Mass balance for on-line $\alpha k_L a$ estimation in activated sludge oxidation ditch

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Abstract The capacity of an aeration system to transfer oxygen to a given activated sludge oxidation ditch is characterised by the $\alpha k_L a$ parameter. This parameter is difficult to measure under normal plant working conditions. Usually this measurement involves off-gas techniques or static mass balance. Therefore an on-line technique has been developed and tested in order to evaluate $\alpha k_L a$. This technique deduces $\alpha k_L a$ from a data analysis of low cost sensor measurement: two flow meters and one oxygen probe. It involves a dynamic mass balance applied to aeration cycles selected according to given criteria. This technique has been applied to a wastewater treatment plant during four years. Significant variations of the $\alpha k_L a$ values have been detected while the number of blowers changes. This technique has been applied to another plant during two months.

Keywords Wastewater; activated sludge; aeration; estimation; measurement; on-line

Introduction

Most of the electric power used on wastewater treatment plants (WWTP) is utilised to provide oxygen to the biomass. This implies that, in recent years, a lot of researches have led to improve the efficiency of the aeration system. These researches led to the development of new regulation systems optimising the sequencing of the aeration period and the aeration power involved (Lefevre *et al*., 1993; Caulet *et al*., 1998). High efficiency air injection systems have also been developed. These systems are composed of rubber membranes and may present therefore a risk of physical degradation. Their efficiency is then to be controlled regularly. The degradation of these membranes would induce a significant diminution of the air supply efficiency and, as a consequence an increased cost of the plant management.

Usually the estimation of the aeration capacity needs expensive experiments and involves highly qualified personnel. In the following paper we will present a simple method to measure the aeration capacity. This method needs only flow rate and dissolved oxygen measurements. In the following paragraph we are going to describe the data treatment that gives a $\alpha k_L a$ value from this information.

Determination method of $\alpha k_l a$

The $\alpha k_L a$ is a parameter that characterises the aeration capacity of the aeration system. It is related to the flux of oxygen transferred to the liquid by the following relation:

$$F = V\alpha k_L a\,(C^* - C) \qquad (1)$$

The aeration capacity is defined as the maximum flux of oxygen transferred, i.e. the flux of oxygen transferred when the dissolved oxygen concentration is zero. This quantity is directly proportional to the $\alpha k_L a$, the aeration tank volume and the saturated concentration of dissolved oxygen. However $\alpha k_L a$ is a more universal parameter, this is why it is used to characterise the aeration capacity of the system.

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Usually the measurement of $\alpha k_L a$ is performed using off-gas techniques (Boyle *et al.*, 1989) or static mass balance (Tewaki and Bewtra, 1982). In the present paper we will describe a method to evaluate $\alpha k_L a$ based on the analysis of the dissolved oxygen concentration evolution.

The aeration tank is one of the elements of a sewage treatment plant (Figure 1). It has two inputs: one of raw water, one of mixed liquor coming back from the clarifier. In the present method we have supposed that the concentration of dissolved oxygen in these inputs is zero. The following points justify this supposition.

- The oxygen demand in raw water is high enough to ensure that all the oxygen transferred into the sewage in the sewer system is consumed. In order to be sure that this condition is met we did not take into account aeration events that occurred during storm events or any other event that induces abnormal values of the inlet flow rate.
- Dissolved oxygen is consumed within the sludge blanket of the clarifier. So the flow recirculated back from the clarifier has very little, if any, dissolved oxygen.

Assuming these simplifications, Equation 2 represents the mass balance of the reactor shown in Figure 1.

$$V\frac{\mathrm{d}C}{\mathrm{d}t} = V\alpha\,\mathrm{k_L}a\left(C^* - C\right) - \phi - \mathrm{QC} \qquad (2)$$

Parameters $\alpha k_L a$ and ϕ of Equation (2) can be adjusted so that experimental measurements are fitted as close as possible. Doing so a value of $\alpha k_L a$ can be estimated at each aeration cycle. This method has been tried but the results found are noisier than those obtained by the method described below. This noise is obtained because all the data measured during an aeration cycle are taken into account. So the data that contains the information (i.e. the evolution of the dissolved oxygen concentration just after starting or stopping of the blowers) is “diluted” with data that contain less information.

