Saving Energy in the Activated Sludge Process by online NH_4- and DO-Monitoring

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WWTPs treat wastewater with high nitrogen content on a routine basis. This is commonly achieved in a biological two-stage process, nitrification and denitrification, where bacteria decompose the nitrogen compounds to gaseous nitrogen. This process has to be supported with blowers - which are the most energy-intense equipment on a WWTP. Online measurement of the process parameters can ensure that aeration with the blowers meets the demand of the bacteria and thereby significantly reduce energy costs. Presented is a practical example where aeration times could be reduced by 35%. Further the article outlines the relationship between the available process parameters and explains the preferred combination of parameters to be measured.

Among the most important nitrogen-containing compounds in wastewater is urea. Urea can stem from industrial production, from humans and animals, who produce it in their metabolism or can be leaching from fields, where it is used as fertiliser. Microorganisms convert urea and other organic nitrogen compounds to ammonium (NH_4^+). This conversion starts in the sewer system.
Additionally agriculture and industry contribute ammonium and nitrate (NO_3^-) to the wastewater.
In these forms nitrogen is a readily available nutrient for algae, bacteria and plants. Water with high nitrogen levels can lead to excessive growth of these organisms, for example as algal bloom. The possible secondary effects of such events can be severe, for example the death of fish and the contamination of drinking water.
Therefore, the nitrogen content must be reduced to acceptable levels before the wastewater is released to the environment.

Removal Strategy

Some groups of bacteria use ammonium or nitrate in their metabolism. If these bacteria are used together in a well-controlled process, ammonium and nitrate are consumed and the final product is gaseous nitrogen (N_2). This form of nitrogen is inaccessible for algae, plants and most bacteria. Nitrogen

gas is already the main constituent of our atmosphere and has no negative effects on the environment.
This biological treatment, termed activated sludge process, is a very common treatment process in wastewater treatment plants.

Nitrification

Several steps are involved. Nitrifying bacteria consume ammonium (NH_4^+) and finally oxidize it to nitrate (NO_3^-):

$$NH_4^+ + H_2O + 2\,O_2 \rightarrow NO_3^- + 2\,H_3O^+$$

This part of the process is termed nitrification and can be performed by several species of bacteria. The oxidation of ammonium requires dissolved oxygen (see O_2 on the left side of the equation).

Denitrification

Another group of bacteria can use the produced nitrate (NO_3^-) in a denitrification reaction and produce nitrogen:

$$2\,NO_3^- + 12\,H^+ + 10\,e^- \rightarrow N_2 + 6\,H_2O$$

The bacteria require sufficient organic carbon (as source of the electrons e^- on the left side of the equation) for the denitrification and produce gaseous nitrogen. The denitrification can only be performed efficiently in the absence of molecular oxygen (anoxic conditions).

Aeration Fine-tuning Strategies

Due to the size of the tanks and the sheer number of bacteria, substantial amounts of oxygen are required for the nitrification. Oxygen uptake from air is far too slow if the nitrification is supposed to be completed in a timely manner. The aeration has to be supported with blowers to overcome this limitation. However, blowers consume a lot of energy. According to statistic evaluations aeration with blowers makes up 50–75% of the energy costs of a WWTP.
Several aeration schemes have been developed and applied in WWTPs. A basic scheme is intermittent aeration, with regular aeration times and pause times (compare figure 3, lower half). This scheme works independently from any process parameters.
An improved aeration scheme tries to determine the oxygen demand of the bacteria and activate the blowers only when necessary. This can improve treatment efficiency as well as reduce energy costs. Easily accessible parameters on which an aeration scheme can be based on are DO, Nitrate and Redox.

