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Effect of oxidation ditch horizontal velocity on the nitrogen removal process

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Abstract

Simulations of oxidation ditch plants equipped with surface aerators are frequently carried out while variations in the horizontal velocity are neglected. However, taking the variations in the horizontal velocity (0.25 to 0.6 m/s) into consideration, it is found that, at non-limiting oxygen concentration, especially the denitrification process is drastically affected by a small change in the horizontal velocity. The study was carried out for a model of an oxidation ditch plant, which has the same volumes and dimensions as a real typical plant. Results of the study were further assessed, using real measurements. To counteract the negative impacts of the horizontal velocity variations on the nitrogen removal processes, the study recommended the following. Either to consider the horizontal velocity as a control variable, from *TN* removal efficiency point of view, or to decouple the aeration and propulsion functions, for maintaining robust operation of the plant and saving energy, by using air diffusers and flow recirculating pumps (boosters) instead of mechanical aerators.

Keywords: horizontal velocity, oxidation ditch, modelling, benchmark, control strategies.

Nomenclature

A	channel cross-sectional area (m^2).	K_La	overall oxygen transfer rate (h^{-1}).
ASM	activated sludge model.	NH_4-N	ammonia nitrogen, mg/l.
BOD	biochemical oxygen demand (mg/l).	NO_3-N	nitrate nitrogen, mg/l.
COD	chemical oxygen demand (mg/l).	Q_{in}	inflow rate (m/d).
CSTR	completely stirred tank reactor.	*TKN*	total Kjeldahl nitrogen, mg/l.
DO	dissolved oxygen, mg/l.	*TN*	total nitrogen, mg/l.
IR	internal recirculation rate.	*TSS*	total suspended solids, mg/l.

Introduction

In oxidation ditches, horizontal velocity can vary between 0.25 to 0.60 m/s, with typical values between 0.25 to 0.35 m/s [1]. A minimum velocity of 0.25 m/s is usually required to prevent the organic particles from settling on the channel surface [2], whereas the velocity is restricted to a maximum of 0.60 m/s to avoid excessive erosion, hydraulic jump, or other undesirable non-uniform flow phenomena [3].

Horizontal velocity in oxidation ditches, equipped with vertical shaft aerators, is principally created by the operation of mechanical aerators. For such an oxidation ditch, oxygen input into the ditch depends on (i) number of aerators in operation, (ii) aerator design (diameter and shape of the rotor) and (iii) aerator operational pattern (immersion depth and the rotational speed). For oxidation ditches that are equipped with brush rotors, Stalzer and von der Emde (1972) [4] found that the mean horizontal velocity increases with an increase in the specific energy input (W/m^3), irrespective of the different combinations of rotors to be chosen. Further, variations in the influent flow also affect the horizontal velocity. In practice, however, simulations of the performance of oxidation ditches usually carried out for a constant horizontal velocity.

Variation of the horizontal velocity in the range of 0.25 to 0.60 m/s (which corresponds to internal recirculation rate (*IR*) equals to 60 - 120 of the inflow rate, depending on the reactor dimensions), however, can significantly affect the performance of the ditch. Due to the high internal recirculation rate, significant amounts of nitrate and dissolved oxygen are recirculated from the last (effluent) compartment to the first (influent) compartment. These amounts will obviously affect the *DO* profile along the ditch, and consequently the ditch performance. For reducing the impacts of internal recirculation of nitrate and dissolved oxygen on nitrogen removal processes, Olsson and Newell (1999) [5] suggest that the effluent *DO* should be kept as small as possible.

In the following simulation example, which is based on typical conditions, we illustrate the effect of both the horizontal velocity and the aeration intensity (K_La) on nitrogen removal process of oxidation ditches. In this study, we have chosen to evaluate the effect by simulation, because evaluation by carrying out practical tests is obviously too expensive due to natural variations in the influent flow. Thus, computer simulations offer a useful approach to solve this problem. In order to help the reader in realizing the real effects of the horizontal velocity, data from real measurements of horizontal velocity variations were also incorporated in assessing the results.

Simulation example

The simulations were carried out for a typical (10^5 p.e.) oxidation ditch plant. Values and sizes were taken from a real plant with the same capacity. Volume of the reactor is 6000 m^3 (187.5m x 8m x 4m), and volume of the secondary settler is 6000 m^3. Further, the oxidation ditch has two aerators;one at the inlet port and the other at the mid-point of the ditch. This corresponds exactly to assuming that the 1st and 6th compartments of the simulation model are aerated.

The reactor was modelled as a loop of 10 equal-volume (600 m^3) completely stirred tank reactors

(*CSTR's)*, as suggested by Abusam and Keesman (1999) [6], whereas the non-reactive ten-layer settler model [7] was used for modelling the secondary settler. *ASM No. 1* [8] was used for modelling the biochemical processes taking place in the reactor.

