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# STUDIES ON WASTEWATER TREATMENT PLANT PERFORMANCE MEASUREMENTS

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## ABSTRACT

*Firstly, in this study, the possibility to control an activated sludge plant by using continuous dissolved dry solids (DDS) measurements and conductivity analysers was investigated. In addition, the correlations of the attained results were compared to typical wastewater sum parameters, such as COD or TOC. The tests were performed by installing five (5) refractometers and five (5) conductivity analysers in the wastewater treatment plant (WWTP) and by collecting data and hand samples from a Finnish Kraft pulp mill. The results indicate that new precision refractometers can be used for the detection of very small changes in the DDS at low concentrations (about 50 ppm) in WWTP. The results also indicate that measured DDS had a good correlation to COD- and TOC-values, providing a great potential to use it as a "police meter" for the quality of wastewater before it is introduced into the local water course. However, more tests will be needed to gain a better understanding of the phenomena around WWTP, using these on-line measurements.*

*Secondly, the biochemical dynamics of the purifying process and the use of an aeration capacity were studied by measuring concentration profiles, with respect to time, in a plug flow aeration basin. The measured parameters were: dissolved oxygen concentration (DO), redox potential (ORP) and oxygen uptake rate (OUR) in sludge, as well as residual COD, TOC and total phosphorus in a water phase. OUR, DO, ORP and total phosphorus profiles showed that the major part of the biochemical activity occurred during the first hours of aeration. Only COD and TOC profiles continued after a slow decline during the whole aeration time, which indicates that there was a limiting factor, probably the defiance of phosphorus, in the process. This kind of aeration profiling can be used when optimizing an existing ASP.*

***Keywords:*** *Refractometer, Conductivity, Activated Sludge Plant, Wastewater, Chemical Pulping*

## 1. INTRODUCTION

In recent years, the awareness of the state of the environment has been increased, particularly in the growing economic market of Asia and South America, where the amount of population and industrial activities is still growing strongly. The concern of the availability of pure fresh water and the state of the local water system will cause tighter permits for the quantity and quality of effluents from municipal and industrial systems. This trend has created a need for an improved online monitoring and control of wastewater treatment plants (WWTP).

A chemical pulp mill alone could be a great source of effluent loader to local water courses. The total load is dependent on the quality and quantity of the effluent and the efficiency of the effluent purification system. Normally, the wastewater is treated using an activated sludge plant (ASP), where easily degradable organic materials are treated in an aeration basin with oxygen. This system also includes a primary clarifier for removing fibres and all heavy particles, such as sand. Before the treated effluent is introduced to the local water course, the sludge that is formed in the aeration basin is removed by a secondary clarifier. The principle of a typical wastewater treatment plant used for Kraft pulp mill effluents is presented in Fig. 1 [1].

For the controlling point of view, the most critical parameters of an ASP operation are: pH, temperature, nutrient balance, oxygen concentration, sludge age (SA) and hydraulic retention time (HRT). The first three are set by using the amount of additional chemicals (acid/alkaline, urea and phosphorus acid), oxygen concentration, by air pumping and temperature by a cooling tower. The HRT is normally set when the ASP system is originally planned. To keep the ASP in

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good mode, the conditions in the aeration basin, when the effluent from a chemical pulp mill is treated, should be as follows [1]: pH 6.8-8, temperature 35-37 $^{o}C$ and oxygen 1.5-2.0 mg/l. The nutrient amount is typically set by the influent BOD content being as follows: $BOD_5$:N:P ratio of 100:5:1. When treating Kraft pulp mill effluents, the need for nutrients, especially phosphorus, are, however, usually lower. In a study [2] with Kraft pulp mill effluents, the optimum ratio between $BOD_5$:N:P was found to be 100:5:0,3.

