Application of biosensors in wastewater treatment

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Abstract

"Biosensors" are defined as sensors that allow the measurement and interpretation of the biological response of activated sludge to a known disturbance. The purpose of "biosensing" the activated sludge, on-line at the full-scale plant or off-line in lab-scale tests, is to obtain specific information about one or several activated sludge processes. This information can serve as plant performance indicators. Examples are the concentrations of readily biodegradable organic substrate fractions, concentrations of nitrogen components, toxicity of wastewater, degradation capacity of the sludge, settling characteristics etc.

The disturbance the sludge is subjected to is most often in the form of a substrate addition (organic carbon, nitrogen, mixtures, wastewater, etc.). The measurement typically takes place in a small reactor filled with activated sludge that was previously sampled from a treatment plant. The measurement device within this reactor vessel can be a simple probe, for example a dissolved oxygen or pH electrode, but it can also be a more complicated flow injection analysis system. Processing and interpreting the recorded response, in several implementations already done automatically, can be based on a simple regression analysis or a more advanced model-based data interpretation procedure.

In the sequel, "biosensor" applications for COD and N removal processes will be described. We also include some general concepts that are currently applied to detect increased acute toxicity of the influent using on-line "biosensors".

COD and N removal processes

The introduction of combined COD, N and P removal in wastewater treatment significantly increased the complexity of the biological interactions. This created a need for a better understanding of the performance of the biological processes. For COD and N removal processes the "biosensor" development has gone in two directions. First, on-line sensors were developed to obtain information about wastewater and sludge characteristics. These data can be important to control the wastewater treatment plant. Secondly, the introduction of more advanced dynamic models to simulate COD and N removal in activated sludge plants (Henze *et al.,*1987) created a need for adequate tests to characterize wastewater and activated sludge. Research here is concentrating on the development of methods and techniques, both on-line

and on lab-scale, that can provide the information needed for model calibration. Indeed, the quality of the model predictions is strongly depending on the quality of the model calibration.

Respirometry, the measurement and interpretation of the activated sludge oxygen uptake rate (OUR), is one of the most popular techniques to study the characteristics of wastewater and activated sludge biodegradation kinetics. Spanjers *et al.* (1998) give a detailed description of different respirometric techniques. Interpretation of respirometric data is often model-based. A good example is given in Coen *et al.* (1998). The RODTOX respirometer (which is built around a continuously aerated batch reactor) was operated on-line at a full-scale industrial wastewater treatment plant (COD removal, no nitrification) to monitor the readily biodegradable organic substrate. Figure 1 shows a sequence of raw dissolved oxygen data for 8 batch experiments with wastewater, 4 calibration experiments and 1 decantation cycle. Each of the wastewater oxygen profiles contains three sharp “shoulders”, indicating that the wastewater contains three main biodegradable fractions. Models were developed to describe wastewater and calibration profiles, and were applied to the on-line data. Results are illustrated in Figure 2 as the ratio between readily biodegradable COD of the three identified wastewater fractions and the total readily biodegradable COD of the wastewater.

Apart from respirometry other methods are useful in the characterization of wastewater and sludge kinetics. For nitrogen removal processes measurements of Ammonium Uptake Rate (AUR) or Nitrate Uptake Rate (NUR) have been applied (Kristensen *et al.*, 1992). However, on-line application of AUR and NUR is more problematic since ammonium and nitrate sensors are not as robust as for example a dissolved oxygen probe. Recently, a titrimetric method, where the proton consumption or production rate is monitored in a reactor vessel, has been successfully applied for the characterization of nitrification (Gernaey *et al*., 1997) and is currently under development for other processes. This method has proven to be rather simple and robust, and prototypes are tested for on-line measurement of the nitrification capacity. Data, collected over one month during autumn 1998, is illustrated in Figure 3. The decreasing trend in Figure 3 can be explained by a slow decrease of the temperature in the activated sludge tank, which negatively influences the nitrification capacity.

