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Aeration length phase control using on-line ammonia and dissolved oxygen feedback control at Choutrana II WWTP

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ABSTRACT

The purpose of this work was to study the impact of aeration control strategy using on-line ammonia and dissolved oxygen feedback control on energy consumption in a full-scale wastewater treatment plant. Eight identical oxidation ditches treating the same effluent and operated with conventional control aeration strategy with distinct nitrification and denitrification phases were examined. Each oxidation ditch was periodically aerated according to a fixed phase cycle and phase lengths are controlled by constant dissolved oxygen (DO) set points. To improve the plant's energy efficiency, a new control strategy has been performed by a full-scale test to control the phase lengths by variable DO set points determined by criteria functions. Knowing the phase lengths provides flexibility to achieve easily nitrogen treatment with nitrification and dentrification processes and treatment objectives. In the test strategy, each zone was separately controlled and the DO set points were changed to avoid unnecessarily high DO levels. The results showed that the ammonium and DO feedback control method can reduce about 30% of the total airflow and lead to a significant aeration energy savings. The plant could preserve treatment efficiency, enhance simultaneous nitrification–denitrification process, and produce excellent effluent quality. A Ammonia and DO feedback controller system was implemented and compared with the actual DO control system.

Keywords: Aeration control strategy; Ammonium; DO feedback; Energy consumption; DO set points

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1. Introduction

The assessment of energy consumption in the activated sludge plants revealed that the aeration of the biological treatment process can reach up to 70% of the electrical consumption at the plant [1]. DO is used for the removal of ammonium through the process of nitrification. Hence, it makes good sense to relate the removal of ammonium to the energy consumption in plants where denitrification is included (a large part of the biodegradable organic matter is removed in the denitrification process). The best way to do this is to relate the removal only to the aeration energy consumption. Very low effluent ammonium concentrations compared to the discharge limits lead to an inefficient aeration and cause an unnecessary costs in many plants [2–4]. To achieve nitrogen removal, a control process and a DO management are necessary by using on-line supervisory control. So, energy can be saved without deteriorating effluent quality. By the simultaneous nitrification–denitrification (SND) process, nitrogen removal is the key to appropriately set the aeration system and to establish sufficiently aerobic and anoxic zones simultaneously [5]. Several sophisticated control systems based on monitoring both nitrate and ammonia were used in full-scale implementations [6–8]. SND is a well-known phenomenon in biological nutrient removal in activated sludge process. SND has been reported more frequently in oxidation ditches, which operate with low DO concentrations in the majority of their volume. Without controlling SND mechanisms, the reduction of the air flow can decrease DO concentrations in aerated zones where nitrifying organisms take time to develop their population niches, as well as to acclimate to the low DO environment. These conditions may inhibit nitrification process, cause the development of filamentous bacteria, and destroy effluent quality by raising ammonia and nitrite concentrations [9]. When alternating aerobic and anoxic conditions in a full-scale plant where SND has been achieved, nitrified biomasses need to be established. It has been found that SND can reduce carbon, oxygen, and alkalinity consumption by 10–40%, depending on the degree of SND achieved [10].

Different nitrogen removal methods are presented in Samuelsson [11]. Several of those are related to denitrification and the addition of external carbon. The work related to aeration control includes the control of the aerobic volume. Lumley [12] found that return and waste sludge rates are the two principal variables to adjust nitrate concentration and sludge age, respectively. Holenda [13] investigated methods to optimize the aeration length in an alternating system, but also developed a model predictive control (MPC) for DO set point tracking. The MPC is based on a linearized version of the ASM1.

Many researchers improved that dynamic adaptation of the aerated volume to alternate loading conditions is the key to maximize the plant performance and to reduce the energy consumption. It is in this context that we will conduct a study based on the simulation using ASM1 model for testing online ammonia monitoring and DO feedback controllers (Fig. 3) in order to:

1. Define anoxic/oxic lengths, respectively, using on-line ammonia and DO feedback control in full-scale plant in Tunisia.
2. Develop a control strategy via online nutrient and DO feedback for dynamic adaptation to load variations to maximize the plant efficiency;
3. Show the role that online nutrient instrumentations have played at the plant in terms of efficiency, energy, and chemical savings.
4. Use these instrumentations in our existing and future WWTPs.

A successful application of the new strategy in Choutrana II plant could provide an opportunity for future process control automation based on continuous online measurement of DO and nutrient parameters.

2. Methods and materials

2.1. Choutrana II WWTP

Choutrana II plant operates continuously throughout the year and treats 40,000 m^3/d of sewage, 40,000 kg/d of chemical oxygen demand (COD), and 3,000 kg/d of nitrogen corresponding to the equivalent of about 600,000 inhabitants served. It is composed of four parallel lines. Each line consists of an oxidation ditch. It treats about 20,000 kg BOD_5/d with low load of 0.08 gBOD/gTSS/d. Hydraulic retention time is about 22 h and sludge residence time is 18.5 d. DO is served by a fine bubble diffused air system. The return activated sludge (RAS) flow rate is about 75% of the influent flow.

Note that from the standard practice, the RAS flow rate is considered as 150% of the influent flow during dry weather and 100% of the flow during wet weather.

