

Controlling nitrogen removal using redox and ammonium sensors

D. Cecil

Odense Water Ltd., Vandvaerksvej 7, 5000 Odense C, Denmark, (E-mail: dc@ov.dk)

Abstract At the Ejby Mølle WWTP (300,000 PE) operated by the Odense Water Ltd. a system of aeration control which combines ammonium concentration and redox potential has proven itself as a method of reducing nitrogen levels in the effluent. The nitrogen removal process at this plant proceeds in parallel aeration tanks that alternate between periods of aeration and denitrification. At the same time influent is redirected from one tank to the other such that influent and effluent is primarily to and from the tank where denitrification is going on. The aeration stops and the tanks open and close when the ammonium concentration reaches its set point. Aeration is restarted again when redox potential drops to its low set point or when ammonium reaches its upper set point. The average total nitrogen concentration in the effluent from the Ejby Mølle WWTP went from 4.7 down to 2.1 mgN/l after this control system was implemented. Not all of this reduction can be explained by better control. However we believe that at least 1 mgN/L of the reduction and probably more was the result of the control system based on the combination of ammonium and redox sensors.

Keywords Ammonium sensor; nitrogen removal; redox sensor

Introduction

Redox potential measurements have been used in wastewater treatment since the early 40's when practical electrodes were first developed (Rohlich and Oldham, 1948). At that time these measurements were used to control the level of aeration. However with the advent of workable oxygen electrodes engineers and plant operators lost interest in redox, until more recently when nutrient removal became an issue (Koch, 1985). The reason for the renewed interest in redox is that redox can give us some useful information on the progress of particularly nitrogen removal at a very low cost. Seen in this light it's surprising that there isn't more interest in redox. There are a number of explanations for this but probably the most important is that redox measurements are difficult to interpret when compared with the output from e.g. an ammonium sensor. In this paper I will attempt to show that even though this is the case the redox signal can still be used for automatic control of at least one type of nitrogen removal system with good results.

Redox potential

Redox potential is related to the energy released by the chemical processes in the activated sludge. As such, redox changes level according to the electron acceptor available (oxygen, nitrate, sulphate etc.). It also increases and decreases according to the concentrations of reactants and products present. This change is not however proportional with the concentrations but with the log of the concentrations (Mosey, 1985). This means that large changes in concentration only result in small changes in the redox potential. These two factors, that redox reacts with many substances in the activated sludge environment and that large changes in concentration are necessary for small changes in potential do, to a certain extent, limit the use of redox to the identification of which electron acceptor is present.

Materials and methods

Controlling the Biotenitro process

Odense Water Ltd operates three central WWTPs for the City of Odense, Denmark. All three plants remove nitrogen with the help of the Biotenitro process originally developed by the Akvadan Company, now the Krüger Corporation. The central element in this process is that nitrification and denitrification proceed in the same tank and that two or more tanks operating in parallel open and close depending on the process going on in the tank (Tholander, 1977).

The critical control parameter in the Biotenitro and other alternating processes for the removal of nitrogen is the length of time of aeration. Aeration must continue until the ammonium concentration is reduced to an acceptable level at which time aeration must stop in order to allow the greatest possible time for denitrification and thereby nitrogen removal. It will also improve nitrogen removal if aeration is restarted when the nitrate concentration is low so that more ammonium can be converted to nitrate. In other words for effective control one needs a signal for ammonium concentration and a signal that can at least be related to the nitrate concentration. At the Ejby Mølle WWTP (300,000 PE) we have on-line instruments for the measurement of ammonium but not for the measurement of nitrate. Instead we use redox potential.

Redox measurements

We started measuring redox in 1990. The decision to try redox was made on the strength of French and Canadian articles (Charpentier *et al.*, 1989; Koch and Oldham, 1985). At that time redox instruments were installed at Odense's Northwest WWTP (40,000 PE) and the signal was monitored. Figure 1 shows a typical redox curve together with the oxygen signal and measurements of nitrate in grab samples of the activated sludge. As one can see, redox potential falls from about 100 mV to 0 mV when the oxygen concentration drops to zero. It then holds more or less steady at this level until the nitrate concentration goes to zero. At which time the redox potential falls to -100 mV. All of the redox measurements mentioned in this paper are relative to a silver/silver chloride reference electrode.

This pattern in the redox potential can be seen at all three of the larger WWTPs in Odense. It also corresponds well to Koch and Oldham's (1985) observations both with respect to the general level of the signal and to the difference in the level of the signal depending on the electron acceptor available. With respect to the need for a signal that can be related to the nitrate concentration, we now have the possibility of using redox to indicate when the nitrate concentration goes to zero. We can use this to restart aeration.