A combined respirometric-titrimetric method for more accurate characterization of different activated sludge processes is currently under development (Gernaey *et al.*, 1999). In this sensor a respirometer (Vanrolleghem and Spanjers, 1998) is combined with the titrimetric method mentioned above (Gernaey *et al.*, 1997). The respirometer consists of an aerated vessel with an oxygen probe, and a closed respiration chamber equipped with a second oxygen probe. The activated sludge is continuously pumped around from aeration vessel to respiration chamber and vice versa. The principle is illustrated with a simple experiment where acetate has been added to the aeration vessel at t = 0. In Figure 4 two oxygen curves are given from aeration vessel and respiration chamber respectively. The difference between the two oxygen curves is due to the retention time in the respiration chamber. OUR can be calculated by making a mass balance over the respiration chamber (Figure 4). Different information levels are in fact available

from these two oxygen curves: The oxygen mass balance over the respiration chamber gives information on OUR. However, the oxygen data of the aerated reactor separately also give information, comparable to the data derived from a RODTOX experiment. Hence, the different information levels of the sensor data can be combined to yield more information about the process under study. In Figure 4 the information from the simultaneous titrimetric measurements is also given. In the titrimetric method pH is kept constant with an accurate pH controller (within a band of +/-0.03) and the acid and base dosages required to keep this pH are recorded. Generally, degradation of acetate consumes acid, and consequently one has to dose acid to keep pH at the pH setpoint. As soon as acetate is degraded, the acid addition rate drops back to a background level (t = 22 min). The titrimetric data give information about degradation kinetics. A combined respirometric-titrimetric method thus becomes a powerful and information rich method for characterization of activated sludge kinetics and wastewater composition.

Detection of toxic wastewater

Toxic wastewaters can be an important and unexpected source of problems at activated sludge plants. The presence of toxic wastewaters is generally related to industrial activity. In the most optimal situation toxic wastewater is treated at the source. However, this is often not the case. Therefore, rapid and simple on-line test methods are useful to detect increased acute toxicity of the wastewater. Several standardized toxicity test methods are available on the market, e.g. with luminescent or immobilized bacteria. The disadvantage of these methods however is that the bacteria used may not be representative for the specific situation of a wastewater treatment plant. The best correlation between results from a toxicity test and the real behavior of the activated sludge is obtained when the activated sludge itself is used in the toxicity tests. Different respirometric applications have been developed to use activated sludge for wastewater toxicity detection. Toxicity detection is mostly done through a comparison of the sludge response in presence of wastewater with the response obtained for a non-toxic reference substrate.

<u>On-line toxicity detection on the influent of a wastewater treatment plant. A case study</u>

A respirometer, in this case the RODTOX, was installed at the influent of a treatment plant. Influent was regularly dosed in the reactor vessel of the sensor. Toxicity of the influent was evaluated by comparing the respirometric data for the influent with the respirometric data obtained during a calibration cycle with a reference substrate. A 20% reduction of the reference substrate degradation capacity was considered as an indication for increased acute toxicity of the wastewater. During a first phase the normal treatment plant influent was monitored. An alarm was generated twice (Figure 5; event A1 and A2). Both alarm situations were followed by an increase in the effluent NH_4^+-N concentration, an indication that nitrification in the treatment plant was inhibited. Influent Kjeldahl nitrogen data show that the increase was not due to an increased loading. In a second phase the reliability of the respirometer for toxicity detection was tested with a deliberate intoxication of the wastewater with creoline. In a first experiment (Figure 5; event D1) the dosage of the toxic compound was stopped immediately after the detection of the toxic compound in the influent. This is a simulation of a control strategy in which the toxic wastewater

is pumped into a calamity basin as a response to the detection of increased toxicity. Creoline reached a maximum concentration of 5 mg/l in the activated sludge. Toxicity detection was in due time because NH_4^+-N removal was not affected. In a second experiment (Figure 5; event D2) the toxic wastewater addition was continued even after the detection of the toxic pulse, until deterioration of the effluent quality was observed. Creoline dosage was stopped when effluent NH_4^+-N concentrations increased (creoline concentration in the activated sludge tank reached 25 mg/l).