Fig. 1 presents a schematic flow diagram of the liquid process at the plant. Each oxidation ditch is

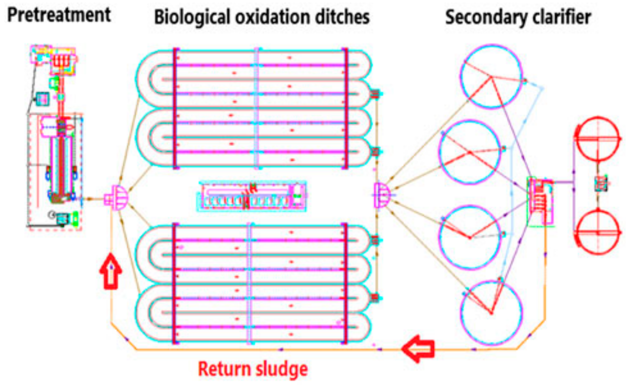

Fig. 1. Schematic flow diagram of Choutrana II plant.

equipped with diffusers and four agitators. In addition, each oxidation ditch is equipped with DO probes which are used in the automatic DO control.

2.2. Aeration in oxidation ditch

Fig. 2 shows aerated and non-aerated zones in oxidation ditch. The first anoxic zone receives raw wastewater. The air diffusers are placed on the bottom of the tanks. The airflow rate through the diffuser is 4.36 Nm^3/h (but it is variable between 3.5 and 6.5 Nm^3/h). The number of diffusers per zone increases and the highest number is located in zone 6. However, the COD and ammonium loads decrease from zone 1 to zone 9 when the flow is passed through multiple anoxic/aerobic zones.

Table 1 shows the number of diffusers, the airflow in each aerated zone, and the volume of each zone.

2.3. DO control system

Since the start-up in 2007, Choutrana II WWTP has been operated firstly with a constant DO set point (2 mgO_2/L) in oxidation ditch where two DO probes were installed to control the airflow (Fig. 2). Currently, aeration control relies on the operator experience and manual mode. The function of blowers is controlled by a timer with fixed phase length: 45 min of aeration and 15 min of non-aeration. The blowers work 18 h/d. Although the plant was equipped with DO probes, aeration adjustment has not been fully completed.

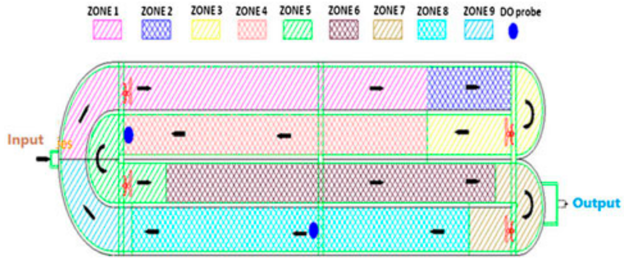

Fig. 2. Aerated and anoxic zones in oxidation ditch. Locations of DO probe ●.

Borglund [14] tested a strategy during low and high loading conditions to control air flow in full scale. It is based on a linear air flow distribution designed to gradually decrease the air flow to the aerated zones according to a step-like structure. Two DO probes are used to control the aeration system. The first probe situated in the first zone controls the total airflow to the oxidation ditch. The second one situated in the last zone controls the inclination of the step-like structure. When the DO concentration in the last zone deviates from its DO set point, the inclination is shifted, affecting the DO concentration in the first zone. This causes the DO probe in the first zone to change the total airflow to the oxidation ditch. The strategy during low and high loading conditions is illustrated in Fig. 3. There are four zones in the illustration, but the principle is the same also in tanks with several zones.

The original DO control strategy at Choutrana II plant (Fig. 2) is based on constant and variable airflow distributions in aerated zones. Table 1 shows airflow distribution in each aerated zone. The amount of oxygen transferred per added volume of air is different in aerated zones. This is not advantageous from the point of view of energy.

2.4. Models

2.4.1. Oxygen transfer model

According to Mulas [15], a change in airflow affects the DO concentration. Eq. (1) describes this relation:

$$\frac{\mathrm{d}C(t)}{\mathrm{d}t} = K_{\mathrm{La}}(q_{\mathrm{air}}(t))(C_{\mathrm{sat}} - C(t)) - \frac{Q}{V}(C_{\mathrm{in}}(t) - C(t)) - R(t) \tag{1}$$

where K_{La} (q_{air}) = oxygen transfer rate as a function of airflow (l/h), C_{sat} = saturated oxygen level (mg/L), $C(t)$ = oxygen concentration (mg/L), $C_{in}(t)$ = oxygen concentration of incoming water (mg/L), $R(t)$ = oxygen consumption rate due to microbial activity (mg/L h), $Q(t)$ = flow (m^3/h), V = aerated volume (m^3).

Lindberg [16] showed that a nonlinear relationship between the airflow rate and the oxygen transfer coefficient (K_{La}) can be considered.

Table 1
Aeration system in oxidation ditch

Zone	Air flow/zone (Nm^3/h)	Number of diffusers	Volume of zone (m^3)	Length of zone (m)
1	0	0	2,408	80
2	1,500	344	602	20
3	0	0	1,204	40
4	8,000	1835	2,408	80
5	0	0	1,204	40
6	5,000	1,146	3,010	**100**
7	0	0	602	20
8	2,500	573	3,010	100
9	0	0	595	20
Total	**17,000**	**3,898**	**15,000**	**500**

Note: Bold values define the oxidation ditch design and is the sum of each value range.

