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AERATION CONTROL OF NITRIFICATION PROCESS BASED ON THE AMMONIUM CONCENTRATION IN THE AERATION TANK

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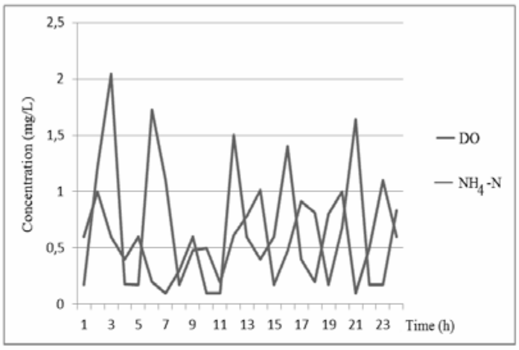
This study presents the measurement and control regarding the concentration of ammonium in the aeration tank. An analysis is then performed to check the long term performances of the optimized controller settings using a set point value for dissolved oxygen concentration. The optimization of nitrification regarding the control of ammonium concentration at the outlet from the nitrification tank, gives a clear clue about the process efficiency and the increase of the dissolved oxygen set-point will result in a higher nitrification rate in the aeration tank, because oxygen is a limiting substrate for nitrification under normal operating conditions. On-line monitoring of nitrification process was achieved using ammonium measurements from the outlet of aeration tank.



INTRODUCTION

Nitrification is an essential process in the nitrogen cycle of wastewater treatment systems. It is responsible for the biological conversion of ammonium to nitrate. While both these compounds are suitable for plant use as nutrients, they behave quite differently in soil systems.

Ammonium is produced as a waste product from cellular and metabolism processes, a breakdown product of organic material. It is the preferred nitrogen source for many plants and algae.[1]

Nitrification is a two-step process in which ammonia (NH_4-N) is oxidized to nitrite (NO_2-N) and nitrite is then oxidized to nitrate (NO_3-N). These two steps are carried out by two separate groups of autotrophic bacteria. Ammonia oxidizing bacteria (AOB) convert the ammonia to nitrite, shown in step 1. Nitrite oxidizing bacteria (NOB) convert the nitrite to nitrate, shown in step 2.

The two-step oxidation of ammonia to nitrate is:

Step 1: $2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$ (1)

Step 2: $2NO_2^- + O_2 \rightarrow 2NO_3^-$ (2)

Total oxidation reaction:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O \quad (3)$$

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Nitrification requires sufficient dissolved oxygen (DO) to be present, a pH range of 6.8 to 8.5, and very little inhibition due to toxic compounds.[2] Equation 3 requires 4.57 g O_2/g N oxidized to completely oxidize ammonia; this does not take into account cell synthesis. When taking into account cell synthesis, only 4.25 g O_2/g NH_4^+ is required. The majority of this oxygen, 75%, is used for nitrite production, whereas, the remaining 25% is used to convert the nitrite to nitrate.

$$NH_4^+ + 2HCO_3^- + 2O_2 \rightarrow NO_3^- + 2CO_2 + 3H_2O \quad (4)$$

Further more the alkalinity of the inflow is important because for each gram of NH_4-N converted, 7.14 g of alkalinity as $CaCO_3$ is required (eq. 4).

Nitrification may occur in an aeration tank after adequate, soluble biochemical oxygen demand (BOD) degradation has occurred and several operational conditions are satisfactory to occur for nitrification. These conditions include the presence of an adequate amount of dissolved oxygen, substrate (ammonium ions or nitrite ions) for nitrifying bacteria, adequate retention time of the wastewater in the aeration tank and a healthy and active population of nitrifying bacteria. Nitrification occurs more easily in the presence of high mixed liquor volatile suspended solids (MLVSS) and high temperatures.

Under favorable operating conditions an activated sludge process may nitrify, because the influent total nitrogen is considerably greater than the MLVSS requirement for the nutrient nitrogen. There are several forms of nitrification that are identified by the amount of ammonium ions, nitrite ions and nitrate ions produced in the aeration tank or found in the aeration tank or mixed liquor effluent. Testing for these three nitrogenous ions may be performed rapidly. Unless industries discharge wastes that contain nitrite ions or nitrate ions to the sewer system, testing for these two nitrogenous ions in the influent of the aeration tank is seldom performed.