DO-based Regulation of the Aeration

Aeration regulation according to the DO value is a viable method. Hands-on experience with DO-based regulation revealed the following observations and conclusions:

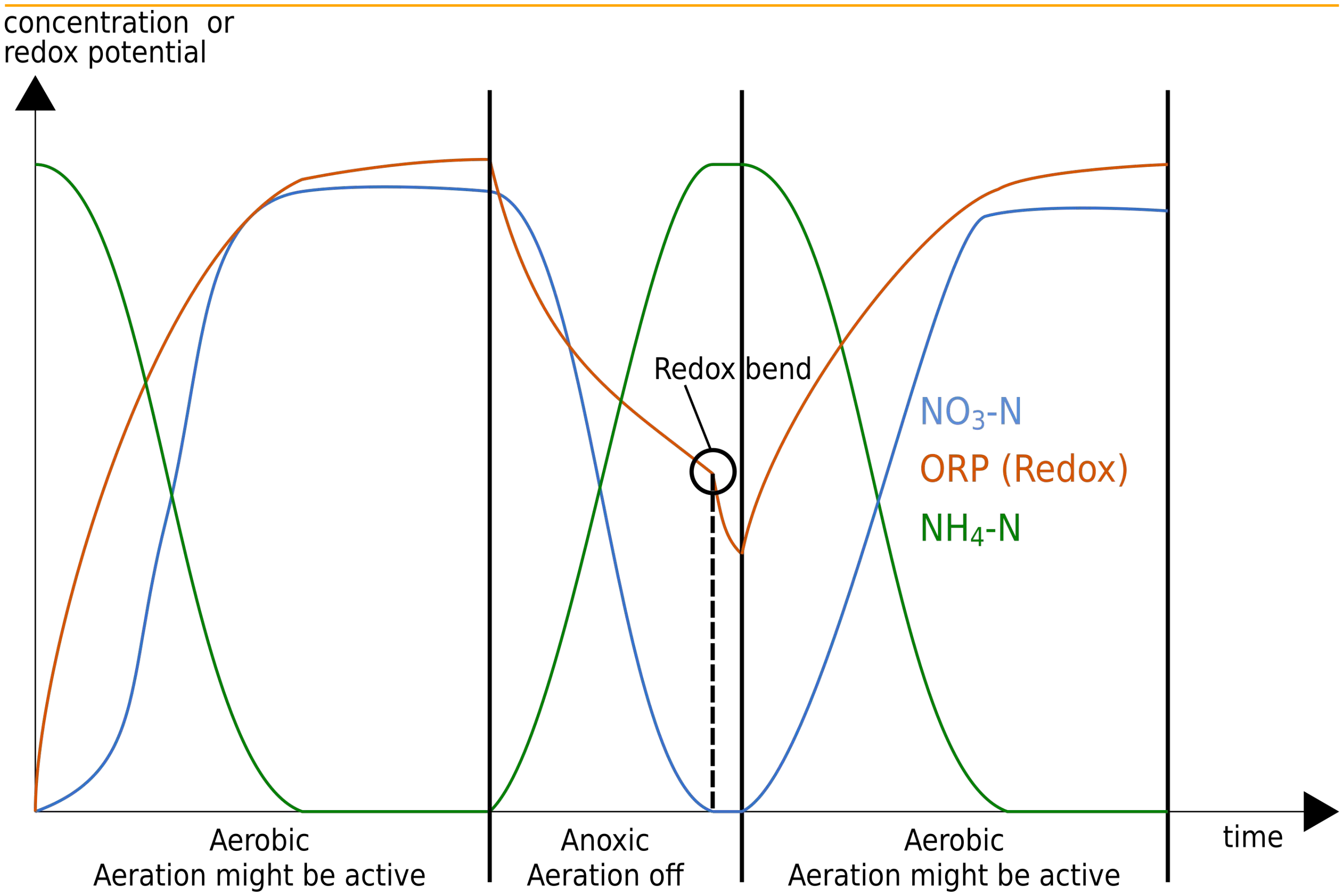

Figure 1: Typical behaviour of ammonium, nitrate and redox values in the biological treatment stage

A higher DO concentration improves nitrification. However, the effects already diminish when the DO exceeds 2 mg/l (ppm). Beyond these 2 mg/l (ppm) the power required for the blowers continues to increase, but the benefit for the nitrification becomes ever smaller. Operation with a target DO concentration of 1.5–2 mg/l (ppm) proved most economical.

DO-only regulation does not take into account any other data, most importantly ammonium or nitrate concentration, which is a major drawback of DO-only aeration regulation. But even additional conditions like pH, temperature and sludge age have an influence on nitrification performance.

A DO probe is a sensible supplementary measurement for aeration systems though, as it allows monitoring of the economical 2 mg/l DO limit during aeration phases.