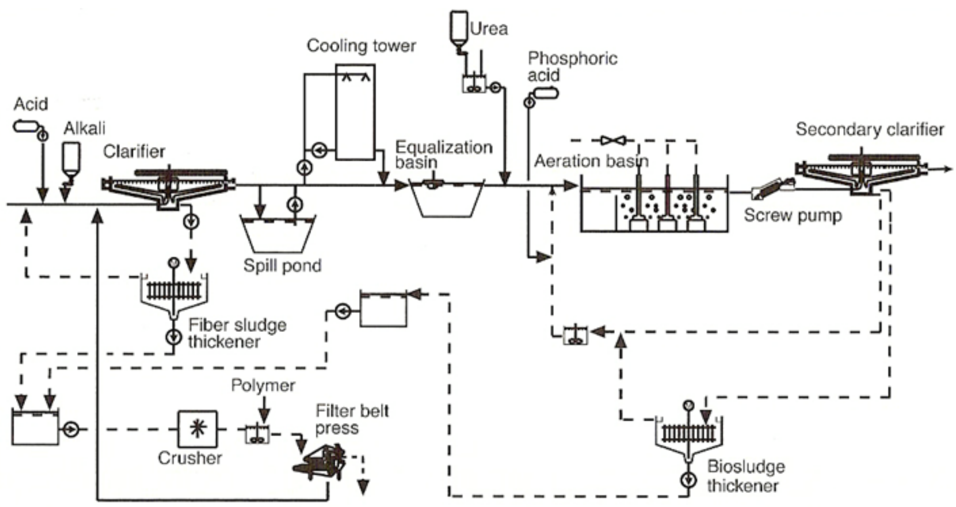


**Figure 1: Typical wastewater treatment process for the Kraft pulp mill effluents. [1]**

From a practical point of view, the efficiency of ASP is greatly dependant on the influent quality and quantity-to-date. If there are some exceptional changes (e.g. leaks from chemical recovery) in the influent quality, the spill pond is used for the cut of unwanted peaks, using a normal conductivity measurement as a “police measure”. The most single important parameter to have an effect on the ASP performance is the sludge age (SA). The more sludge to be produced and removed, the better the purification result. The most suitable SA for the ASP depends on many factors, such as the volume of the organic load [kg/d], the quality of the organic load, temperature, pH and the volume [$m^3$] of the aeration basin. For example, if the existing aeration basin is huge compared to the biosludge production, the SA must be relatively long. If the SA is cut down, in such cases too low, the mixed liquor suspended solids concentration (MLSS) decreases too low at the same time. The range of the MLSS is wide when treating pulp and paper industry effluents with an activated sludge process; from 2,2 to 9,0 g/$dm^3$ [3] depending on the process.

The performance of the ASP is typically estimated by measuring influent and effluent BOD, COD, TOC, phosphorus, pH and conductivity values. From these parameters, the BOD, COD and TOC provides some indication of the amount of organic material and conductivity inorganics respectively. The challenge of the ASP controlling and efficiency estimation is greatly related to the measurement of the mentioned parameters, since only the pH, phosphorus and conductivity can be measured on-line today. The delay for the COD and TOC is hours and for BOD, several days.

In this study, we try to better understand the “life of the soul” of mill scale activated sludge plant using an on-line dissolved solids measurement, based on the refractive index in different places of the ASP and the aeration profiles of different quality parameters, with respect to time in a plug flow aeration basin.

## 2. METHODS

### 2.1 On-line measurement with refractive index in ASP

***Refractive index measurement principle***

The refractometer measures analyte concentrations in solutions, based on a measurement of the refractive index. A refractive index measurement is actually a measurement of the speed of light in a medium. The speed of light in a medium depends on the medium itself, as well as the temperature and wavelength. The refractive index depends on the concentration of dissolved solids. In general, the greater the molecular size of the dissolved solids, the greater the refractive index per concentration unit is. The measurement accuracy is not influenced by the particles, bubbles, fibres, colour or temperature changes in the process medium. The laboratory reference temperature is usually 20 °C or 25 °C. Due to the wavelength dependency, the refractive index is measured with monochromatic light. The measurement principle behind the measurement of dissolved dry solids content through refraction has been presented in detail in our earlier studies [4,5,6].

***Measurement arrangement in the ASP of the mill***

Both influent and effluent from the activated sludge plant were monitored by five (5) refractometers to measure dissolved total solids and five (5) conductivity on-line, as listed in Fig. 2. Before the trial runs, the refractometers were calibrated in co-operation with the refractometer supplier. Calibration was made by taking water samples from all the installation points. More samples were taken during a trial run to re-check the calibration.

