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A Methodology To Upgrade Municipal Wwtps By Alternating System

E. Cola[1], P. Battistoni[1], F. Fatone[2], P. Pavan[3]

[1]Institute of Hydraulics and Transportation Infrastructures - Marche Polytechnical University, Via Brecce Bianche, 60131 Ancona, Italy, Email: e.cola@univpm.it

[2]Department of Science and Technology - University of Verona, Strada Le Grazie 15, Cà Vignal 37134 Verona, Italy.

[3]Department of Environmental Sciences - University of Venice "Cà Foscari", Calle Larga Santa Marta, Dorsoduro 2137 Venice, Italy.

The intermittent aeration activated sludge process is now widely attractive both as new system and for upgrading existing biological treatment plants for nitrogen removal. However, to date the modelling and design of these intermittent systems is not standardized. This paper develops and validates a methodology to upgrade existing municipal wastewater treatment plants by the alternate cycles process, which realizes the process control automation of the intermittent aeration on the basis of dissolved oxygen and redox potential. Firstly, in order to validate a simplified mathematical model, a pilot experimentation was carried out treating real municipal wastewaters. The experimented nitrogen loading rates were in the range 0,03÷0,10 kgN m^{-3} d^{-1} consistently with the typical loading conditions of Italian municipal treatment systems. The experimental durations per day of the anoxic and oxic phases were in good agreement with the simplified mathematical model, which was validated also by full scale data. Therefore, the simplified mathematical model can be used to find the maximal treatable nitrogen loading rate in case the nitrification and denitrification rates are well known, as can easily occur for upgrading of existing plants.

1. Introduction

The wastewater treatment in hilly or mountain regions, rather than in all the scarcely populated areas, is often implemented by a number of small and decentralized plants. If not remote controlled, this practice can likely involve high operation and maintenance costs (O&M) and satisfactory removal performances are difficult to be achieved. On the other hand, the recent European and Italian normative framework is currently establishing stringent limits also for plants with small treatment capacity. As a result, the upgrading of existing systems is an impelling necessity.
According to the present context and also to a correct energy-saving policy, the intermittent aeration is widely attractive because involves: a reduction of power requirements, due to the optimization of the aeration management; an easy up-grading with the best recovery of the existing structures. As for the control of this process, although the nutrient sensors are rapidly improving their reliability involving a growing market, the prices are still too high to allow the widespread application also in small

systems. On the other hand, the alternate cycles (AC) process realizes the control of the aeration for the biological process according to two sensors both unexpensive and already commonly installed in full scale systems: the redox potential (ORP) and the dissolved oxygen (DO). Furthermore, the AC process allows also for the remote on-line control that allows for a continuous monitoring of the process, limit the personnel costs.
The AC process (Battistoni et al., 2003a) realizes the automatic control of the intermittent aeration allows according to two phases: the first, aerobic, achieves near complete ammonia oxidation, whereas the second, anoxic, allows a quite total denitrification of nitrates. The control is basically bending point based, the ammonia break point for the aerobic and nitrate knee for the anoxic phases, but also absolute setpoints are included in the algorithm to safeguard the plant operation in case of bending point non detectable. A simplified mathematical model of the AC process was proposed by Battistoni et al. (2003b) that related the nitrogen loading rates (NLRs), the cycles durations and the constant rates for the biological ammonia nitrification and nitrates denitrification. This model was also supposed to be a basis for a methodology to find out the suitable nitrogen mass loadings to up-grade the existing plants.
This paper develops and validates that simplified model to define a practical protocol for the WWTPs upgrading. At first, a pilot experimentation is dealt with to show the agreement of theoretical and experimental data. Then, operating data from a AC full scale WWTP are used to validate the model. Finally, a methodology to design the upgrading for the existing municipal WWTP can be outlined.

2. Material and Methods

The bench scale pilot plant was composed of one activated sludge tank (23 L), intermittently aerated according to the AC process control, and one secondary clarifier (5.2 L). Real municipal wastewater was used to feed the plant and also the typical flowrate fluctuations were reproduced. The desired nitrogen and carbon speciations (soluble and suspended) were reached according to the following procedure: the raw wastewater was settled for two hours, the clarified supernatant and the settled solids were separately collected. Both were stored at 4°C at most for four days. Feeding was daily prepared mixing fractions of settled solids and supernatant wastewater according to the desired ratios. The chemical/physical parameters were determined according to the *Standard Methods*, while the readily biodegradable COD was determined according to Mamais et al. (1993).

3. Results and discussion

An important resource for the nitrification is the reactor volume, which is also a key design parameter. Therefore, using real municipal wastewater appropriately mixed to prepare the feeding sewage, the pilot plant was fed according to different nitrogen loading rates (NLRs expressed as kgN per unite of reactor volume per day) which cover the possible operating conditions for municipal wastewater treatment systems (table 1).