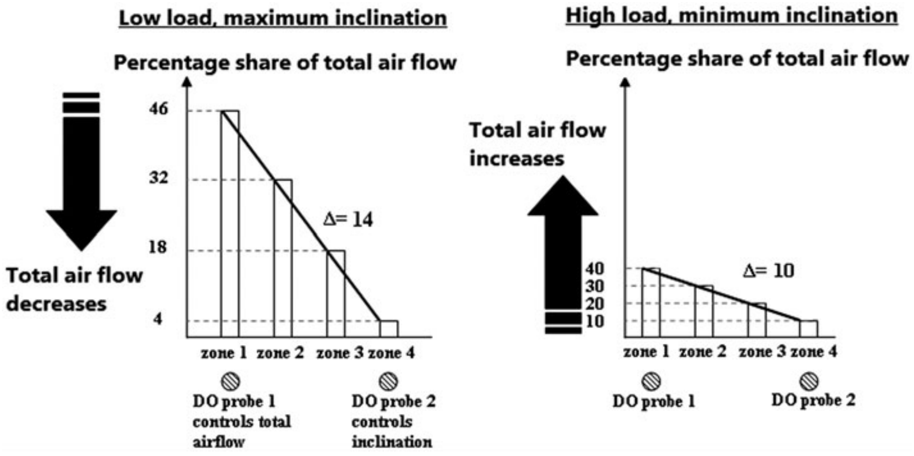

Fig. 3. Air flow profile during low and high load [14].

$$K_{La}(q_{air}) = K_1\left(1 - e^{-k_2 q_{air}}\right) \tag{2}$$

where q_{air} = airflow rate (m^3/h), $k_1 = (1/1 - K_{La}\tau)(C_0 - C_{Sat})$, $k_2 = (K_{La}\tau/K_{La}\tau - 1)(C_0 - C_{Sat})$, τ = delay times of the oximeter (s), C_0 = Initial oxygen level (mg/L).

Capela et al. [17] showed, in specific conditions, that the oxygen transfer coefficient (K_{La}), increases linearly with the aeration rate and the relationship between the K_{La} function and airflow rate can be expected to be nonlinear.

From Eq. (1), it can be seen that the driving force for mass transfer of oxygen is lower at DO concentrations close to the level of oxygen saturation. Since high airflows lead to high DO concentrations, and because of the nonlinear structure of the K_{La}-function, high airflows give an inefficient oxygen transfer.

2.4.2. Blowers energy consumption

Ingildsen [18] carried out an experiment and found that the airflow rate could be translated into power by the Eq. (3):

$$\text{Power} = 0.0115\,\text{kW}/(\text{h}/\text{Nm}^3) \times \text{Airflow} + n \times 28\,\text{kW} \tag{3}$$

where n is the number of blowers in operation. This means that having a blowers running without yielding any air requires 28 kW.

2.4.3. Simulation model

The simulation software used was GPS-X (Hydromantis Inc.). The ASM1 model was selected for the simulation. For the aeration tank, new control mode will be tested and will be compared to the current one.

(a) On-Off control defined by cycle times (current mode)
(b) On-Off function times of the blowers (aeration length phase) using online ammonia concentration and DO feedback: Times of the blowers recorded at the full-scale plant will be applied directly to control data input for dynamic simulations on real data.

2.4.4. *Kinetic of nitrifying biomass*

Biomass growth and decay rates are the key parameters for a successful biological treatment [19]. According to Svardal et al. [20], the growth rate of nitrifying biomasses depends on several factors where DO and ammonium concentrations are the most important parameters. The nitrifying bacteria can reach 80% of their maximum growth at an ammonia concentration of 2 mg/L.

Svardal et al. [20] and Regmi et al. [27] showed that the nitrification rate at low ammonium concentration (<1–2 mg NH_4-N/L) is linearly dependent on the DO concentration. The gradient of the growth rate decreases as the concentration increases. Due to this behavior, there is a potential to decrease high DO concentrations in an aerated zone with only a minor decrease of the growth rate of the nitrifying bacteria. Similarly, there is a potential to increase the growth rate substantially by increasing the ammonium concentration in an aerated zone where it is low.

The growth rate is commonly expressed according to Monod kinetics [21] and it is given by the following equation:

$$\mu = \mu_{\max}\left(\frac{S}{K_s + S}\right) \tag{4}$$

where μ: growth rate (d^{-1}), $\mu_{\max}$: maximum growth rate (d^{-1}), S: Substrate concentration ($g\,m^{-3}$), K_s: Half saturation coefficient ($gCOD\,m^{-3}$).

Eqs. (5), (6), and (7) show the relation between the nitrification rates in aerated and anoxic phases.

2.4.4.1. *Growth rate of aerobic autotrophs.*

$$r = \mu_{A\max}\left(\frac{S_{NH}}{K_{NH} + S_{NH}}\right)\left(\frac{S_O}{K_{OA} + S_O}\right)X_{BA} \tag{5}$$

where $\mu_{A\max}$ = maximum growth rate of autotrophic bacteria (d^{-1}), S_{NH} = ammonium concentration ($gNH_4^+\,m^{-3}$), K_{NH} = ammonia half-saturation coefficient for autotrophs ($gN\,m^{-3}$), K_{OA} = oxygen half saturation constant for autotrophs ($g\,m^{-3}$), X_{BA} = autotrophic biomass ($gCOD\,m^{-3}$).