During the mill trials, samples from each point were taken every two hours during the daytime (8 am. to 4 pm). In every sample, the dissolved solids (DS), ash content, conductivity COD and TOC were measured in a laboratory. On-line data (DS, T, conductivity and flow) from sensors were collected and stored to the mills data collection system.

The physical properties of the examined activated sludge plant was as follows: volume of aeration basin 1 (Aerator 1) 51,000 $m^3$ and aeration basin 2 (Aerator 2) 39,000 $m^3$. The average flow to ASP is about 60,000 $m^3$/d and the total retention time is about 24 h. The amount of total solids in the aeration basin is normally 4-5 g/$dm^3$. The total solids of return sludge is 8-9 g/$dm^{3,}$ with a volume of 55,000 $m^3$/d-65,000$m^3$/d. The calculated sludge age is normally around 18-22 d.

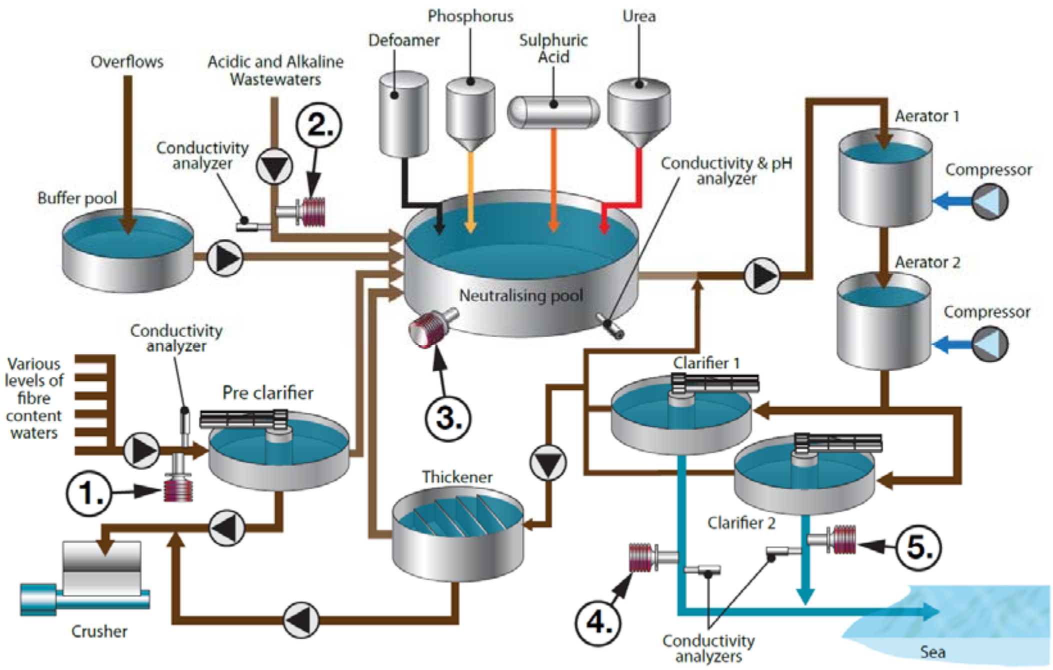


**Figure 2: Refractometer installation points in an activated sludge plant.**

## 2.2 Measurement of aeration basin profile with plug flow principle

The samples from the aeration basin were taken with a plug flow principle, taking into account the actual retention time in the aeration basin. This actual aeration time for the wastewater was calculated, based on influent and return activated sludge flow rates. All of the samples were decanted and the decanted fraction was filtrated (5 µm). After this procedure, all of the wastewater samples were stored in a plastic bottle and frozen for the COD, TOD and total phosphorus analyses.

In addition, the following parameters were measured directly from the aeration basin with a portable measuring unit (YSI Professional Plus Quatro) to make representative profiles: dissolved oxygen (DO), redox potential (ORP) and pH. The oxygen uptake rates (OUR) in different parts of the aeration basin were determined with the following setup; an Erlenmeyer flask (300 ml) with a magnetic stirrer was completely filled up with biosludge and the dissolved oxygen concentration was increased to 4…5 mg/l with an additional air diffuser. After this, the flask was “sealed” with an oxygen sensor and the decreasing DO concentration was recorded in the function of time.