The concentration of ammonium, in some cases at the outlet of the nitrification tank, gives an indication regarding the efficiency of the process.[3,4] Depending on the situation, it may change the necessary of dissolved oxygen in the aeration tank.

Measurement and control concepts allow aeration that can be optimized depending on the concentration of ammonium in the aeration tank.[1] At low loads aeration can be minimized or completely stopped so that an ammonium sensor is required at the end of the aerated area to measure the necessary of oxygen.[1]

The advantage of an ammonium sensor is the fact that you can nitrify only the amount of ammonium which is required according with the environmental requirements.

At a set point of the ammonium sensor, the oxygen introduced decreases, which helps to improve denitrification. In the same time, lower aeration leads to a reduction in energy consumption.

Aeration is the highest energy consumer (around 60% of the wastewater treatment plant). Energy costs can be reduced by using the ammonium sensor in the treatment process.[5-7]

This control strategy refeeds the concentration of NH_4-N. The air quantity blown in depends on the concentration of NH_4-N, but no longer on the concentration of dissolved oxygen.[8,9] The target value of NH_4-N results from an overall consideration of the energy costs and the values that have to be kept at the outlet.

The equation to calculate the efficiency of the simultaneous nitrification and denitrification (SND) process is:[5]

$$\text{Efficiency} = \left(1 - \frac{NO_x^- \text{remaining}}{NH_4^+ \text{oxidized}}\right) \cdot 100 \quad (5)$$

where: NO_x^- remaining after the reaction

NH_4^+ oxidized

There are two ways to control the aeration process: to reduce the energy consumption or improve the process performance. Either the total aerobic volume or the aeration intensity is changed. A common method to change the aeration intensity is to adjust the dissolved oxygen set-points in the process based on the ammonium concentration in the effluent.

SIMULATION STUDIES BASED ON AMMONIUM SUPERVISORY CONTROL

The results obtained by C. Lemoine and P. Greier[10] for an ammonium limiting concentration of 5 mg/L are presented in figure 1. In this case it is not necessary to use an intermediate control loop with a set point of dissolved oxygen to control ammonium concentration. Ammonium and aeration must also preserve a sufficient level of airflow rate in the tank to reduce retention time.

A very low dissolved oxygen concentration, with a maxim of 0.3 mg/L, is also observed which reinforced the fact that DO is not the good measurement for controlling simultaneous nitrification-denitrification (NDN). More over even if the DO is close to zero, nitrification occurs.[10]

Another example of a controlled nitrification process was studied by Myroslav Malovanyy *et al.*[11] who performed simulations in order to determine the influence of ammonium and dissolved oxygen (DO) concentrations on nitrification activity. The variation of ammonium concentration was measured for one hour while the DO concentration kept constant in the reactor.