2.4.4.2. *Growth rate of aerobic heterotrophic biomass.*

$$r = \mu_{H\max}\left(\frac{S_S}{K_S + S_S}\right)\left(\frac{S_O}{K_{OH} + S_O}\right)X_{BH} \tag{6}$$

where $\mu_{H\max}$ = maximum growth rate of heterotrophic biomass (d^{-1}), S_S = COD concentration rapidly biodegradable ($gCOD\,m^{-3}$), K_S = half-saturation coefficient of heterotrophic biomass ($gCOD\,m^{-3}$), X_{BH} = heterotrophic biomass ($gCOD\,m^{-3}$).

2.4.4.3. *Growth rate of anoxic heterotrophic biomass.*

$$r = \eta_{NO}\frac{S_{NO}}{K_{NO} + S_{NO}}\mu_{H\max}\left(\frac{S_S}{K_S + S_S}\right)\left(\frac{S_O}{K_{OH} + S_O}\right)X_{BH} \tag{7}$$

where η_{NO} = correction factor for μ_H under anoxic conditions, K_{NO} = nitrate half-saturation coefficient for denitrifying biomass ($gN\,m^{-3}$), S_{NO} = nitrates + nitrites ($gN\,m^{-3}$).

The Eq. (8) shows that the nitrification rate r_N depends on the ammonia concentration S_{NH} and subsequently r_N is directly proportional to the oxygen uptake rate OUR_N (Eq. (8)).

$$OUR_N = (4.57 - Y_{\mathbf{A}}) \times r_N \tag{8}$$

where OUR_N: Oxygen Uptake Rate, Y_A: yield for autotrophic biomass ($gCOD\,gN^{-1}$).

Eq. (9) indicates that the total oxygen requirement is a function of air flow in the reactor. A linear relationship between DO concentration and nitrification rate provides useful information for process control:

$$TOR = OUR_N \times V \times \frac{C_S}{C_S + S_0} \tag{9}$$

where TOR: Total oxygen requirement, V: Airflow volume (Nm^3/h), C_s: Oxygen level (mg/L), S_0: Substrate (mg/L).

2.5.5. Sample collection and analysis

Currently in Tunisia, there are about 90 wastewater treatment plants with activated sludge process where the aeration is controlled by oxygen probes and by timer. None of these plants is equipped with NH_4/NO_3 instrumentations to control aeration despite their availability later with acceptable cost. The results of recent researches in full and pilot scales have shown that this type of instrumentation has an effective capacity to control and adjust the aeration [7,22–24].

In the absence of these instrumentations and the impossibility to install them in the oxidation ditch, the method is based on changing the airflow and monitoring third levels of DO, ammonia, and nitrate in oxidation ditch. Raw and biologically treated effluent quality was also characterized. The method was tested in one line in the biological treatment of the plant. We conducted nine measuring points in the oxidation ditch (one in each zone) and one for effluent quality. A measurement of oxygen was simultaneously carried out at each zone. The DO probe was placed at 2.5 m deep. Profile samples were collected during one-week period from 24 to 29 March 2014 from 11 hH00 to10 h00 next day. Parameters were analyzed in the plant's lab.

The program set up can be shown in Table 2, which presents the zones and parameters to be analyzed in the oxidation ditch during six day from 24 to 29 March 2014.

2.5.6. Principle of the proposed strategy

The strategy is illustrated in Fig. 4. By installing NH_4-N/NO_3-N probes and changing old DO probes in oxidation ditch, the airflow was controlled with its own DO set point through a cascade control strategy [15]. Here, DO set point can be calculated based on the measured ammonium concentrations in the outlet of the activated sludge process or from an *in situ* sensor in the oxidation ditch.

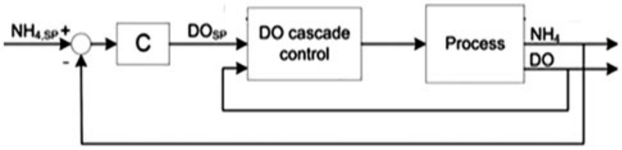

Fig. 4. Strategy controller airflow with ammonium and DO feedback.

The strategy guarantees that no zone will use higher airflows than needed for the instantaneous oxygen requirements. When the influent load decreases, airflows decrease sufficiently in aerated zones to prevent elevated DO concentrations in aerated zones and give energy savings. The DO cascade control is illustrated in Fig. 5.

As shown in Fig. 5, the control will carry out three simultaneous stages: Control of the inlet ammonium load at the station, control of the DO evolution in aerated zones, and control of recycled ammonium load and DO concentration. Two supervisory feedback controllers were used. An ammonium feedback model controlling the DO levels in aerated zones coupled with online measurements in influent will adapt the DO set points to the current load [25]. All information is controlled by a master controller.