### 2.3 Laboratory analyses

All of the influent and effluent samples in this study were measured in laboratory conditions, by using the follows standards: pH (SFS 3021), conductivity (SFS-EN 27888), $COD_{Cr}$ (SFS 5504), TOC with Shimadzu *TOC-V CPH* analyser (SFS-EN 1484), total phosphorus (SFS-EN 1189) and dissolved solids (SCAN-N 22:77). Onsite measurements were performed with YSI Professional Plus Quatro portable measuring unit with polarographic dissolved oxygen, pH and redox potential (ORP) sensor. The oxygen uptake rates were measured with an Oxi 330i instrument.

## 3. RESULTS AND DISCUSSION

### 3.1 On-line and laboratory measurements

***Influent to ASP***

The dissolved dry solids measured by the refractometer, versus the COD, TOC (laboratory analysis) and on-line conductivity are presented in Fig. 3. The results indicate that the correlations of the measuring results are quite equal during the trials. The wastewater quality was quite normal with DDS 0.3% and COD 2000 mg/dm$^3$. After a steady beginning (24 and 25.1), some problems in the fibre line occurred, causing an extra load to the ASP. These concentration changes in the influent stream (26.1 and 27.1 again) were observed in time by an on-line refractometer and conductivity measurements, however.

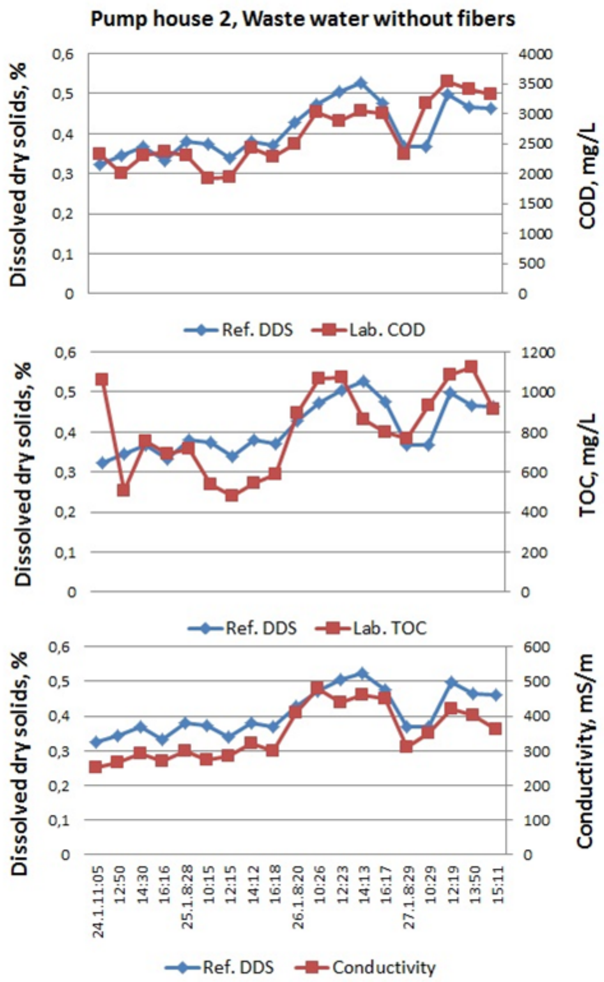


**Figure 3: Influent DDS content versus the COD-, TOC- and conductivity analyses.**

The results of the on-line refractometer and laboratory COD-, conductivity- and ash from the influent stream to the ASP are presented in Figure 4. Normally, ash content is approximately 40 - 60% in wastewater. In the examined wastewater, DSS was evenly distributed to organic and inorganic matters. The results show an exception, point 6 (25.1.11:59), where the ash content was higher at 76%. It can be seen that a momentary inorganic matters spike very clearly shows an increase in the results of the conductivity and on the refractometer values, while no effect on the COD value was observed. These results support the theory that conductivity tells us more about the inorganic materials, the COD tells us more about the organic materials and the refractometer measurement emphasizes both with the measuring DDS.