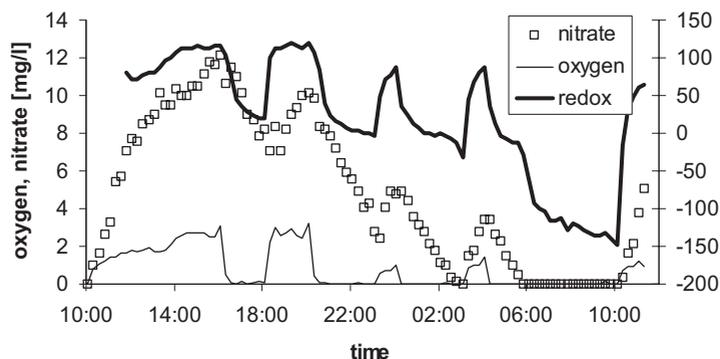


Figure 1 The Northwest WWTP, May 30–31, 1990, grab samples of the mixed liquor in one of the aeration tanks

Control of aeration using both ammonium and redox signals

Since 1990 we have developed a number of control strategies based on oxygen uptake rate and redox (Cecil, 1995; Cecil, 1999), with some success, however there were drawbacks to these systems. The worst being that these systems didn't respond correctly to toxic events. We were therefore interested in trying a more sophisticated form of control. In 1997, we installed two Danfoss ammonium online sensors (Lynggaard-Jensen *et al.*, 1996) at our Northeast treatment plant (25,000 PE). Redox instruments had been installed previously. By early 2000 both signals had been monitored for some time but we hadn't as yet coupled these instruments in an advanced control loop. One reason that we hadn't attempted this was that the ammonium sensor was still under development prior to 2000. This meant that the instrument was not stable enough for rigorous automatic control. By 2000 however these problems had been ironed out.

After we were convinced that the ammonium signal could be used for control we then wanted to use the redox signal as a substitute for the nitrate signal. When the nitrate concentration is zero we would restart aeration. This we would do by simply choosing a redox set point low enough that we were fairly certain that the nitrate concentration was zero. This strategy is used with good results by many (e.g. Charpentier *et al.*, 1989).

In March of 2000 a control strategy based on ammonium and redox was initiated at the Northeast Plant. In the months following this change there was a marked reduction in the total nitrogen concentration in the effluent compared with the previous year (Cecil, 2000). It was therefore decided to install ammonium sensors at the Ejby Mølle plant. Figure 2 shows the nitrogen removal process initiated at the Ejby Mølle plant at that time. At this plant there are two sets of two tanks for the Biondenitro process.

Figure 2 shows the process cycle for one of the two sets. The cycle starts with the beginning of aeration. At this time the outlet and inlet gates to the tank where aeration starts are usually closed and there is no influent to the tank. In this respect aeration is a batch process.

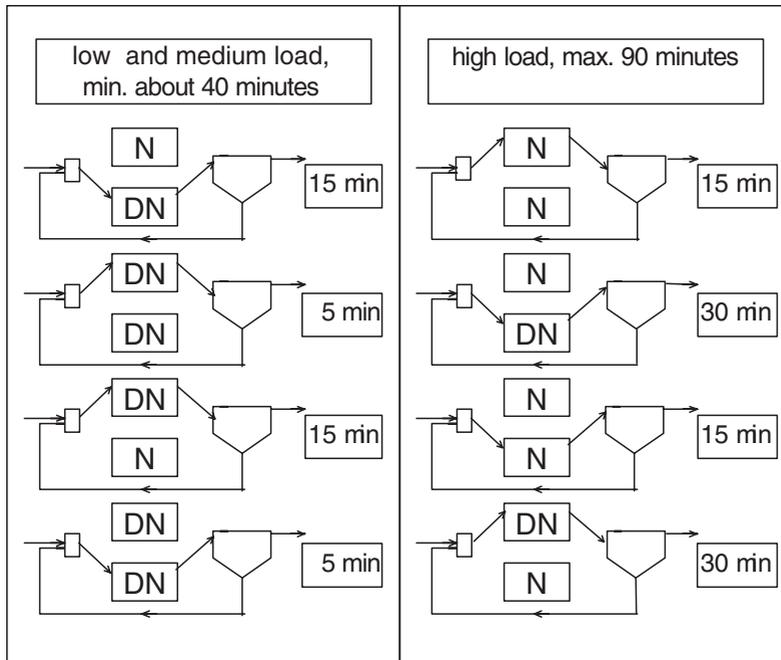


Figure 2 Ejby Mølle WWTP: the nitrogen removal cycle; the times shown may vary within each cycle. (N = nitrification, DN = denitrification)

