.

The method described in this paper provides real-time measurements of active biomass population, stress levels and solids viability in any treatment plant and all stages of the effluent treatment process. It will also detect toxicity in untreated effluent and monitor the effect on the wastewater treatment by new chemicals used in manufacturing.

MATERIALS AND METHODS

The pulp and paper mill selected for this study is an integrated pulp and paper mill in Scandinavia. The wastewater treatment process consists of primary sedimentation, biological activated sludge process, secondary sedimentation and finally tertiary treatment with flotation. Real plant data were used in the study and the authors had daily contact with the mill personnel.

Measurement of ATP can be used to quantify the living biomass in the activated sludge process to confirm the presence of sufficient biomass to degrade the wastewater constituents entering the process. (LuminUltra website 2014; Whalen 2015). This information will assist in optimizing sludge inventories and feeding of nutrient, allowing the living biomass to re-populate for optimal efficiency. ATP measurement can also be used to alert operators if any toxic components to bacteria are present in the wastewater.

The wastewater treatment process was monitored with ATP measurements on daily samples. This ensures that
ATP data would be consistent with other plant parameters monitored at the same frequency. In general, the samples that were used for TSS analysis were also used for ATP analyses. Samples for analysis were collected at various locations throughout the plant: primary clarifier effluent, activated sludge basin outlet and return activated sludge flow.

ATP was measured with high specificity by the firefly luciferase assay using reagents designed and optimized for wastewater treatment applications (LumiKem® technology, manufactured by LuminUltra).

The technology behind the measurements is as following: a sample containing ATP is introduced to a solution containing the enzyme luciferase, which naturally occurs in the tails of fireflies, to produce light. The light is detected in a Luminometer as relative light units. See Figure 1.

Chemical energy produced from the breakdown of ATP is converted into light energy. Each molecule of ATP consumed in the reaction produces one photon of light. The light intensity is measured in a Kikkoman C-100 Lumitester.

The Luciferase assay was stored at 4 °C and preheated to room temperature before use. As the enzyme degrades with time its activity was controlled, and the Lumitester calibrated by daily analysis of an ATP standard.

Two basic ATP measurements were performed at the above-mentioned locations, namely the total ATP (tATP) and dissolved ATP (dATP). While the latter represents the extracellular ATP content of activated sludge, tATP is the sum of intracellular and extracellular ATP contents.

The tATP analysis was performed by adding wastewater to an ATP-releasing agent, followed by mixing. The mixture was then diluted with a phosphate buffer and assayed for ATP.

dATP was measured by adding wastewater to an ATP-stabilizing reagent. The diluted sample was then assayed for ATP. From these basic ATP measurements, a number of parameters were derived:

- AVSS™ – represents the true mass of living microorganisms. This parameter greatly facilitates inventory and process management. AVSS is calculated from the concentration of cellular ATP in the sample.
- BSI™ – represents the stress level experienced by the microbiological population. This parameter is very useful in monitoring toxicity in and around bioreactors.
- Active biomass ratio (ABR™) – represents the percentage of bioreactor solids that are active micro-organisms. Maximizing the ABR provides many benefits such as enhanced sludge quality and improved settling. ABR is calculated as the ratio of AVSS to TSS.
- Specific floc-bulking ATP (sfbATP™) – represents the quantity of ATP from bulking floc relative to micro-organisms. This measurement has been shown to provide early-warning of bulking conditions, allowing operators to proactively identify bulking conditions.

**RESULTS AND DISCUSSION**

The results presented in this paper will focus on samples taken from primary clarifier effluent and activated sludge effluent. Trend curves are complemented with statistics and correlation factors between series. Smoothing and/or gliding average calculations have been used to correct for short-term fluctuations (Portal Gz website 2014).

Sludge inventory in activated sludge processes varies over time and it can thus be difficult to capture the true variation of biological activity in the process. Figure 2 shows a long-time trend of variations in suspended solids concentration in the activated sludge basin. Different types of organic matter in the wastewater, from high to low molecular mass COD, hydrophobic fractions such as extractives and inert material are all detected in the TSS analysis. The quality of effluent entering the biological treatment also varies a lot with various grades produced at the mill. To achieve the best possible effluent treatment it is important to know how bacteria develops under these conditions.

Sludge age, calculated from TSS measurements, is an important, commonly used parameter for biological growth follow up. During normal conditions, the active biomass (AVSS) correlates well with sludge age over time, as shown in Figure 3.

But sometimes there is no clear correlation between TSS and the activated sludge process and biological activity. Figure 4 describes how AVSS and the biological activity dropped on 25 March 2012 due to a sudden biological instability, caused by overloading, and later recovered well with increased AVSS activity and consequently lower discharge of organic matter.
(COD). So instead of just calculating sludge age, it is important also to take the biological activity into account.

ATP measurements can be utilized in other ways too, as both dissolved and tATP is measured. Normally, most ATP is found inside the bacterial cell, so a sudden increase in dissolved (extracellular) ATP indicates a stress situation. The bio stress index (BSI) is calculated from the ratio of dissolved and tATP and it gives an indication of eventual toxic impacts on biological life (Gytel & Papin 2013; LuminUltra website 2014). Experience shows that if BSI is below 50%
in the primary sedimentation basin, there will be no negative impact on the activated sludge process (LuminUltra website 2014).

The trend curves in Figure 5 indicate an increased biological stress (BSI), out from the primary sedimentation. In this case, bacterial life in the primary sedimentation was disturbed due to toxic effects, mainly from higher peroxide residuals originating from the pulp mill.

Information about AVSS will assist in following up changes and optimizing the biological process for the
highest possible efficiency in terms of both cost and performance (Rönnbäck & Papin 2015).

Figure 6 displays curves for AVSS as well as the total wastewater treatment cost index. The index includes the costs for typical process chemicals, sludge dewatering chemicals and nutrients and electricity cost for aeration. The cost index was followed during a period in which optimization was done at the mill. During the optimization period, new process equipment was installed in order to remove at least a part of the identified detrimental substances from the

Figure 6 | Treatment cost (blue curve with circles) and AVSS (red curve with squares) before and after process changes. The full color version of this figure is available online at http://www.iwaponline.com/wst/toc.htm.

Figure 7 | Dissolved COD in inlet (orange curve with triangles) and outlet (green curve with rhombs) effluent before and after process changes. The full color version of this figure is available online at http://www.iwaponline.com/wst/toc.htm.
effluent entering the biological treatment. Nutrient addition was also optimized.

Total treatment cost was decreased by approximately 30% as average cost index decreased from 1.05 before optimization to 0.75 during the optimization period. Biological activity (AVSS) was sustained at the same level during both periods. See Figure 6.

Reduction of dissolved COD in the biological treatment step was, on average, 87% for both periods although the incoming dissolved COD was slightly higher during the second period. See Figure 7. Dissolved COD in the outlet was also more stable with fewer variations during the second period.

CONCLUSIONS

Measurements of AVSS using ATP are useful tools to quantify living biomass in the activated sludge process. Information about biological activity, AVSS, will assist in following up changes and performing optimization work in order to reach optimal efficiency and performance. Sludge age is calculated from TSS measurements and is a common and important parameter used to follow biological growth. But as bacterial activity may change due to process disturbances, it is important also to take this into account when calculating the sludge age.

Toxicity effects on the bacteria in primary sedimentation and in the activated sludge basin can be identified and followed by using ATP and the calculated BSI.

Biological activity, AVSS, was maintained and total treatment cost was decreased by approximately 30% following installation of new process equipment and optimized nutrient addition compared to the reference period.

REFERENCES


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