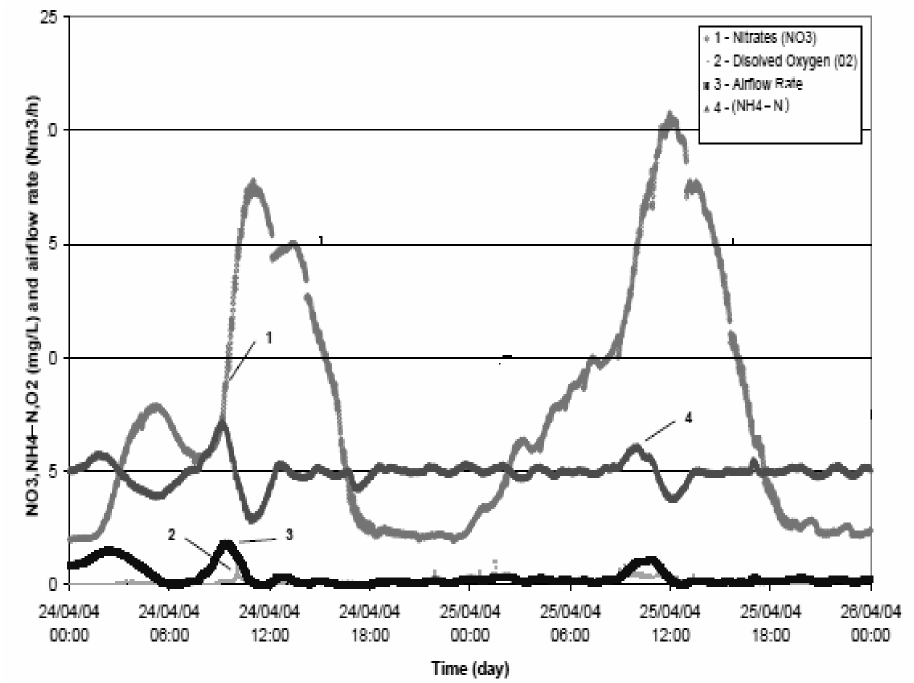

Fig. 1 – Ammonium control[10].

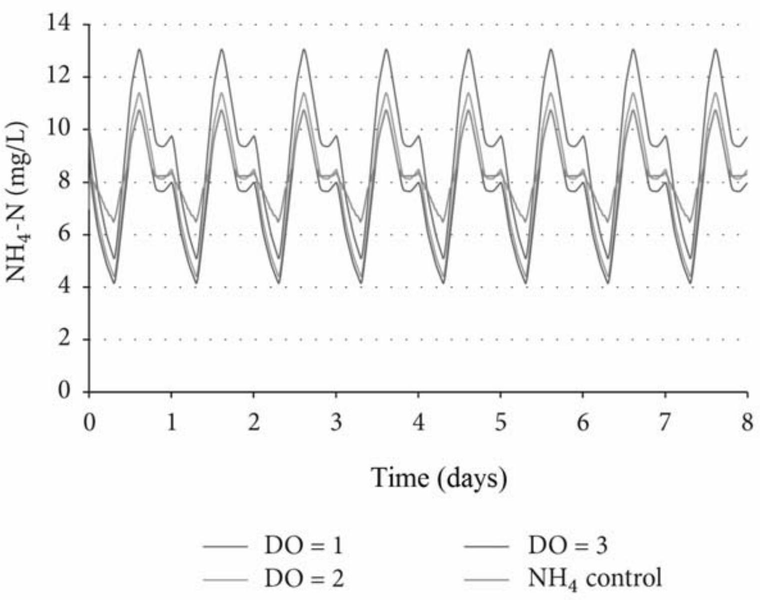

Fig. 2 – Nitrification process for high concentrations of ammonium[11].

The DO set-points were optimized for the three cases in order to get the lowest possible air consumption and at the same time have the average ammonium concentration in the outlet at approximately the same level as in the strategy with the stable DO concentration of 1 mg/L. The obtained DO set-points for the three cases are the same for low and medium content of ammonium in the bioreactor and are somewhat lower in the case of higher ammonium content (see figure 2).

The graphic showed that the variation in ammonium content is the highest when the DO concentration is high. Low DO values give lower effluent ammonium variations but also higher average ammonium content in the treated wastewater. Aeration is more efficient at lower DO content which gives lower specific aeration requirement.

Also, the same nitrogen removal is reached with ammonium based aeration control as with constant value of dissolved oxygen control but with a lower air consumption. However, in the control strategy with the stable DO one needs to predict the incoming load so that the right DO concentration could be chosen.[11]

The aim of the current study is the control of nitrification processes in a tank intermittently aerated and which is continuously fed with activated sludge, using ammonium and dissolved oxygen sensors.

RESULTS AND DISCUSSION

Nitrification and DO concentration are both optimized in an aeration tank. The ammonium controller shown in figure 3 compares the measured ammonium with the ammonium set-point and calculates the DO set-point which is forwarded to the DO controller. The DO controller compares the measured DO concentration with the calculated set-point and calculates the required air flow which is forwarded to the air flow controller. Alternatively, the DO controller may be set on top of the ammonium controller to limit the DO concentration to a maximum value. One potential problem with this configuration is that the two controllers fight over authority because the DO concentration changes faster than the ammonium concentration.