Aeration continues until the ammonium set point is reached at which time the aeration stops and the tank is opened for influent and effluent. At the same time the second tank of the set is closed. At some time after the second tank was closed either the redox signal in the first tank falls below its lower set point or the ammonium concentration exceeds its upper set point and aeration is started again. While the first tank is still open the second tank completes its aeration period and it then signals the opening of its outlet and inlet gates and the closing of the first tank. At low and medium loads aeration begins and ends in a closed tank. At high load conditions aeration begins in an open tank and goes to completion in a closed tank.

Timer control for backup

To ensure that the system doesn't lock in one position there are two important time limits set. One of these is the maximum time of aeration. If this limit is reached before the ammonium concentration reaches its set point aeration is stopped and the influent to the tanks is switched. At the present time this limit is set to 75 minutes. The other limit is the maximum cycle time. The timer for this limit is started when aeration starts and continues into the denitrification period. If the redox potential doesn't drop below its set point or the measured ammonium concentration doesn't reach its upper limit then this timer restarts aeration when its limit is reached. At the present time this limit is 90 minutes. If one or both of the sensors fail these time limits come into effect. As aeration is permitted to operate 75 minutes out of a total cycle time of 90 minutes then nitrification has priority under these conditions.

Typical operation

Figure 3 shows four hours of operation in one of the four tanks in the activated sludge unit at the Ejby Mølle plant.

At that time the set points used were:

- Start aeration -120 mV redox or
- Start aeration 1.5 mg/L ammonium-N
- Stop aeration 0.5 mg/L ammonium-N

At 14:22 aeration was restarted because redox was less than -120 mV. At that time the ammonium concentration was 1.2 mg/l. Two minutes later the ammonium concentration passed the 1.5 mark and this would have started aeration if redox hadn't done so already. At 14:50 aeration stopped as the ammonium concentration was less than 0.5 mg/l. At 15:22 aeration started again. This time, because the ammonium concentration was less than 0.5 mg/L. The gate controlling the flow to this tank opened at 14:50 when aeration stopped.

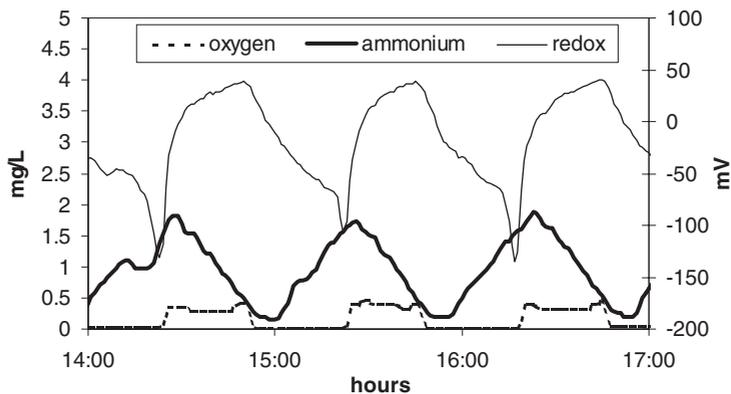


Figure 3 Ejby Mølle WWTP, December 11, 2001, Aeration tank 1

At the same time the gate to the other tank closed. The total cycle time was in this case 60 minutes corresponding to an average load. During the night as the load decreased the cycle time decreased automatically.

One can observe a 5-min. delay between the start of aeration indicated by the oxygen sensor and peak ammonium values. This delay is a result of the deadtime of the ammonium sensor.

Something else worth noting in Figure 3 is the knee or bend in the redox curve. This bend occurs at about -60 mV. This is higher than the -120 mV setpoint chosen by the operator. The -120 mV set point was chosen on the basis of worst case for recent operation. In other words a value which insures that the bend is always reached before a restart based on redox potential.

Results and discussion

In Figure 4 measurements of total nitrogen in the effluent for 2000 and 2001 are compared. The ammonium sensors were brought on-line June 1st 2001. The average nitrogen concentration in the effluent during the period from June 1st 2001 to January 1st 2002 was 2.1 mgN/L. The corresponding effluent concentration for 2000 was 4.7 mgN/L. These results are from 24-hour composite samples taken once a week and analysed at an external laboratory using Danish Standard Methods.