Regulation According to NO_3-N

NO_3^- is the product of the nitrification and a resource for denitrification. The principle behind a nitrate-based aeration scheme is that very low NO_3-N values indicate when most of the nitrate has been consumed by the denitrificators. At that point aeration should be increased to support the activity of the nitrifying bacteria and enable them to produce more NO_3-N. When, following these events, the increase comes to an end, the aeration can be stopped again.

The drawback: If this happens when the NH_4^+ values are low as well (e.g. at night, when the load of the WWTP is low), then the aeration will have no effect, as there is not much NH_4^+ available that would require nitrification.

Regulation According to Redox-Potential (ORP)

ORP shows a distinct drop when the NO_3^- concentration drops to very low values. This regulation is similar to a NO_3^--based regulation. The ORP serves as an indirect indicator of the nitrate concentration.

Figure 1 illustrates the relationship between the parameters ammonium, nitrate and redox.

At the beginning the ammonium concentration is high. As the wastewater undergoes nitrification, the ammonium concentration drops and the nitrate concentration increases. This step is usually supported by aeration to some extent. When the nitrification (and other oxygen consuming steps such as carbon oxidation) are complete, the aerobic phase ends, aeration is stopped.

The treatment enters the anoxic phase. As the denitrification progresses, the nitrate concentration decreases. When the nitrate concentration drops to zero, the redox curve (ideally) shows a characteristic shape, the redox bend. Depending on the conditions, the redox bend can be more or less pronounced. Among the most widespread problems with redox-based control is that the redox bend cannot always reliably be identified, e. g. in plants which are not able to reach 0 mg/l (ppm) NO_3-N.

Shortly after 0 mg/l (ppm) nitrate or the redox bend have been detected, the system is ready for the next aerobic phase with aeration.

Figure 2: Controller GICON 1000 with ammonium and dissolved oxygen probe

Results & Discussion

GIMAT installed an *insitu* multiparameter measurement system on a customer's wastewater treatment plant. The system consisted of an ammonium probe, a dissolved oxygen probe and a GICON controller (figure 2). The plant has a treatment capacity of 4000 population equivalents, its biological treatment stage uses an activated sludge process in a single aeration tank. As a consequence of this common plant design, the aeration scheme of the plant needs to meet a few requirements:

1) There needs to be sufficient aeration in the aeration tank for the oxygen-consuming nitrification.

2) There need to be sufficient phases without aeration to create oxygen-free zones in the tank where denitrification can take place (which does not tolerate dissolved oxygen).

3) Extended phases without any aeration would upset the balance of the different bacteria species in the aeration tank and have to be avoided.

Up to this time the plant had been using an intermittent time-pause aeration scheme. This scheme had 7.1 hours of aeration planned per day. In this mode of operation the blowers were responsible for 66% of the plant's whole energy costs.