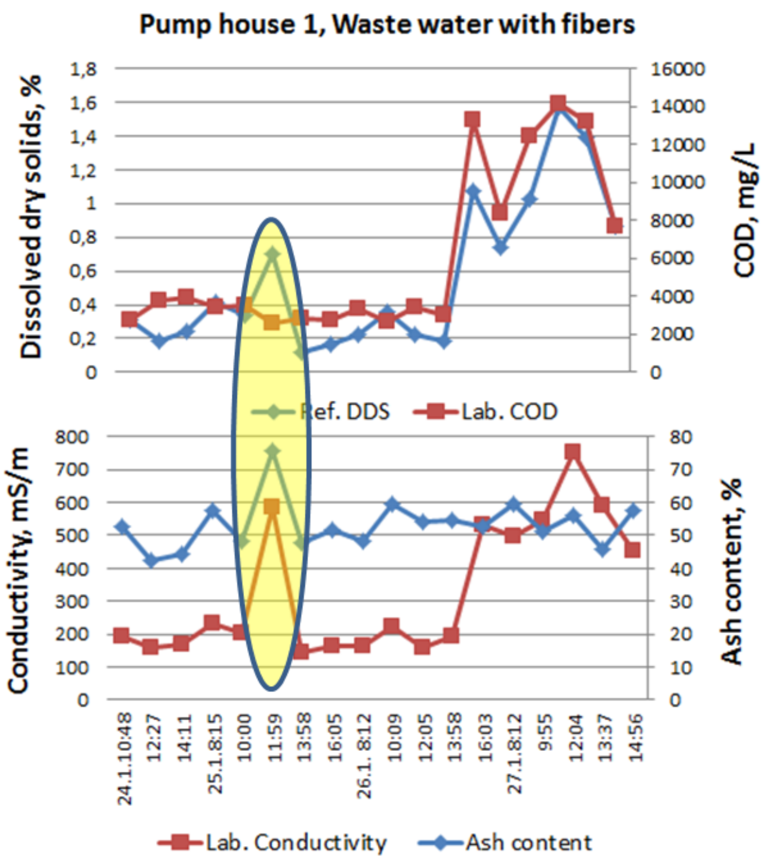


**Figure 4: Influent DDS, COD, conductivity analyses and ash content**

***Effluent from ASP***

The results of the on-line refractometer measurement and laboratory COD- and TOC-analysis are presented in Figure 5. The results indicate that the refractometer measurement follows the mill's COD and TOC-analysis evidently in the effluent stream from ASP. The conductivity measurement only responds to level changes. With help of the on-line measurement results, it could be noted that an aeration system can compensate for momentary changes in the wastewater load, but larger problems show for increasing the concentration of DDS. During the monitoring period, the DDS rose from 0.17% to 0.22% and COD from 500 mg/l to 800.