To avoid disturbances of rapidly changing loads, ammonium feedback control is reinforced by another one using DO feedback control in the last aerated zone. With a DO- feedback control from the last aerated zone, the DO set points adapt faster to changes in load. Zhao et al. [5] and Thauré et al. [26] put an advanced control strategy based on measurement of ammonia and nitrate in SND process. This strategy reduces the aeration energy. However, this control model usually requires the upgrade of the aeration system to allow variable airflow rate. Ammonia and nitrate measurements are done in cascade zones. The first controller regulates the nitrate concentration (S_{NO} in g m^{-3}) by adjusting a set point of ammonia (S_{NH} in g m^{-3}) while

Table 2
program set up in Choutrana II WWTP

			Zones illustrated in Fig. 2									
Parameters	Unit	Input	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Output
Flow rate	m^3	x										
COD	mg/L		x									x
TKN	mg/L		x									x
N-NH_4	mg/L		x	x	x	x	x	x	x	x	x	x
N-NO_3	mg/L		x	x	x	x	x	x	x	x	x	x
DO	mg/L		x	x	x	x	x	x	x	x	x	

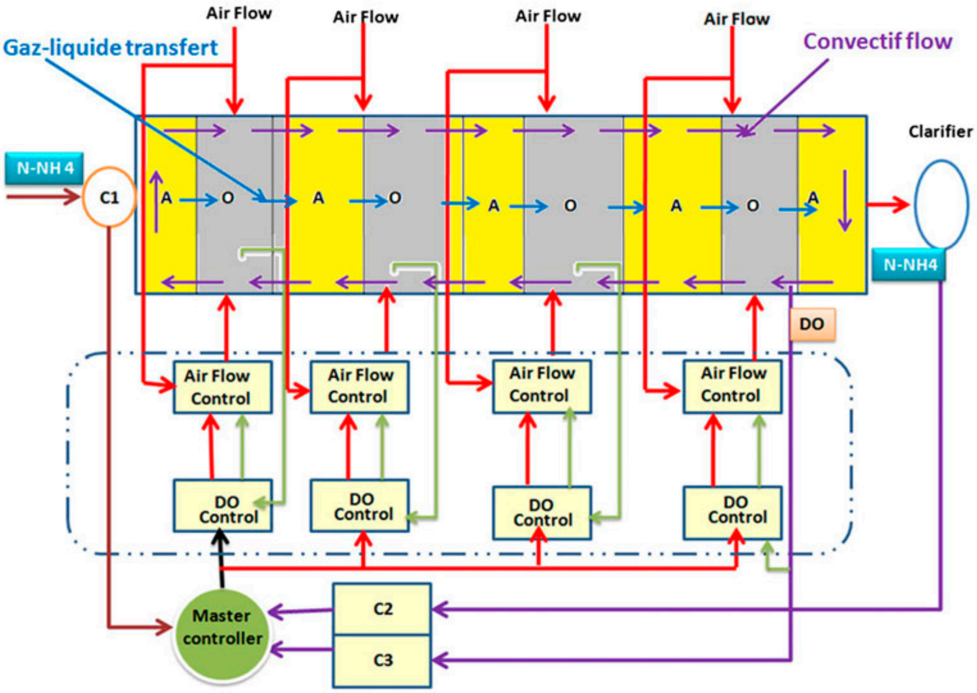

Fig. 5. DO cascade control.

the second controller regulates the ammonia level by handling the airflow rate (Q_{air} in $Nm^3\ d^{-1}$).

The controllers (C1, C2, C3, and master controller) used are Predictive Integral Controllers (PICs). PICs are an implementation of Model Predictive Controllers originally proposed by Regmi et al. [27]. They are based on an internal model of the process that ensure fast disturbance rejection and robustness around a nominal point of functioning. In our case, controller's behavior can be expressed with first-order linear models as a relation between nitrate and ammonia and between ammonia and oxygen transfer coefficient. Eqs. (10) and (11) show an example of criteria functions [28–30]:

$$NO_{MIN} = \alpha\, NH_4\text{-}N + \beta \qquad (10)$$

$$NH_{MIN} = \gamma\, NO_3\text{-}N + \delta \qquad (11)$$

where α, β, γ, and δ are predefined parameters.

NH_4-N and NO_3-N are the measured ammonia and nitrate concentrations, respectively

This includes a considerable simplification, but it ensures a simple parameterization of the control model and still provides a very good performance [5]. Even with these simple models, the parameterization on real processes is not easy as the inlet pollution is continuously disturbing these models and the gain and time constants of each transfer functions are not easy to identify. The parameters that can be optimized in this control law are:

(1) the set point of nitrate or DO and
(2) the upper and lower limits of ammonia.

These two limit parameters are necessary to avoid high and low ammonia levels. They also will allow that the nitrate level will be reduced during the night when ammonia levels are low and it will increase during the peak of ammonia.

The fundamental principle is ending nitrification phases when ammonia is "low" and is stopping denitrification phases when nitrate is "low" [31,32]. Several control strategies have been reported to implement this principle.

Three different scenarios are tested at Choutrana II plant. Table 3 summarizes the tests carried out.