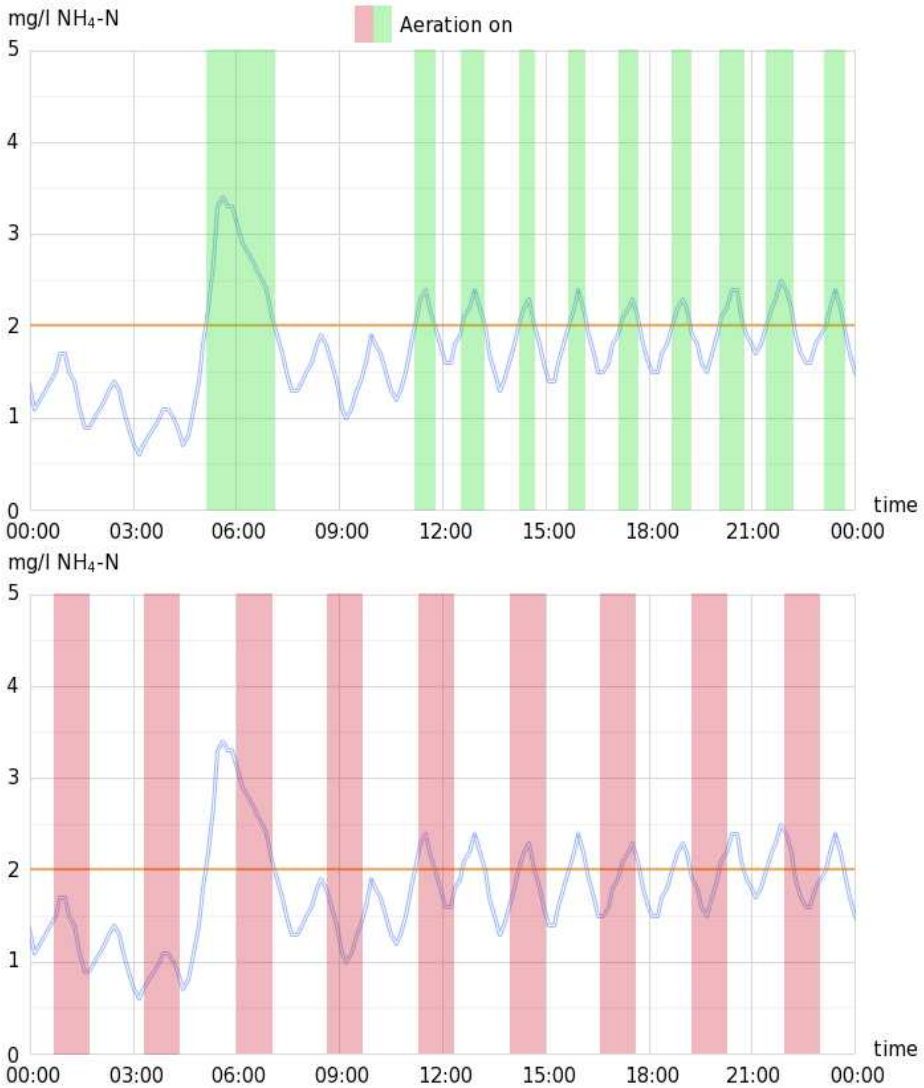

Figure 3: Aeration based on data from the ammonium measurement (top) and regular intermittent aeration (bottom).
Note: The plant has 3 blowers, which can be operated separately. Only the main aeration phases (at least 2 of the 3 blowers active) are shown in the diagram, weaker aeration was omitted for clarity.

Figure 3 shows exemplary data from the WWTP, shortly after the ammonium measurement was installed. Selected was a typical day of operation.

In the top half of figure 3 the optimised aeration scheme is shown (main aeration phases in green). Regulation is based on the measured ammonium values. The plant's newly devised aeration strategy uses a target value of 2 mg/l (ppm) NH_4-N. Ammonium levels exceeding this value indicate high oxygen demand. The blowers are switched on to meet the oxygen demand if values of 2 mg/l NH_4-N or higher are detected.

In addition to the aeration times highlighted in green two short aeration phases were applied between 00:00 h and 05:00 h and two more between 07:00 h and 11:00 h (not shown in figure 3) in order to conserve the balance between the bacteria species in the tank.

In retrospect the plant compared the data obtained on this day with the previously used aeration scheme. The bottom half of figure 3 illustrates the aeration times which would have been applied if the plant had still been using its old intermittent aeration scheme (in red).

By comparison of the two charts in figure 3 it is evident that the ammonium-based regulation more closely matches the actual demand of the bacteria. Even the high load around 06:00 h was fully covered by the new aeration scheme. The old aeration scheme on the other hand would have started aeration one hour late. A major part of the ammonium would not have been digested, resulting in high ammonium values in the effluent of the WWTP.

During aeration phases the data from the additional DO probe is used to tweak aeration intensity. Whenever the DO rises to a concentration beyond 2 mg/l, one of the blowers is switched off. This takes into account that aeration is most efficient as long as the DO concentration is between 0 and 2 mg/l. This addition to the aeration scheme prevents excessive aeration and waste of energy.

The new aeration scheme was tested for several weeks before being adopted permanently. After half a year statistical evaluation showed that aeration times had been reduced to 4.6 hours per day on average, 2.5 hours less than with the previous intermittent time-pause aeration scheme. The aeration energy savings amount to 2.5 h/7.1 h = 35%.

Conclusion

The ammonium measurement was able to provide valuable data for aeration fine-tuning. A new aeration scheme based on this data has been adopted. The scheme successfully detected times when the plant encountered high load and allowed for appropriate aeration, increasing plant performance. The aeration times could be cut down 2.5 h or 35% on average.

If this trend continues, the estimated energy savings will cover the expenses for the new ammonium measurement within two years.