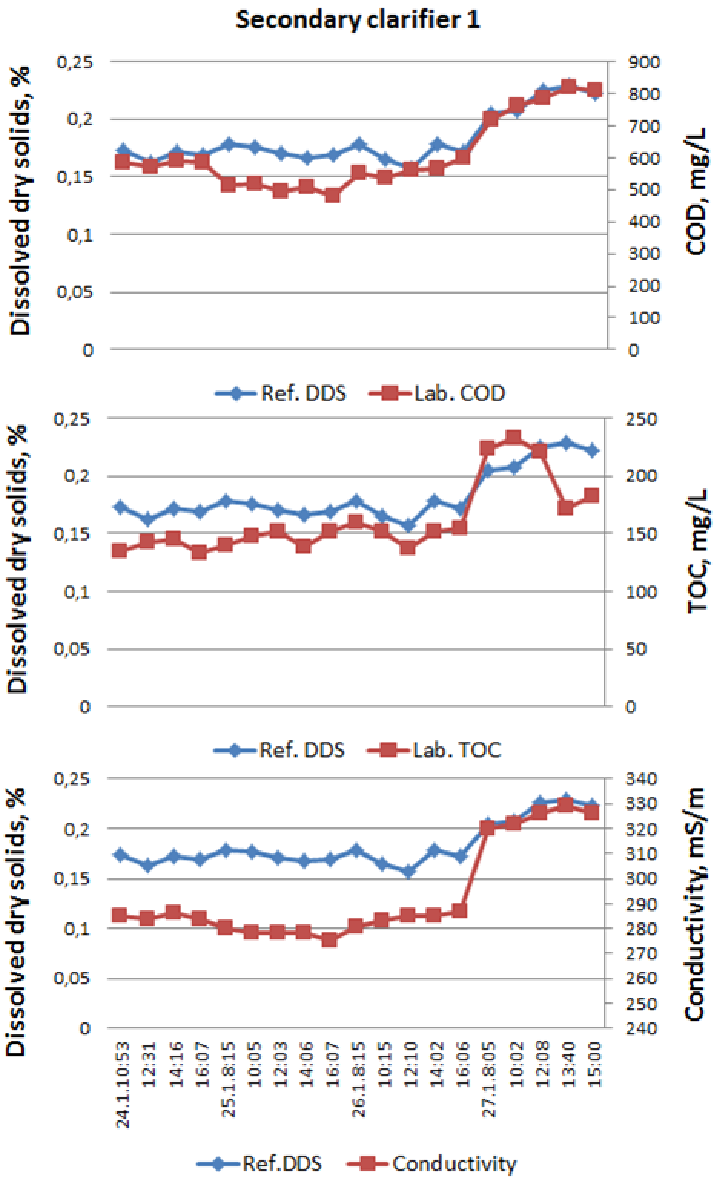


**Figure 5: Effluent DDS content versus the COD-, TOC- and conductivity analysis.**

## 3.2 Measurement of aeration basin profiles with a plug flow principle

Onsite measurements (DO, ORP and OUR) from the aeration basin suggested that the major part of the biochemical activity occurs during the first six hours of aeration (Figs. 6 and 7). DO concentration was very low at the beginning of the aeration, despite effective aeration. ORP in the aeration basin showed a negative value for the first two hours, but increased relatively quickly to a stable level after the DO concentration had increased. After six hours of aeration, no significant changes in the ORP were detected. Similar observations have been made in a previous study [7] within the activated sludge processes of different pulp and paper mills.

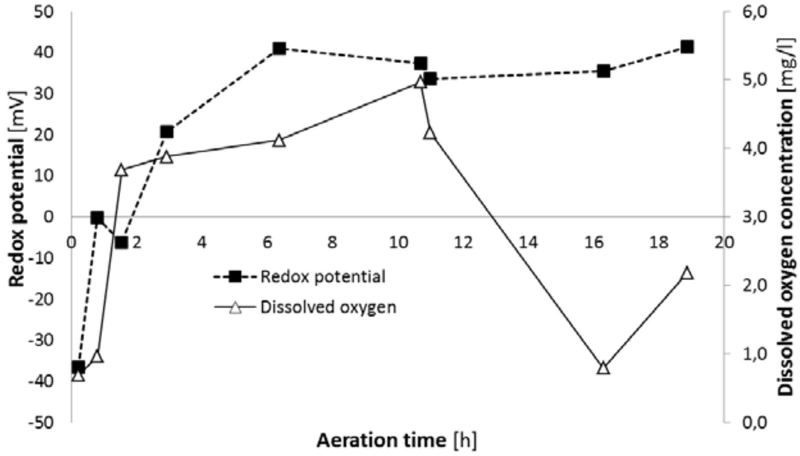


**Figure 6. Redox potential and dissolved oxygen profiles in the aeration basin with respect to actual aeration time.**

The drop of the DO concentration and ORP at the beginning of the aeration was due to the high level of OUR (Figure 7). The OUR in the aeration basin decreased relatively quickly during the first two hours of aeration. After two hours of aeration, only minor changes in the OUR occurred and the eventual OUR level was reached after six hours of aeration. The total phosphorus concentration in the water phase followed the onsite measured OUR levels quite closely. The rapid intake of phosphorus during the aerobic phase probably took place due to polyphosphate accumulation in the cells, rather than due to the biomass synthesis.