3. Results and discussion

The strategy has been implemented at one line of Choutrana II WWTP during six days, from March 24 to 29, 2014. During the experiment, various simulations were done. The aim of this study was to reach a concordance between simulated and measured DO

Table 3
Summary of tests

Test	NH_4 length[a] (m)	NO_3 length[b] (m)	Air flow in aerated zones	Anoxic fraction[c] (%)	Oxic fraction[d] (%)
Reference (actual strategy)	170	330	Z2 = 1,500 Nm^c/h Z4 = 8,000 Nm^c/h Z6 = 5,000 Nm^c/h Z8 = 2,500 Nm^c/h	34	66
Test 1	190	310	Z2 = 0 Nm^3/h + (Z4 = 5,000 Nm^3/h)	38	62
Test 2	200	300	Test 1 + (Z6 = 3,500 Nm^3/h)	45	55
Test 3	250	250	Test 1 + (Z8 = 1,500 Nm^3/h)	50	50

[a] development length of anoxic zones.
[b] development length of oxic zones.
[c] Anoxic fraction = NH_4 length/(NH_4 length + NO_3 length).
[d] Oxic fraction = NO_3 length/(NH_4 length + NO_3 length).

in biological line, and save at the same time the aeration energy in terms of total airflow rates to the biological line. One of the experimental tests (test 2) aimed to enhance SND in oxidation ditch according to the inlet load. This test was implemented by using gain functions which yielded lower airflow and DO levels in the three last zones (zones 7, 8, and 9).

Fig. 6 shows that the strategy gave a reduction of the total airflow of 30% (from 15,000 to 10,500 Nm^3/h). This reduction was mainly due to the better use of the aerated volumes. The zone 2 can be switched-on in peak loads. The control model adapted the DO set points to the influent load variations giving additional reductions. Especially when the load decreases at night and when no personnel is at the plant during weekends, large savings will be made.

With the proposed strategy, DO levels are controlled and the first three zones are used for denitrification process. The aerated zone 4 uses the high airflow and the maximum DO set points (from Fig. 7a, simulated level is 3.12 mg/L and measured level is 3.68 mg/L). This situation decreases the airflows in the following zones because the majority of ammonium and organic carbon is removed in the first aerobic zones. The remaining loads are pushed to the following zones which are effectively aerated depending on these loads.

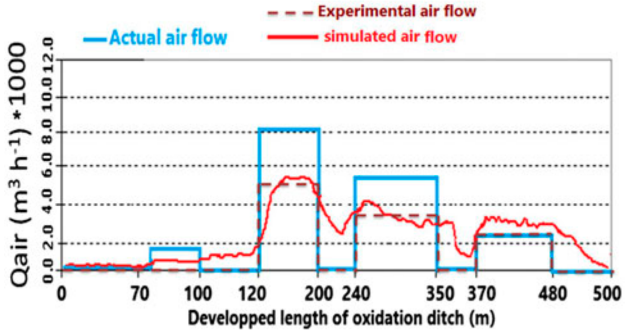

Fig. 6. Total airflows in the various zones.

Figs. 7a and 8a show the evolution of DO concentrations in experimental and current line in oxidation ditch. In the experimental line, the DO concentrations range between 0.1 and 3.02 mg/L in anoxic and oxic zones, respectively (Fig. 7a), however the current management leads to high DO levels which can inhibit the denitrification process in anoxic zones. Fig. 8a shows that DO concentrations in zones 4–9 range between 2.8 and 4.4 mg/L where denitrification process cannot take place and the nitrate effluent concentration is very high, about 60 mg/L, while in zones 1, 2, and 3, return nitrate could be removed by denitrification process (Fig. 8b). This is a highly inefficient use of the aired volumes resulting in unnecessarily high energy consumption. Fig. 7a shows the DO variation in oxidation ditch. The DO concentration decreases in the first, the second and the third anoxic zones where the return nitrate is reduced to nitrogen gaseous and increases in the following zones to oxidize the ammonia to nitrites and nitrates. The maximum DO set point, founded in the fourth zone (about 3 mg/L), could be used as a reference to operate the aeration system until the installation of the nitrogen probes.

Table 4 shows the treatment efficiency during evaluation of the strategy. It is shown that this strategy could contribute to significant improvements in the management of the plant and could be valuable to optimize the treatment efficiency and the energy savings.

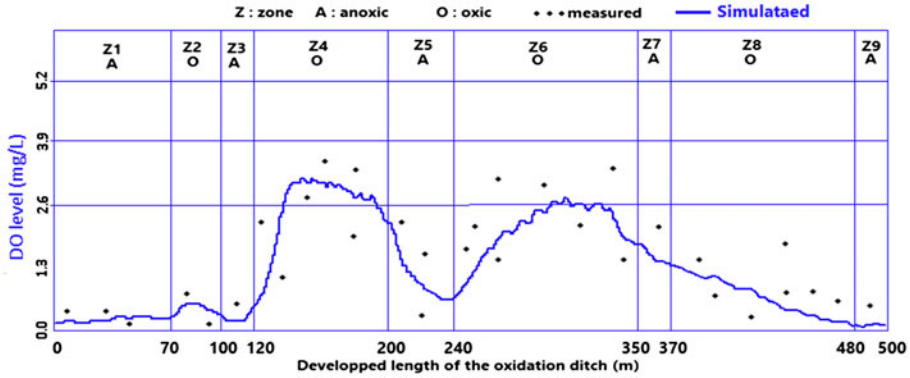

Fig. 7a. DO levels in the various zones.