Table 1 Nitrogen loading rates in the pilot experimentation

Run	Loading	NLR (KgTN m-^{3} day^{-1})
1	High	0.10
2	Medium – high	0.08
3	Medium	0.06
4	Medium-low	0.05
5	Low	0.04
6	Diluted (wet weather)	0.03

Six steady state experimental runs were carried out according to increasing NLRs from 0.03 to 0.1 kgN m^{-3} d^{-1} (table 1), so to investigate the behaviour of the biological process for the treatment of weak and strong wastewaters.

Both raw wastewater and activated sludge, respectively to continuously feed and initially seed the plant, were withdrawn from the same full scale plant. Also, the operating parameters were consistent to those commonly adopted for full scale real systems (table 2).

Table 2 Operating parameters

Run	pH	Alk mgCaCO$_3$ L^{-1}	NLR (kgTN m^{-3}day^{-1})	MLSS (g L^{-1})	MLVSS/MLSS	SRT (day)	SVI
1	7.8	440	0.10	4.2 ± 0.9	0.67 ± 0.02	16	149
2	7.7	395	0.08	4.2 ± 1.1	0.68 ± 0.02	16	171
3	7.9	464	0.06	4.0± 0.3	0.67 ± 0.02	16	141
4	7.8	436	0.05	3.8 ± 0.4	0.66 ± 0.02	15	158
5	7.9	447	0.04	3.4 ± 0.8	0.63 ± 0.02	12	173
6	7.8	358	0.03	3.6 ± 0.6	0.62 ± 0.01	11	141

The MLSS content was lowered for diluted and low loaded runs, when hydraulic overflows are expected and the sludge settling property has to be improved. Consequently, the sludge retention times (SRTs) were 15÷16 days for the more loaded periods, 11÷12 days for the low and diluted wastewaters. However, the SRTs were always sufficient to guarantee the adequate nitrification potential to cope with all the influent ammonia. The characteristics of the influent are typical of wastewater coming form combined sewers system: COD/TKN ratio ranged from 6.7 to 9.5 and the readily biodegradable COD (rbCOD) was from 8 to 19% over the total COD (see table 3 for the main physical-chemical characteristics – average every experimental run).

Table 3 Physical-chemical characteristics of influent

Run	NLR	TSS	COD	sCOD	rbCOD	TKN	TN	TP
	(kgTN m^{-3}day^{-1})	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mgN L^{-1}	mgN L^{1}	mgP L^{-1}
1	0.103	406	436	91	52	62	65	6.5
2	0.079	361	409	91	50	49	52	5.4
3	0.062	364	482	109	68	54	58	6.4
4	0.052	253	353	107	67	45	47	5.4
5	0.039	344	357	74	29	38	40	4.9
6	0.028	195	268	59	22	20	28	2.0

The average effluent characteristics are given in table 4 and show the impact of different NLRs on the AC process. However, the effluent quality met always high quality standard within the range experimented.

Table 4 Chemical physical characteristics of effluent

Run	TSS	COD	SCOD	NO_x-N	NH_4-N	TKN	TN	PO_4-P	TP
	mg L^{-1}	mg lL^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mgN L^{-1}	mgN L^{-1}	mgP L^{-1}	mgP L^{-1}
1	2.0	33	27	6.1	5.3	8.3	14.3	2.1	3.0
2	2.0	35	29	3.5	2.4	4.5	8.0	1.6	2.2
3	2.5	35	25	6.2	2.7	4.7	10.9	2.5	2.9
4	2.4	33	24	5.9	2.3	4.3	10.2	2.3	2.6
5	1.5	32	25	5.0	1.1	3.8	8.8	1.6	2.0
6	1.2	35	28	3.0	0.2	2.9	5.9	1.0	1.4

The removal of biodegradable COD was always quite complete and the effluent sCOD confirmed that basically only the non-biodegradable organic carbon was effluent. Otherwise, effluent NH_4-N was satisfying for NLRs up to 0.08 and worsened sensitively when it increased to 0.10. Within the range of NLRs experimented, three different conditions can be pointed out: (1) from 0,02 to 0.04 kgN $m^{-3}d^{-1}$, where over aeration occurred influencing the denitrification; (2) from 0.04 to 0.08 kgN m^{-3} d^{-1}, where the maximum performances are reached; (3) from 0.08 to 0.1, where the performances are decreasing, but are still suitable to reach high quality standard of the effluent. The impact of low and high influent loadings is easily understandable even after a quick examination of the on-line patterns of DO and ORP (Figure 1).

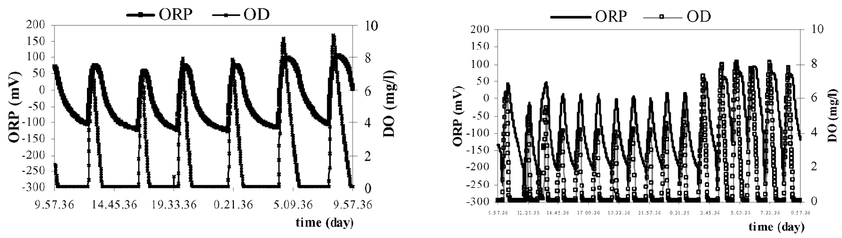

Figure 1 Cycles per day during high nitrogen loading (left) and low nitrogen loading (right)

The durations of the aerobic-anoxic phases were heavily influenced by the over-aeration phenomena. The air supply was unchanged run by run and the number of cycles per day was generally dictated by the de-nitrification rates. Therefore about 17÷19 cycles per day were performed with high loadings, on the contrary no more than 7÷8 cycles were observed for low NLRs when severe over-aeration during the aerobic phases reduced the carbon source for heterotrophic denitrification during the following anoxic phase.