Conclusions

Full understanding of the complicated biological interactions in a wastewater treatment plant is essential to optimize treatment plant operation, aiming at reaching a good effluent quality against minimum cost. Application of “biosensors” is essential in the frame of these evolutions.

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References

Coen F., Petersen B., Vanrolleghem P.A., Vanderhaegen B. and Henze M. (1998) Model based characterisation of hydraulic, kinetic and influent properties of an industrial WWTP. Wat. Sci. Technol., **37**(12), 317 - 326.

Gernaey K., Bogaert H., Massone A., Vanrolleghem P. and Verstraete W. (1997) On-line nitrification monitoring in activated sludge with a titrimetric sensor. Environ. Sci. Technol., **31**, 2350 - 2355.

Gernaey K., Petersen B., Ottoy J.P. and Vanrolleghem P. (1999) Activated sludge monitoring with combined respirometric - titrimetric measurements Water Res. (submitted).

Henze M., Grady C.P.L. Jr., Gujer W., Marais G.V.R. and Matsuo T. (1987) Activated sludge model No. 1. IAWPRC Scientific and Technical Reports No. 1. London, UK.

Kristensen H.G., Elberg Jørgensen P. and Henze M. (1992) Characterisation of functional micro-organism groups and substrate in activated sludge and wastewater by AUR, NUR and OUR. Wat. Sci. Technol., **25**(6), 43 - 57.

Spanjers H., Vanrolleghem P.A., Olsson G. and Dold P. (1998) Respirometry in control of the activated sludge process: principles. IAWQ Scientific and Technical Report No. 7.

Vanrolleghem P.A., Kong Z. and Coen F. (1996) Full-scale on-line assessment of toxic wastewaters causing change in biodegradation model structure and parameters Water Sci. Technol., **33**(2**)**, 163 - 175

Vanrolleghem P.A. and Spanjers H. (1998) A hybrid respirometric method for more reliable assessment of activated sludge model parameters. Wat. Sci. Technol., **37**(12), 237-246.