Comparing operating results in this manner at a full-scale plant is always difficult. For example November 2001 was the warmest on record. On the other hand October 2001 was an unusually rainy month. To add to the problem, the organic load on the plant was also about 10% greater in 2001 than in 2000. All in all we estimate that the combination ammonium and redox control system has reduced the effluent concentration by at least 1 mgN/L and probably more. In Denmark the discharge of nitrogen from treatment plants is taxed at a rate of US\$ 2.40 per kg. The Ejby Mølle plant treats about 20 mill. m³ wastewater per year so a 1 mgN/L reduction in the effluent concentration results in tax savings of US\$ 48,000 per year. At this rate our investment in ammonium and redox instrumentation will be paid back in about 2 years.

Conclusions

Redox sensors have been in use at the wastewater treatment plants in Odense, Denmark since 1990. Starting in June 2001 at the Ejby Mølle WWTP the signals from ammonium

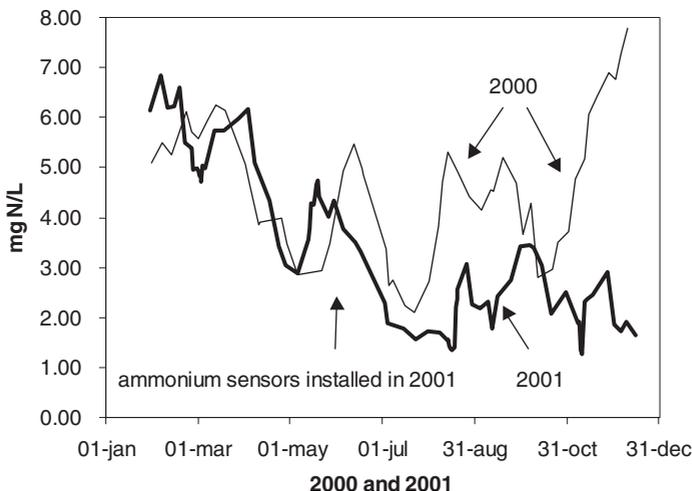


Figure 4 The Ejby Mølle WWTP: Total N in the plant effluent; 30-day average of weekly composite samples

and redox sensors have been employed for the automatic control of the nitrogen removal process. The average total nitrogen in the plant effluent was 2.2 mgN/L in the period from June 2001 to December 2001. The average concentration in the same period in 2000 was 4.7 mg N/L. We believe that much of this improvement in effluent quality is a direct result of improved control.

References

- Cecil, D. (1995). Aeration Control for Optimizing Nitrogen Removal. *Nitrogen Removal from Municipal Wastewater*. TemaNord 995:580. Nordic Council of Ministers, Copenhagen. p.156–165. ISBN 2 9120 709 8, ISSN 0908-6692.
- Cecil, D. (1999). Redox and the control of nitrogen removal, a paper presented at the Nordic conference on nitrogen removal and biological phosphorus removal in Oslo, February 2–4, 1999.
- Cecil, D. (2000). Controlling Nitrogen Removal using Redox and Ammonium Sensors, *Vatten* **57**, 147–152.
- Charpentier, J., Godart, H., Martin, G., and Mogno, Y. (1989). Oxidation-Reduction Potential (ORP) Regulation as a Way to Optimize Aeration and C, N, and P Removal: Experimental Basis and Various Full-Scale Examples. *Wat. Sci. Tech.*, **21**(10–11), 1209–1223.
- Koch, F.A. and Oldham, W.K. (1985). Oxidation-Reduction Potential – A Tool for Monitoring, Control and Optimization of Biological Nutrient Removal Systems. *Wat. Sci. Tech.*, **17**(11–12), 259–281.
- Lynggaard-Jensen, A., Eisum, N.H., Rasmussen, I., Svanklær Jacobsen, H. and Stenstrøm, T. (1996). Description and test of a new generation of nutrient sensors. *Wat. Sci. Tech.*, **33**(1), 25–36.
- Mosey, F. (1985). Redox Potentials in Wastewater Treatment. *The Chemical Engineer*, May 1985 21–24.
- Nielsen, M. and Lynggaard-Jensen, A. (1993). Superior Tuning and Reporting (Star) – A new concept for on-line process control of wastewater treatment plants. *Wat. Sci. Tech.*, **28**(11–12), 561–575.
- Rohlich, G. (1948). Measurement and Control of Sewage Treatment Process Efficiency by Oxidation-Reduction Potential – A Discussion. *Sewage Works Journal*, **20**(4), 650–653.
- Tholander, B. (1977). An Example and Design of Activated Sludge Plants with Denitrification. *Prog. Wat. Tech.*, **8**(4/5), 661–672.