A detailed analysis of all the cycles lets define the relation between oxic/anoxic time-lengths and NLRs (Figure 2).

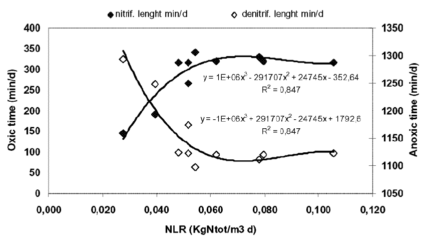

Figure 2 Trends of experimental anoxic-oxic durations

Nitrification in the range 300÷350 min d^{-1} is required for NLRs higher than 0.05 kgTN $m^{-3}day^{-1}$, while low loadings (0.03 kgTN $m^{-3}day^{-1}$) correspond to minimum nitrification and maximum denitrification time. Depending on the nitrification and denitrification rates, the durations of the anoxic and oxic periods reached a plateau for NLRs higher than 0.06 kgTN $m^{-3}day^{-1}$.

This is a fundamental factor to design the plant up-grading because indicates the loss of flexibility of the alternating process. In fact, once known the durations of the aerobic and anoxic phases reached in the plateau of the plots, the design NLR can be fixed depending on the required standard for the treated effluent and the kinetic constants. Therefore, since the existing plants allow a reliable determination of the nitrification rate (K_n), equ. 1 gives the NLR that can effectively be treated by the alternate system.

$$NLR_{treatable}=K_n*t_{aerobic\_plateaux}*MLVSS \quad (1)$$

Pilot validation of the simplified mathematical model

The experimentally observed durations of the oxic and anoxic phases were compared with the values coming from the AC simplified mathematical model (Battistoni et al., 2003b) (figure 3), where nitrification and denitrification rates determined by respirometry tests (Christensen *et al.*, 1992) were used.

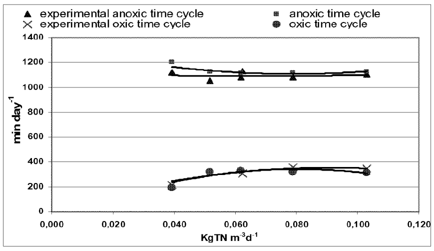

Figure 3 Comparison of experimental and theoretical results – pilot plant

The better agreement with the model was found out for the aerobic phases, while the anoxic had greater discrepancy especially in case of low loadings and consequent over-aerated conditions.

This phenomenon was due to the imprecision of applying always the maximum denitrification constant rate, even when the over aeration caused shortage of biodegradable carbon for the denitrifying biomasses.

On the other hand, the nitrification rate was rather invariant in the pilot experimentation and corresponded to the maximum measured by the respirometry tests. Therefore, once known the nitrification rate and the duration of the aerobic phase, the simplified model could be used to know the maximal NLR treatable by the AC system. On the contrary, the model is not reliable for C/N ratio < 6÷7 when the value of the real denitrification rate is not consistent with the results of the respirometry batch test.

Full scale validation

A different procedure was carried out for the full scale validation of the simplified mathematical model. In practice, given the real nitrification and denitrification rates of respectively 0.04 and 0.08 kgN $kgMLVSS^{-1}$ d^{-1}, the mathematical model was applied to find out the plateau phases (figure 4).

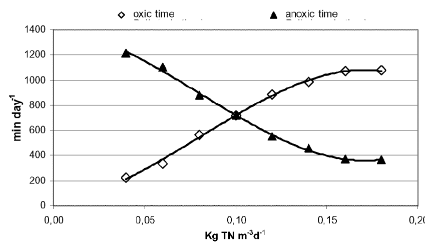

Figure 4 Theoretical durations of the aerobic and anoxic phases in a full scale AC WWTP

According to the theoretical calculations, the plant would have reached the plateau conditions, that are the maximal effective nitrogen treatment capacity, for aerobic time of about 1100 minutes. This duration corresponds to NLR of 0.15 kgN m^{-3} d^{-1}. As a matter of fact, this was just the nitrogen loading that has been really treated successfully from the full scale plant.

4. Conclusions

A methodology to upgrade the existing municipal wastewater treatment plants by the alternate cycles has been developed. This procedure was mainly based on a simplified mathematical model which demonstrated to be useful for the upgrading design. In fact, in case of plant upgrading, when the nitrification and denitrification rates can be well determined, the model is used to determine the maximal aerobic and anoxic time. So, the maximal treatable nitrogen loading and the suitable volume of the reactor can be calculated. However, this methodology is reliable only when the denitrification is not the limiting step for the alternating process, that corresponded to influent wastewater with C/N ratio < 7.

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