First, 100-day steady state simulations were carried out. Then, two sets of simulations, in which the horizontal velocity was manipulated using the internal recirculation rate (*IR*), were carried out. The influent flow and concentrations used in these simulations were assumed to be constant, i.e. an influent flow of 18446 m^3/d with an average biodegradable *COD* concentration of 300 mg/l and NH_4-N concentration of 30 mg/l. Further information about the composition of the influent and parameter values for *ASM No. 1* can be obtained from the website of the European Concerted Action Programme *COST* 624 [9].

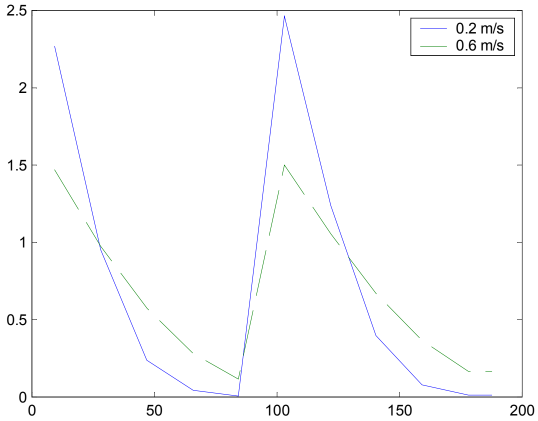

Fig. 1: Effect of horizontal velocity on DO profile; KLa in the aerated compartment is 28.3 h-1 , effluent port is 187.5 m away from the inlet port (first aerator).

In the first set of simulations, the effect of horizontal velocities $\left(\frac{IR \cdot Q_{in}}{A}\right)$;0.2, 0.3, 0.4, 0.5 and 0.6 m/s on the nitrogen removal processes was investigated at constant K_La value in compartment 1 and 6. Thus ignoring the interdependence between horizontal velocity and K_La that can be expected when the aerators act both for aeration and propulsion. In this first set of simulations, K_La was adjusted, by trial and error method, to give about 2 mg *DO*/l in the aerated compartments; at the nominal velocity of 0.3 m/s. Results of this simulation are shown in Fig. 1 and 2. In the second set of simulations, the effect of varying simultaneously the horizontal velocity and K_La on *TN* removal was studied (see Fig. 3 and 4).

As can be seen from Fig. 1, a change in the horizontal velocity, while keeping K_La constant, significantly affects the *DO* profile. With high speed, the *DO* profile becomes more flat. It is important to note that *DO* concentration in the effluent increases with the increase in the horizontal velocity. Consequently, both the nitrification and denitrification processes are affected (see Fig. 2). Nitrification and denitrification simultaneously take place in the alternating zones of aerobic and anoxic conditions that exist along the ditch. Fig. 2 also shows that the impact of the horizontal velocity on the denitrification process, in terms of mg *N* converted, is higher than that on the nitrification process. It is apparent that at high horizontal velocities, the rate of nitrate removal is lower than the rate of ammonia removal, due to increase in the volume of the aerated zones. Thus leading to high *TN* concentration in the effluent, at high horizontal velocity.

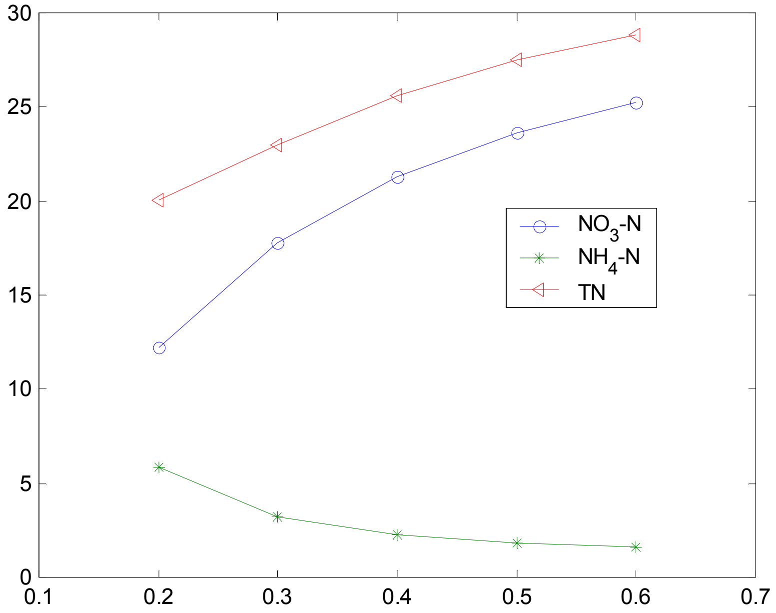

Fig. 2: Effect of horizontal velocity on nitrogen removal process;nominal velocity is 0.3 m/s.