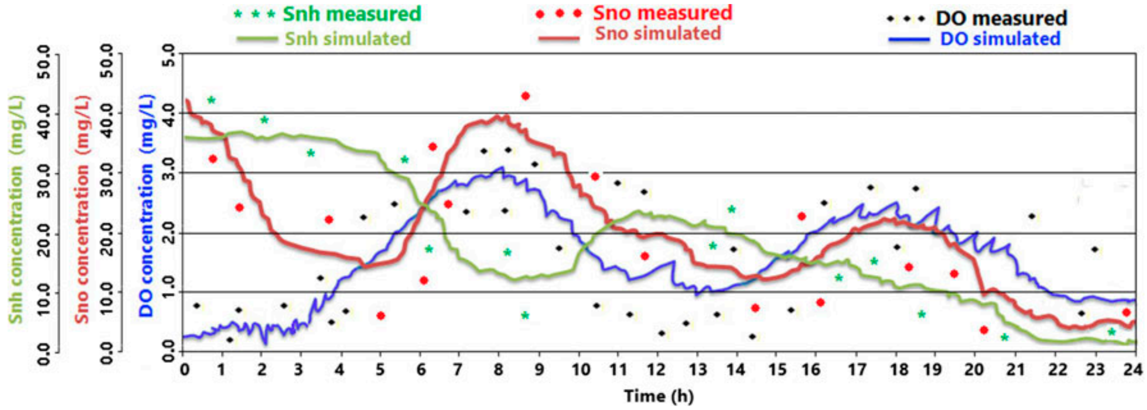

Fig. 7b. Nitrogen removal in the various zones. Notes: Snh: Ammonia concentration in mg/L and Sno: Nitrate and nitrite concentration in mg/L.

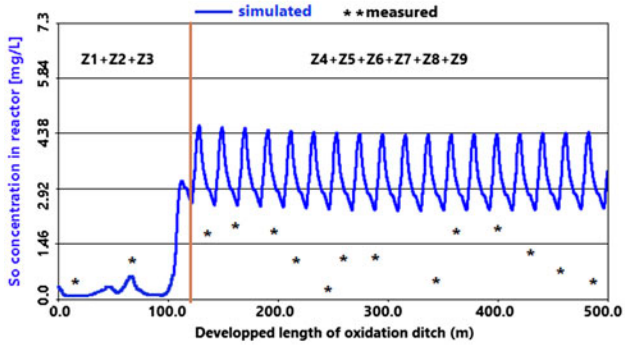

Fig. 8a. DO levels in the various zones. Notes: Snh: Ammonia concentration in mg/L and Sno: Nitrate and nitrite concentration in mg/L.

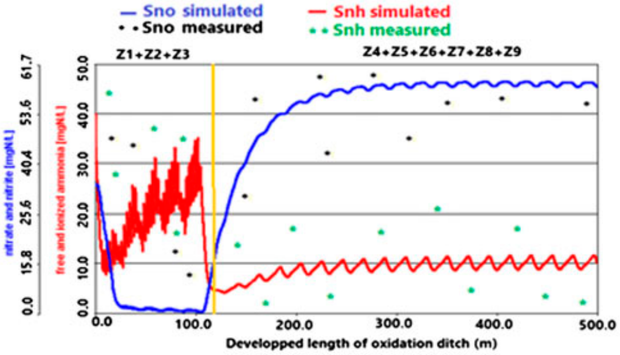

Fig. 8b. Nitrogen removal in the various zones.

The filamentous bacteria could be developed in the case of a significant reduction in DO with a high sludge age (about 20 d) [15]. Sludge volume index (SVI) tests have been performed two times at the end of the experiment and did not indicate the presence of such problems. The SVI values were 98 ml/g in the first test and 105 ml/g in second one. These values are similar to those measured by the operator. The SVIs

Table 4
Treatment efficiency with the new strategy

	COD (mg/L)			$N\text{-}NH_4$ (mg/L)			TKN (mg/L)		
Date	Input	Output	Treatment efficiency (%)	Input	Output	Treatment efficiency (%)	Input	Output	Treatment efficiency (%)
24 March 2014	1,352	85	94	44	5	84	58	11	81
25 March 2014	1,085	92	92	38	10	79	45	8	82
26 March 2014	938	88	91	48	10	88	55	10	82
27 March 2014	1,120	87	92	44	8	82	51	12	76
28 March 2014	987	85	91	37	6	84	48	9	81
29 March 2014	1,050	80	92	45	5	89	53	13	75

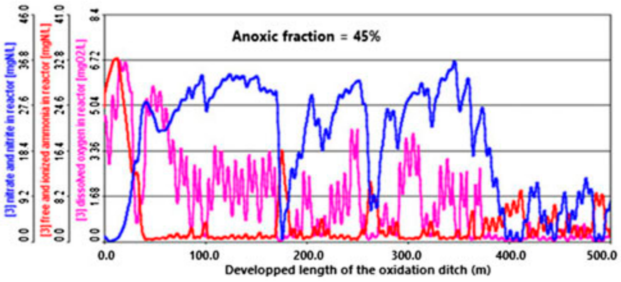

Fig. 9. Predicted ammonia, nitrate, and DO profiles in ditch.

are in a normal range. This result indicates that the extension of anoxic conditions did not reach the threshold which causes the appearance of filamentous bacteria. Microscopic investigations of the sludge have not been performed.