Proper location of the ammonium sensor presents an additional level of complexity for plug flow (PF) reactors. In a PF configuration, concentration varies along the length of the reactor with higher concentrations upstream and lower concentrations downstream.

One philosophy is feedback control based on measurement of effluent ammonium. This provides a direct indication of performance but a delayed control signal.

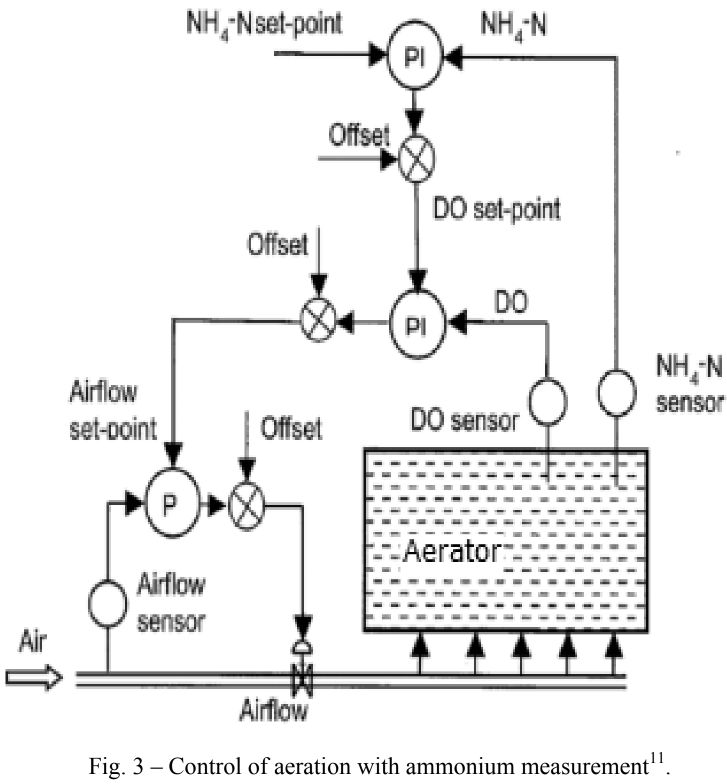

Fig. 3 – Control of aeration with ammonium measurement[11].

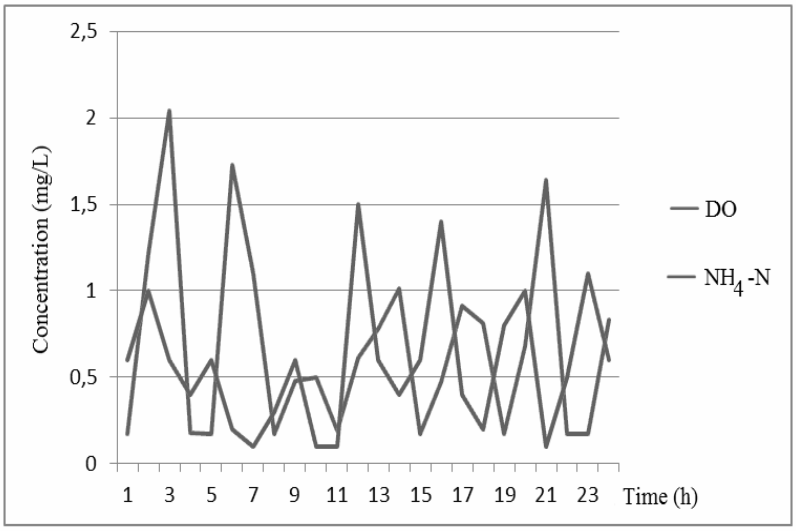

Fig. 4 – DO and NH_4-N cycle profiles during monitoring of the nitrification process.