We have also developed another method for data analysis. In this method we used the fact that Equation (2) may be simplified if its validity is limited to certain values of time. We have chosen two particular times:

- t_1: Just after the starting of the blowers. In this case the dissolved concentration of oxygen is zero. Equation (2) may be simplified as:

$$V\left.\frac{\mathrm{d}C}{\mathrm{d}t}\right)_{t_1} = V\alpha\,k_L aC^* - \phi_1 \qquad (3)$$

- t_2: Just after the blowers stopped. $\alpha k_L a$ is then equal to zero. Equation (2) may then be simplified as :

$$V\left.\frac{\mathrm{d}C}{\mathrm{d}t}\right)_{t_2} = -\phi_2 - Q(t_2)C(t_2) \qquad (4)$$

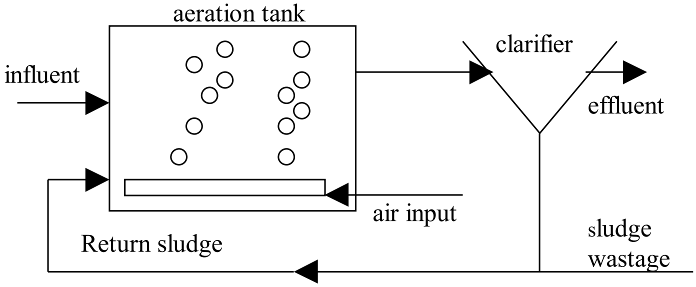

Figure 1 Sewage treatment plant flow sheet

Assuming that ϕ_1 is equal to ϕ_2 (i.e. that the respiration rate is the same at time t_1 and at time t_2), the following expression of the $\alpha k_L a$ was extracted from these two equations:

$$\alpha k_L a = \frac{\left[\left(\frac{\mathrm{d}C}{\mathrm{d}t}\right)_{t_1} - \left(\frac{\mathrm{d}C}{\mathrm{d}t}\right)_{t_2} - \frac{Q(t_2)C(t_2)}{V}\right]}{C^*} \quad (5)$$

Equation (5) is valid only if ϕ_1 is equal to ϕ_2. In order to be sure that this condition is met, we did not take into account some cycles. We used only the cycles when the functioning of the plant is constant for the estimation of $\alpha k_L a$. We have supposed that the functioning of the plant was constant if the following criteria were met:

- the recirculation and influent flow rate were stable (less than 10% variation) during the aeration cycle;
- the aeration cycle corresponds to a "normal" day of the plant functioning. For us a "normal" day is a day when the inflow flow rate is in the range of plus and minus 20 per cent of the usual value.

Usually these periods take place during the night. During these periods the influent flow rate is quite stable and takes low values. The two values of the flux of oxygen consumed by the biomass, ϕ_1 and ϕ_2, are then equal to the endogenous respiration of the biomass.

The estimation of the aeration capacity was aimed at the control of the aeration membrane efficiency. We wanted then to evaluate the evolution of this capacity and not to have a precise value of the aeration capacity itself. Therefore, as $\alpha k_L a$ is proportional to $1/C^*$, we were not so much concerned with a precise estimation of the C^* value. An error in the estimation of the C^* value would not mask an abnormal variation of $\alpha k_L a$. We have assumed C^* to be approximately equal to 9 mg/l.

The measurement of a flow rate is needed to evaluate the expression $Q(t_2)$ $C(t_2)$ in Equation (5). It is to be noticed that, on the test cases we studied, the $\alpha k_L a$ value found when the expression $Q(t_2)$ $C(t_2)$ is neglected in Equation (5) is different by less than 10% from the value given by Equation (5).

Description of the plant

The previous technique has been applied to a WWTP we will name A. This plant is a classical activated sludge facility (Figure 3). The sewage to be treated by WWTP A is mainly urban wastewater, with little industrial wastewater and little infiltration water.

The aeration of the activated sludge is performed by air injection through rubber membranes. Two blowers provide the air. The mean characteristics of the raw water are given in Table 1. As CIRSEE lead various studies on this plant many sensors have been installed and controlled with special care. All this information gave us a precise idea of what was going on in the plant and was confirmed by every day observation of the plant functioning. Sensors were installed to measure the following information:

- input flow rate,
- recirculation flow rate,
- suspended solids in the recirculation,
- suspended solids in the aeration tank,
- oxidation-reduction potential in the aeration tank,
- dissolved oxygen in the aeration tank,
- working period of electric engine (pumps, blowers).