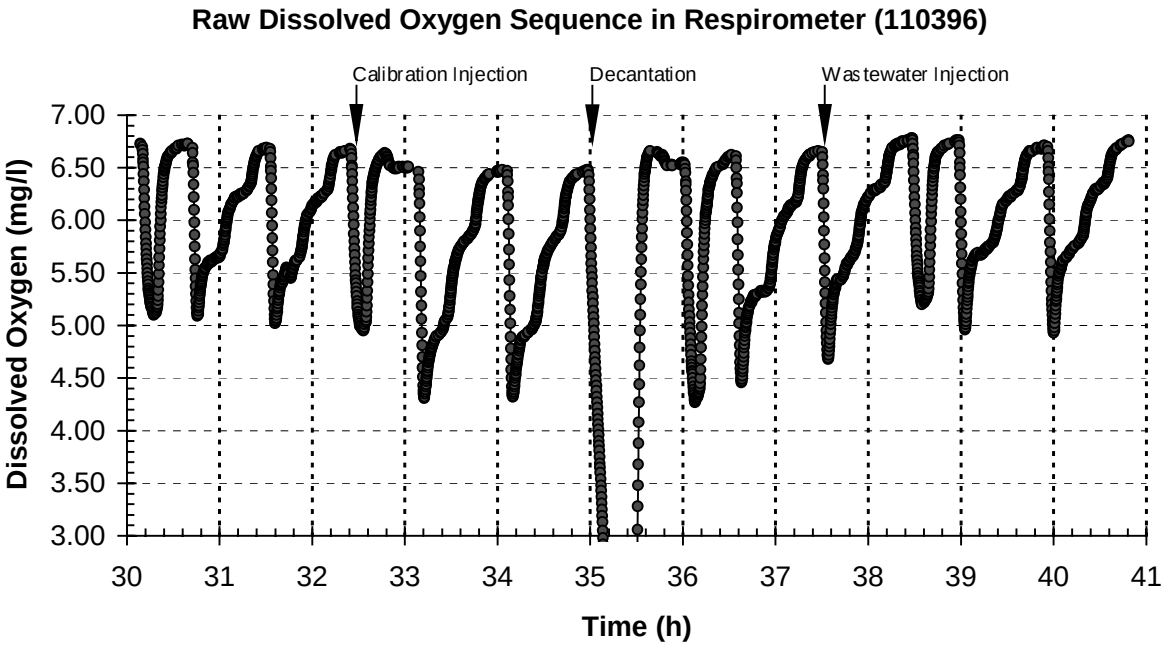

Figure 1. Dissolved oxygen data from the RODTOX respirometer installed on-line at the influent of an industrial wastewater treatment plant (Coen *et al.*, 1998).

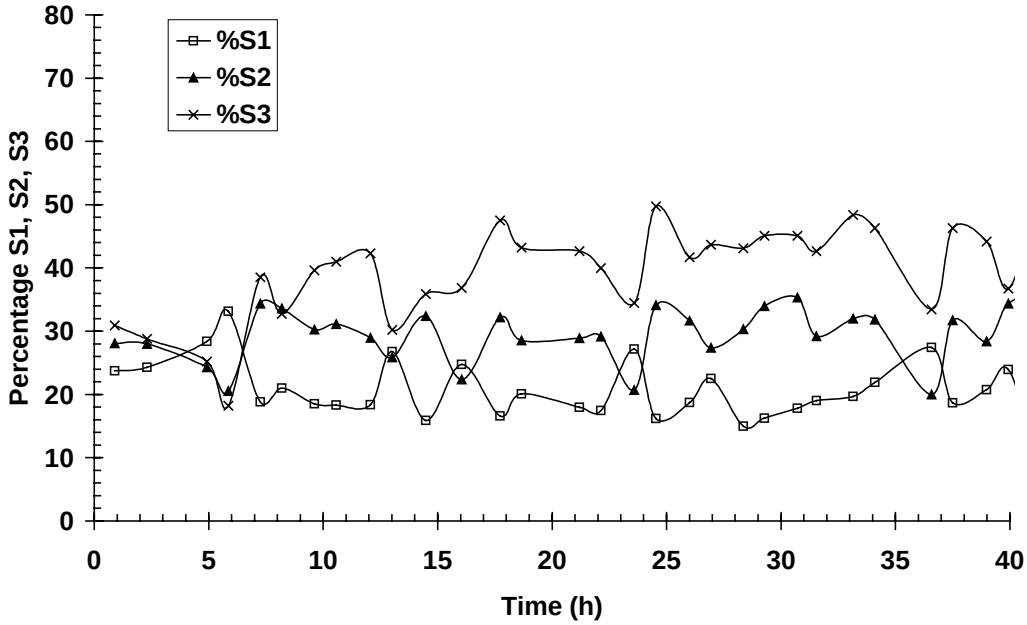

Figure 2. Result of the estimation of wastewater fractions (S1, S2 and S3) as a percentage of total readily biodegradable COD using a model-based approach (Coen *et al*.,1998).