Fig. 3 depicts the contour plot of the effect of both aeration intensity (K_La) in *CSTR* 1 and 6 and the horizontal velocity on the *TN* removal efficiency (%). As it can be seen from this figure, at high aeration, the horizontal velocity has significant effect on the *TN* removal. As expected, high horizontal velocity resulted in poor N removal due to decrease in the volume of the anoxic zones. Note that when the oxygen input into the system is not enough (inadequate aeration intensity, K_La), poor *N* removal is also predicted.

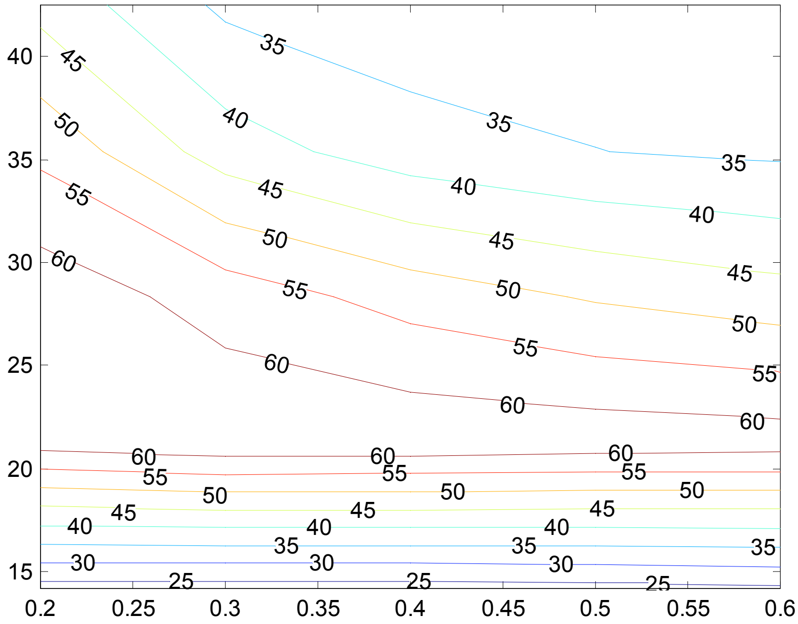

Fig. 3: Effect of K_La and horizontal velocity on *TN* removal efficiency (%).

Fig. 4 shows that the effect of the horizontal velocity on the effluent quality fines is the same as the effect on *TN* removal. As can be seen from this figure, at excess aeration, the horizontal velocity has a substantial effect on the effluent quality fines to be paid. Effluent fines are based on the effluent quality index (*EQ*), which is the weighted sum of the effluent components (*COD*, *BOD*, NO_3-*N*, *TKN* and *TSS*) that have major influence on the receiving water. For more information about the effluent quality index and effluent quality fines see *COST* (2000) [9]. Note that 30 Euro per kg/d effluent load is used in computing effluent fines presented in Fig. 4.

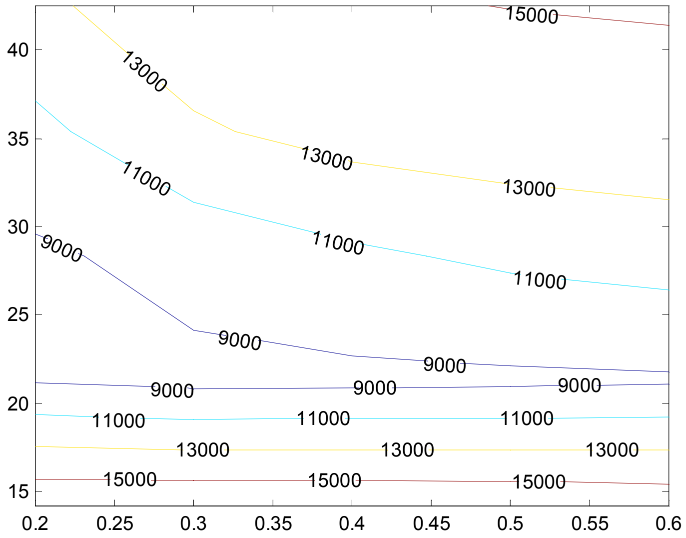

Fig. 4, Effect of K_La and horizontal velocity on effluent quality fines (Euro/d), calculated at 30 Euro per kg/d of pollution load.