Table 1

Concentration values of dissolved oxygen and ammonium for 24 hours in 01.08.2016

Time	Dissolved O_2 concentration	NH_4-N
1	0.17	0.6
2	1.21	1
3	2.04	0.6
4	0.18	0.4
5	0.17	0.6
6	1.73	0.2
7	1.1	0.1
8	0.17	0.3
9	0.48	0.6
10	0.5	0.1
11	0.19	0.1
12	0.61	1.5
13	0.78	0.6
14	1.01	0.4
15	0.17	0.6
16	0.47	1.4
17	0.91	0.4
18	0.81	0.2
19	0.17	0.8
20	0.68	1
21	1.64	0.1
22	0.17	0.5
23	0.17	1.1
24	0.83	0.6

The control system depicted in figure 4, based on the data obtained from Gherla wastewater treatment plant, is based on a control signal from a DO sensor located at the effluent end of the aeration tank and the ammonium sensor in the aeration tank near the outlet. A high value of dissolved oxygen as 2.04 mg/L corresponds to a ammonium level of 0.6 mg/L. Also to a high ammonium value of 1.5 mg/L corresponds to a low dissolved oxygen concentration of 0.61 mg/L. The graphic in figure 4 confirms the measurements from table 1.

During ammonium inlet load peaks between 02 to 03 o'clock, there are also peaks of DO concentration.

Placing the ammonium sensor in the effluent of the aeration tank offers a few advantages. First, the lag time for the control signal is reduced. Second, locating the ammonium sensor closer to the effluent increases the reliability of meeting performance goals. Third, maintenance of an ammonium ISE is easier at concentrations between 1 mg/L and 10 mg/L.

Using ammonium sensor with a continuously measurement of NH_4-N can be considered helpful to the aeration system. Thus, at low concentrations of ammonium it is not necessary to have oxygen concentration greater than 1 mg/L only if the amount of ammonium increases. Changes occurr with the variations in temperature during spring and fall, leading to the need of continuous measurements in order for the system to respond to changing conditions and to balance the DO concentration appropriately to the situation.

Implementation of this sensor in the treatment process can be considered really helpful to reduce energy costs. Using sensors for ammonium and dissolved oxygen, reduces energy consumption up to 44% leading to an optimization of aeration process.

EXPERIMENTAL

The whole study was conducted in a wastewater plant designed for an average daily flow of 9.400 m^3/d and 20.000 population equivalents. It was built as an activated sludge treatment plant with a simultaneous aerobic sludge stabilization. The aeration tank with a volume of 4050 m^3 was operated under different organic loading rates with anoxic and oxic sections (see figure 5). The aeration tank was equipped with an air–compressor, providing oxygen at a rate of 90 L/s.

A submersible mixer was used in the aeration tank for mixing the wastewater with the activated sludge in a circular flow. The influent entered the aeration tank at the beginning of the anoxic phase. The experiments were conducted for a period of 24 hours. The control of nitrification process was performed by obtaining continuous online measurements of ammonium and DO concentration.

The ammonium sensor used (AN-ISE sc) is a combined ion selective electrode for ammonium and nitrate ions, measuring both levels simultaneously. In AN-ISE sc the ammonium or nitrate ions are measured directly in the aeration tanks using an ion-selective electrode (ISE) with continuous online operation. The operation requires no chemical reagents and no further processing of the sample. [12,13]

The measurement principle of the luminescent dissolved oxygen (LDO) sensor is that it does not consume oxygen, so that the concentration of dissolved oxygen can be measured as in the case of low flow, as well as in absence of flow. Both ammonium and oxygen sensors must be connected to a controller such as sc 1000 for measurements recording.

The sc1000 is a multi-parameter controller designed to function with any of the digital probes. A stand-alone sc1000 controller must have one display module and one probe module. The probe module can be configured to accept up to 8 digital probes simultaneously. More probes can be connected by creating an sc1000 network. An sc1000 network must have one display module and two or more probe modules. Only one display module is allowed per network.