3.1. Strategy performance

Predictions of the effluent ammonium concentration based on controller airflow with ammonium and DO feedback as illustrated by Fig. 9 have shown to be rather efficient to the plant. These predictions are based on the nitrification rate (Eq. (5)) which describes the dependency on DO set points and by estimating the parameters r_{nit}, K_{NH}, and K_{OA} with simulation by ASM1 model. The optimization is based on the minimization of the difference between measured and simulated effluent ammonium concentrations.

The new strategy was tested on 24 d. The simulation results with ASM1 model can be seen in Figs. 9 and 10. Fig. 9 shows the simulation of the evolution of the ammonium, nitrate, and the DO in the ditch. By using the ASM1 model, we can decrease the oxic fraction from 66 to 55%, and increase the anoxic fraction from 34 to 45% (Table 3) thus saving energy.

Fig. 10 shows the fluctuation of the ammonium concentration between 0.2 and 11 mg $N\text{-}NH_4/L$. This variation could be explained by the fact that several processes influencing ammonium are not considered especially the ammonification, heterotrophic growth, and hydrodynamic in the oxidation ditch (a completely mixed reactor is assumed). The variation of the key parameters can be seen in Fig. 11, maximum removal rate (r_{max}) can be seen in Fig. 11(a), and the evolution of K_{OA} and K_{NH} can be seen in Fig. 11(b).

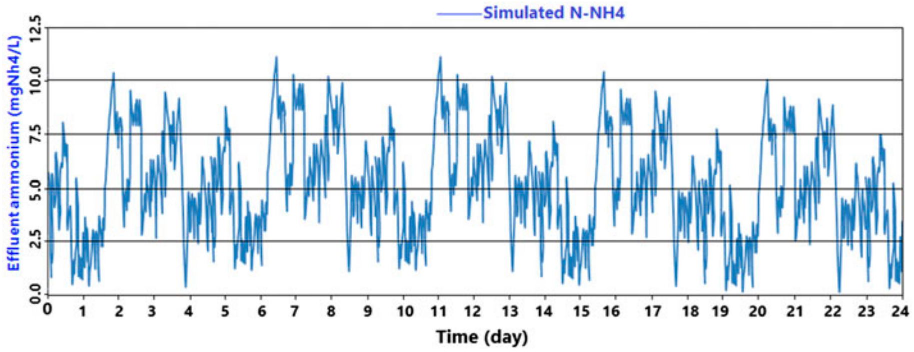

Fig. 10. Predicted of the plant performance based on the strategy controller airflow with ammonium and DO FFFB.

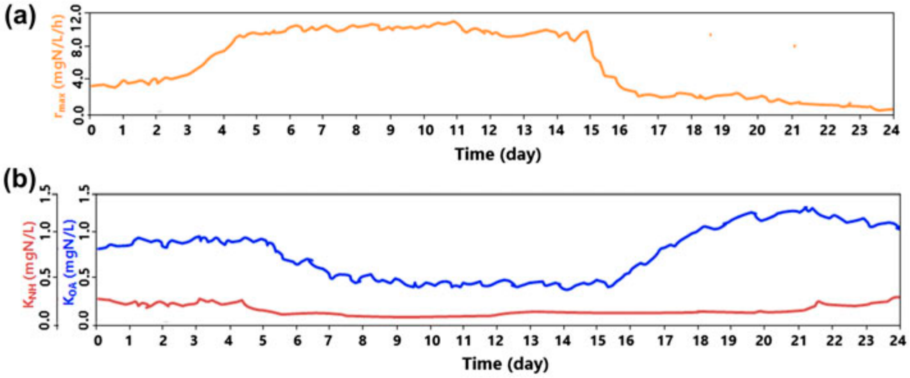

Fig. 11. Evolution of r_{nit} (a); K_{OA} and K_{NH} (b) based on the ASM1 model.

The parameters show relatively small variation, which indicate that the strategy is practically stable over the experimental period. The ASM 1 will be used to perform a simulation taking into account others parameters (ammonification, heterotrophic growth, etc.).

3.2. Savings

Since the strategy was tested in one line, it induces a reduction of the airflow of about 30% (4,500 Nm^3/h). The savings become substantial about 18,000 Nm^3/h when the strategy will be implemented to all lines of the plant. A reduction of the airflows of 30% corresponds to a yearly savings of approximately 125,000 $. Instrumentation costs are close about 38,000 $/year and maintenance costs are about 7,500 $/year.

4. Conclusions

A strategy controller of the airflow with ammonium and DO feedback control with online measurements of the ammonium load has been proposed and tested in a full-scale plant over 6 d. Preliminary results show that the suggested strategy can lead to a decrease in the DO concentration during large parts of the day. It can save 30% of the airflow and improve effluent quality.

Simulation results over 24 d indicate that the strategy is practically stable and can be implemented to the plant.

This work shows that the setup of online instrumentations is critical for real time response to the load changes. The benefit of online instrumentation is substantial compared to intensive sampling and analysis.

The results of this experiment could be an opportunity to install nitrogen sensors for online measurements of the ammonia and DO concentrations in the existing and future Tunisian WWTP.

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