Practical assessment

In order to help the reader visualize the effect of the horizontal velocity, in conjunction with concurrent changes in K_La, we have used some real measurements for the horizontal velocity [10] in this study. These measurements were obtained from a full-scale oxidation ditch that has almost the same capacity, dimensions (210m x 8m x 4m deep) and position of the aerators, as the hypothetical oxidation ditch. Furthermore, it is equipped with two Landy-F type mechanical aerators. The rotor diameter of these aerators is 3.15 m. Horizontal velocity measurements were carried out at various combinations of rotor speed (33.5, 25.1 or 0.0 rpm) and immersion depths (–20.8, –10.0, 0.0, +10.0, +13.0 and 15.0 cm). Electrical energy consumption (kW) was also measured. Data of horizontal velocity and the electrical energy consumption are obtained at various operating conditions for the aerators. From the energy consumption, we have calculated K_La using the reported average aeration efficiency of 2.2 kg O_2/kWh, at standard conditions [11]. Fig. 5 presents the calculated K_La versus the measured horizontal velocity plotted on top of Fig. 3 (the contour plot of *TN* removal efficiency). The dashed lines roughly indicate the working area for these aerators in terms of horizontal velocity and K_La. Fig. 5 clearly shows that only few combinations of horizontal velocity and K_La allows the oxidation ditch to work at high *TN* removal efficiency. In agreement with the findings of Gillot *et al.* (2000) [12], Fig. 5 also shows that oxygen input increases as horizontal velocity increases.

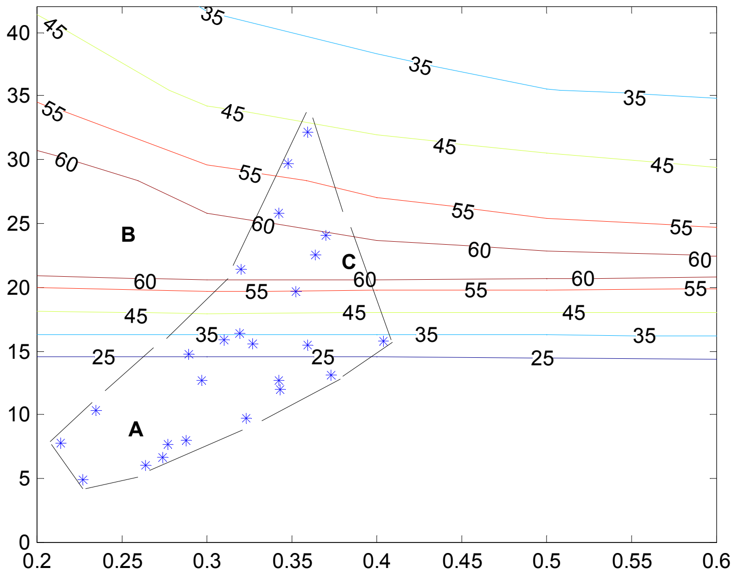

Fig. 5: Real velocity measurements plotted on top the contour of *TN* removal efficiency (%).

Thus, it is clear that the relationship between the oxygen input and the horizontal velocity should be taken into consideration when optimising the performance of an oxidation ditch for achieving a maximum *TN* removal efficiency. As a matter of fact, this requires that the relationship between oxygen input and horizontal velocity, on the one hand, and aerator operating conditions (speed and immersion depth), on the other hand, should be found first.

Impacts of horizontal velocity variations on nitrogen removal processes can be taken care of either by (i) considering the horizontal velocity as a control variable, from *TN* removal efficiency point of view, or by (ii) decoupling the effects of horizontal velocity and oxygen input, in order to maintain a robust operation of the plant and to save some energy. From Fig. 5, it can be seen that the plant is more robust to K_La variations at low horizontal velocity (point B) than at high horizontal velocity (point C). In fact, by decoupling, it would be possible to operate the plant in this robust region (moving from point A to point B). In contrast, high removal efficiency can also be achieved by increasing the aerator speed to e.g. point C, but, in this case, the plant would be working in less robust region.

Decoupling of the horizontal velocity and the oxygen input (K_La) can be achieved by using air diffusers and flow recirculating pumps (boosters) instead of the mechanical aerators, as in the conventional activated sludge systems. With such arrangements, the horizontal velocity can be kept at a value that prevents settling of organic particles and minimizes the negative effects of the recirculated nitrate and *DO*, based on *TN* removal efficiency, while the oxygen input can independently be varied according to the system needs. However, practical studies are needed to investigate the feasibility of this proposed solution.

Conclusions

Because of the significant impact on the nitrogen removal processes, changes in oxidation ditch horizontal velocity should be taken into account when maximizing the *TN* removal efficiency. To maintain robust operation of the plant and save energy, a solution will be to decouple the effects of horizontal velocity and oxygen input, by using air diffusers and flow recirculating pumps (boosters) instead of the mechanical aerators. However, feasibility of this solution needs further investigations.

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