The aeration tank is a classical oxidation ditch where the fluid circulation is induced by low speed agitators. The circulation velocity is over 30 cm/s and no sludge settles in the bottom of the ditch. Measurements show that the dissolved oxygen concentration is the same in all the non aerated areas of the ditch. In the following experiments the oxygen probe was

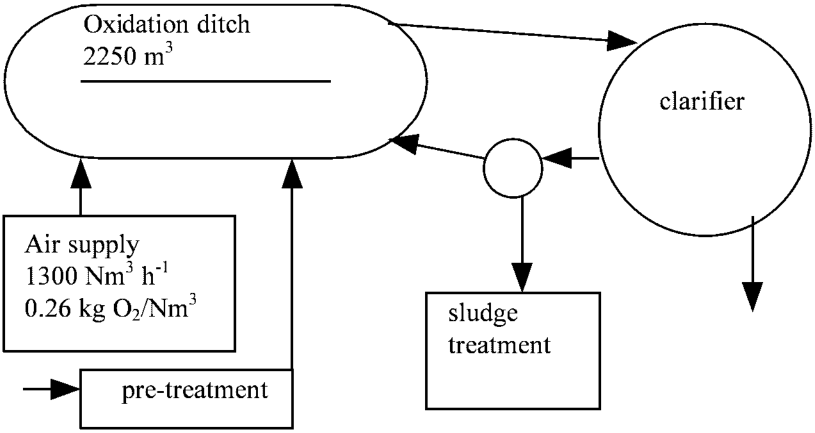

Figure 2 Wastewater treatment plant A flow sheet

Table 1 Influent characteristics

Flow rate, m^3/d	1024
BOD, kg/d	255
COD, kg/d	673
SS, kg/d	347
TKN, kg/d	64

located at the outlet of the ditch. This position has been chosen because it is a well-mixed non-aerated area that is representative of the rest of the ditch.

Results and discussion

Equation (5) has been applied to the wastewater treatment plant A during 4 years. The data we used are the raw data obtained directly from the SCADA system. No filter has been applied and no data has been removed from this set of data. We have selected more than 800 aeration cycles for which the mass balance can be applied. For each of these aeration cycles we applied Equation (5) to estimate a value of $\alpha k_L a$. Figure 3 shows the values we computed for the year 1999.

The results of these computations showed that the estimated values of $\alpha k_L a$ significantly vary from one aeration cycle to another. Most of these changes cannot be explained by a modification of the process functioning but rather by an error in the measurements. This error cannot be neglected for two reasons: Firstly, we use full-scale data that are less reliable than lab scale data. Secondly, the $\alpha k_L a$ value is obtained from the difference between the increasing and decreasing rate of dissolved oxygen concentration. This difference induces a big relative error in the results. In order to remove the noise caused by measurement errors we studied the smoothed evolution of the $\alpha k_L a$. This information is more reliable and can be applied to detect any malfunction of the aeration system.

In some cases significant variations of the smoothed $\alpha k_L a$ values have been detected. These variations are justified by malfunctions that temporarily appear in the plant. The online estimation of $\alpha k_L a$ described above has then proven to be efficient in the detection of malfunction of the aeration system of an activated sludge wastewater treatment plant. For example we stopped one of the two blowers in the plant during one week (Figure 4). The estimated value of $\alpha k_L a$ went down during this period.

Usually the $\alpha k_L a$ parameter is deduced from the standard oxygen transfer efficiency. This efficiency is one of the characteristics of the aeration system. The link between the standard oxygen transfer efficiency and $a k_L a$ is given by Equation (6).

$$\alpha k_L a = \eta Q\rho / VC^* \quad (6)$$

In our case Figure 3 shows a mean value of the $\alpha k_L a$ of 3 h^{-1}. The application of Equation (6) gives:

$$3.0 = \eta \times 1400 \times 0.26/(2250 \times 9 \times 10^{-3}) \quad (7)$$

The numerical application of relation (7) gives an estimated value of the standard oxygen transfer (η) of 0.17 kg O_2 transferred/kg O_2 injected. This value is in the range of other values obtained in the bibliography (Groves *et al.*, 1992).

Figure 3 shows significant variations of $\alpha k_L a$. The $\alpha k_L a$ value correlates neither to the water temperature nor to the air temperature. We have stated the hypothesis that the $\alpha k_L a$ lowers when the suspended concentration or the loading rate is too high. During the first three months there is a strong increase of the suspended solids concentration. This is correlated to the decrease of $\alpha k_L a$. After this period the sludge extraction device recovers, the suspended solids concentration decreases sharply and the $\alpha k_L a$ increases. After this period, the suspended solids concentration remains constant and the $\alpha k_L a$ goes back to its initial value. Then comes the summer period when the plant loading rate lowers. This leads to an increase of the $\alpha k_L a$.