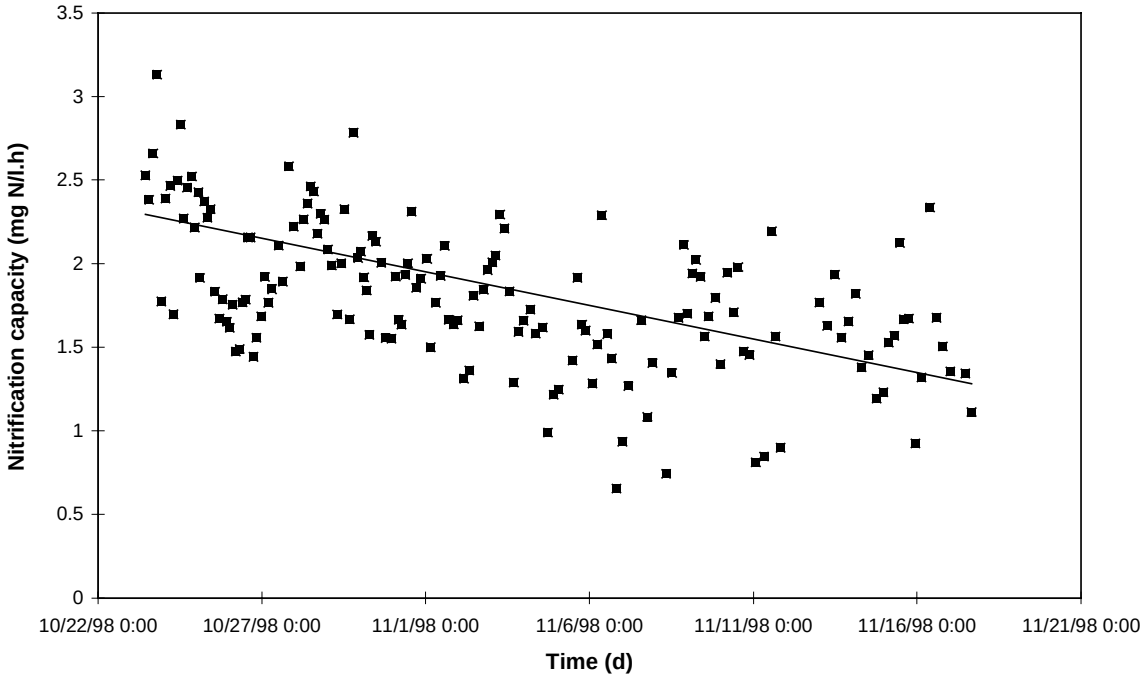

Figure 3. Nitrification capacity measured for a municipal treatment plant with an on-line titrimetric sensor