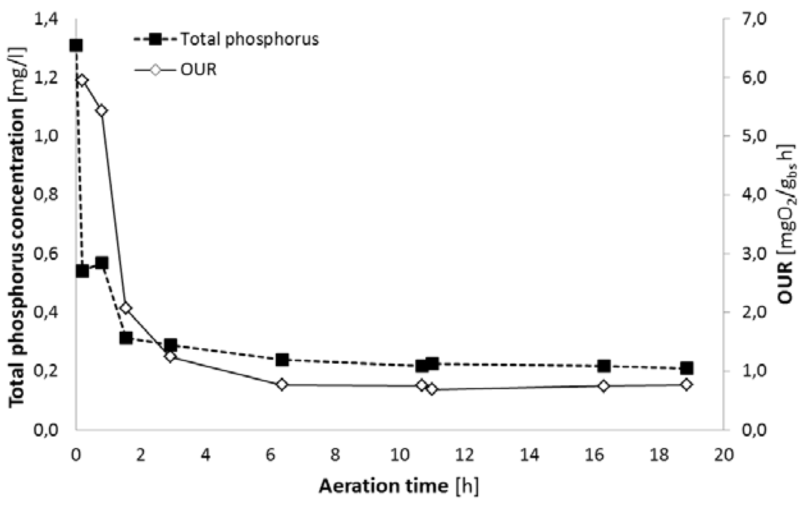


**Figure 7. Total phosphorus (decanted and filtered samples) and oxygen uptake rate (OUR) profiles in the aeration basin with respect to actual aeration time.**

The reduction of COD and TOC concentrations was also high during the first hours of aeration. Unlike the other measured parameters, COD and TOC concentrations continued to decrease throughout the entire aeration time (Figure 8). This further degradation of organic matter was very slow and did not consume any phosphorus, according to the total phosphorus profile (Figure 7), and had quite a constant OUR (aeration time 6…18 hours). This may indicate that the phosphorus was, indeed, a limiting factor in the aeration basin after the very beginning of the process, even though polyphosphate had apparently accumulated in the cells at the beginning of the aeration. The low and constant total phosphorus level in the aeration basin, together with a very constant biological degradation rate, suggests that the required available phosphorus for the biosynthesis was obtained from the degradation of biosludge, and not from the water phase.

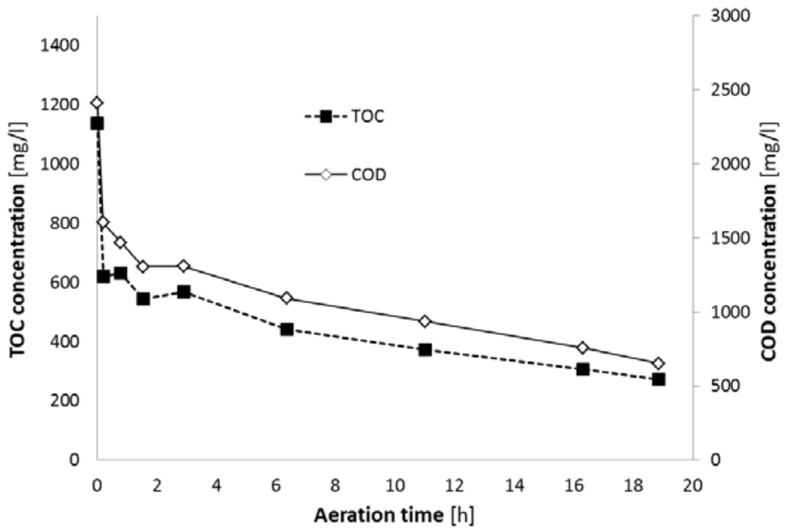


**Figure 8. COD and TOC profiles (**decanted and filtered samples**) in the aeration basin with respect to actual aeration time.**

## 4. CONCLUSIONS

The results indicate that refractometers are suitable for the detection of very small changes in the dissolved dry solids at low concentrations (about 50 ppm). The results also indicate that the real-time refractometer measurement follows the mill's COD and TOC-analysis evidently in the effluent stream from ASP. Conductivity measurement only responds to level changes. The measuring of conductivity by oneself is not adequate. A reliable DDS measurement, combined with a conductivity analyzer, could give new possibilities for controlling the performance of ASP.

In addition, the COD and TOC profile from the aeration basin, together with the OUR or redox potential profile, would reveal useful information about the state of the biological wastewater treatment process. Aeration profiles can be used when optimizing and controlling the sludge age or aeration itself within a plug flow ASP.

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