Our data analysis technique has been applied on another WWTP we will call B. This plant is based on the modified UCT flow sheet. The value we found for the $\alpha k_L a$ parameter is bigger (Figure 5) than the one found on WWTP A. The following points may explain this difference. On one hand the amount of oxygen to be transferred per mass of biomass per day is in the same range as in the process shown in Figure 3. This quantity is a function of the mass of biomass stored in the plant (endogenous respiration) and of the amount of pollution received per day (metabolic respiration). On the other hand, in this process the air is introduced in only one basin of the plant (modified UCT flow sheet). No air is introduced in the anoxic and anaerobic area. The consequence of these two points is that the same amount of air is to be transferred in a smaller reactor. It follows (Equation 2) that $\alpha k_L a$ is bigger than the one obtained on plant A.

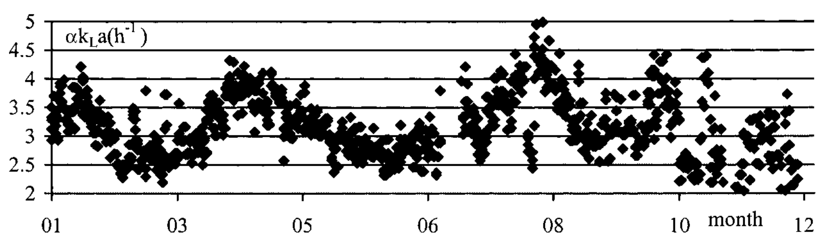

Figure 3 Evolution during year 1999 of estimated $\alpha k_L a$

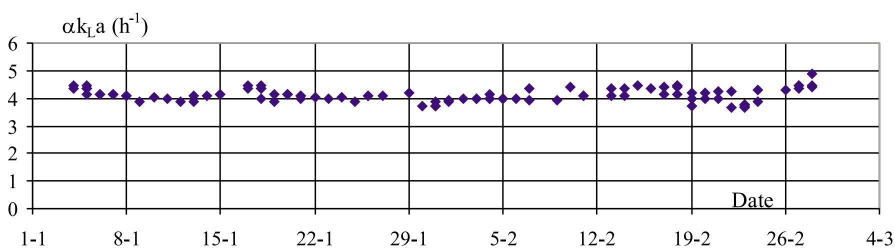

Figure 4 Evolution during the test week (one blower instead of two) of estimated $\alpha k_L a$

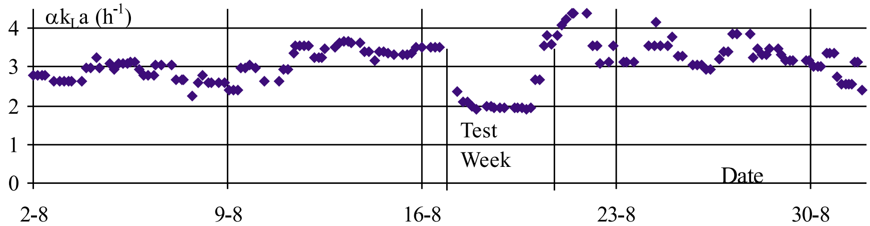

Figure 5 Evolution of estimated $\alpha k_L a$ on plant B during two month

Conclusion

The dynamic mass balance method presented above gave reasonable values of the $\alpha k_L a$ coefficient. The constancy of the values obtained in the studied case confirmed the reliability of the estimation technique.

The application of the estimation algorithm we described involves only one dissolved oxygen probe (one or two flow meters may be added to get more accuracy). Therefore it can easily be installed on wastewater treatment plants. It will then help the plant manager to assess the quality of the aeration system and to plan enhancement or repairs if necessary.

Nomenclature

C = Dissolved oxygen concentration
C^* = Saturated dissolved oxygen concentration
F = Flux of oxygen transferred
Q = Flow rate through the aeration tank
V = Volume of the aeration tank
$\alpha k_L a$ = Characteristic of the aeration capacity
ϕ = Flux of oxygen consumed by the biomass
η = Standard oxygen transfer efficiency (kg O_2 transferred/kg O_2 injected) dissolved oxygen of 0 mg/l, temperature 20°C and pressure 1 atm
ρ = constant (0.26 kg O_2/m^3 air at temperature 20°C and pressure 1 atm)

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