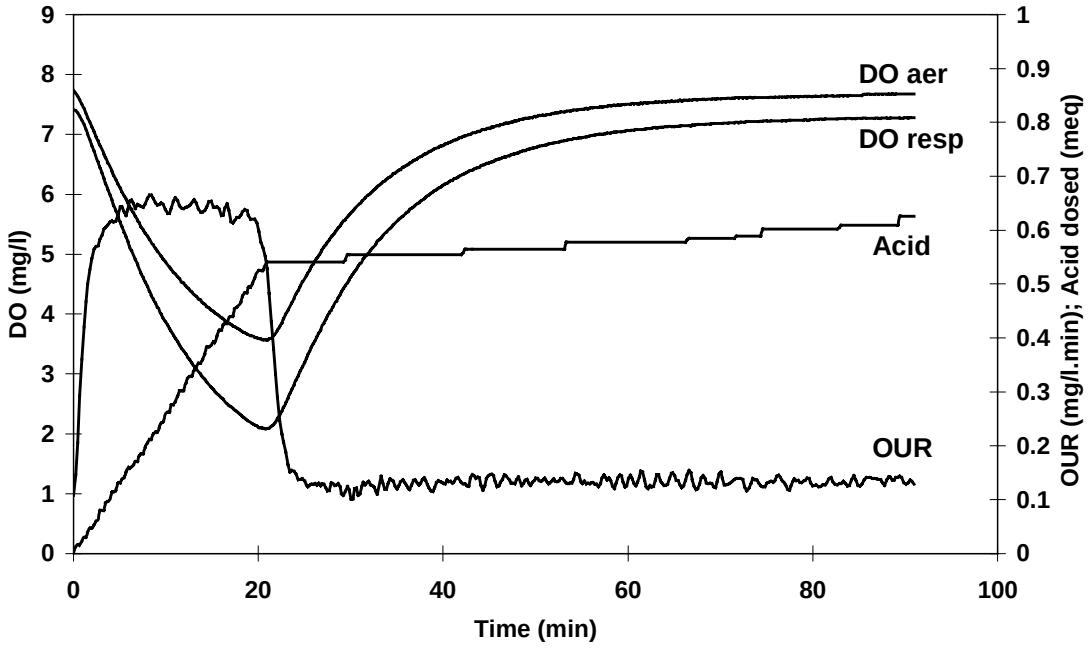

Figure 4. Acid addition and dissolved oxygen concentrations measured in aeration vessel (DO aer) and respiration chamber (DO resp) after the addition of 100 mg COD to the aeration vessel of a combined respirometric-titrimetric set-up. OUR values were calculated based on the dissolved oxygen data by making a mass balance for oxygen over the respiration chamber

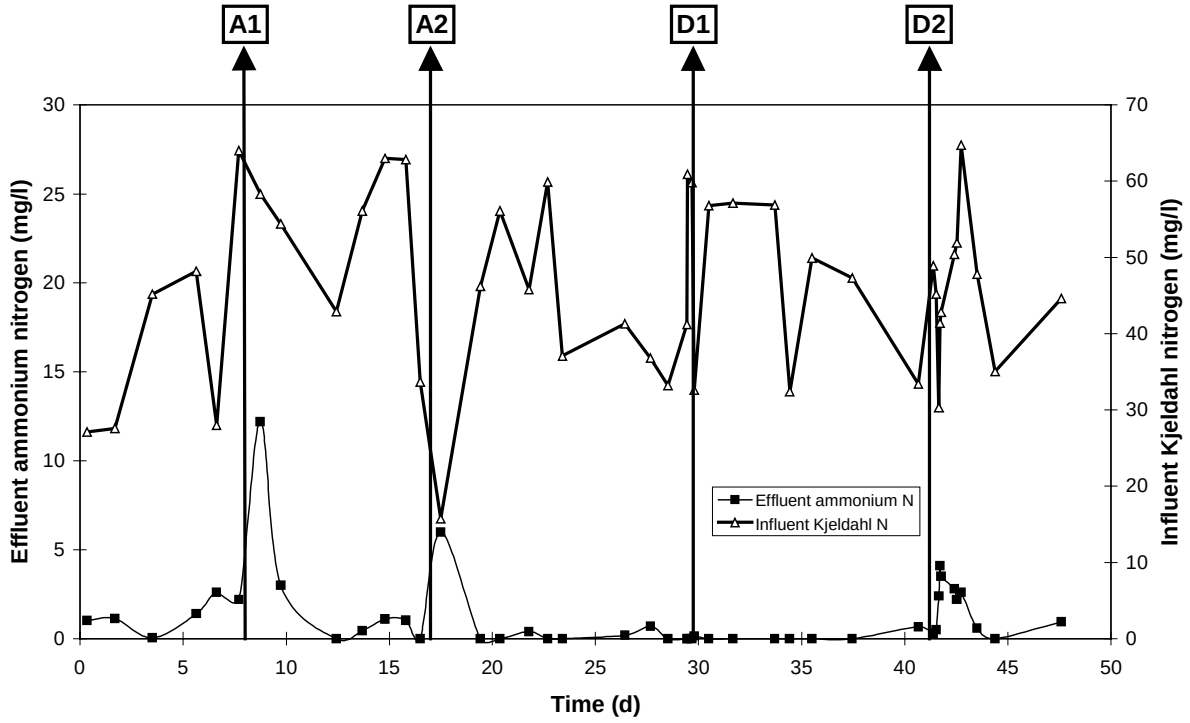

Figure 5: Influent Kjeldahl nitrogen and effluent NH_4^+-N measured at a hospital wastewater treatment plant during toxicity detection experiments with the RODTOX biosensor (Vanrolleghem *et al.*, 1996)