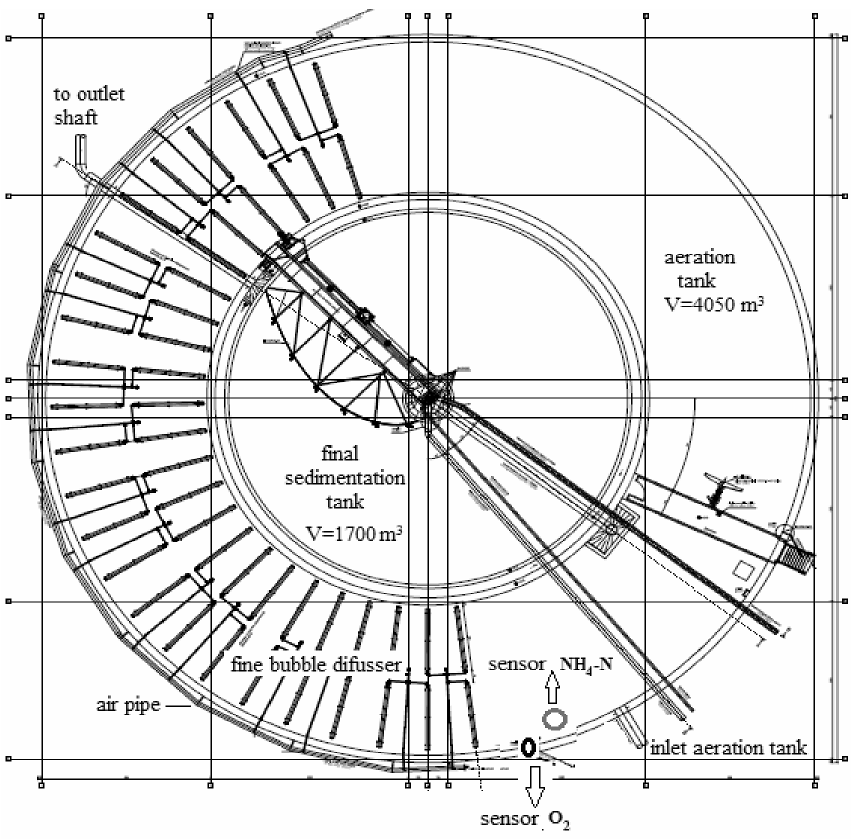

Fig. 5 – Sensor location of NH_4-N and oxygen for measurements in the aeration tank.

The NH_4-N concentration is measured at the end of the nitrification zone. By this control strategy, the air stream is controlled in such a way that the NH_4-N degradation rate grants the desired value of the NH_4-N concentration.[2] This is possible because the value of the NH_4-N concentration is refed into the system. One advantage of this arrangement is that a constant value of the NH_4-N concentration can be achieved. This means that the outlet value of the wastewater treatment plant is kept constant. Additionally, the necessary air quantity is reduced during phases of high effectiveness of the N elimination. This leads to a considerable cost reduction.

Blowers are turned off in order to maintain the ammonium-nitrogen concentration between two set-points of 0.7 mg/L and 1.0 mg/L in the aeration tank. Blowers are turned "off" 25% of the time with this strategy creating anoxic conditions for denitrification and saving about $1.000 per month in energy costs.

CONCLUSIONS

The control of aerobic phase was achieved by using a controller and NH_4-N and DO sensors located in the aeration tank were carried out. Setting the minimum desired concentration of ammonium and DO as target, the optimization of the nitrification process was attained.

The evaluation of the results showed that large reductions in air consumption can be made with a simple DO control, enabling a higher sensitivity to variations in influent load and improving the aeration process. Because there is a higher transfer rate of oxygen in wastewater at low DO concentration an increase in efficiency can be obtained by maintaining the lowest DO concentration needed by the nitrification bacteria.

The rate of nitrification increases proportionally with DO concentration up to about 1.5 to 2.0 DO mg/L. However, above a DO of 2.0 mg/L only a marginal increase in the nitrification rate is achieved. Furthermore, a higher than needed DO is detrimental to denitrification. Therefore, if DO isn't optimized, nitrification or denitrification capacity is limited and energy is wasted.

This can give substantial energy savings. The strategy achieved the lowest airflow demand, around 11% lower than with DO feedback control, achieving the main objective which was to reduce energy usage.

The control of NH_4-N concentration brings the following advantages: minimisation of the aeration costs, obtaining a stable nitrification and optimisation of denitrification by reducing the O_2 load in denitrification zone.

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