Process control automation and remote on-line supervision: the strategy for wastewater treatment in an Italian piedmont

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ABSTRACT

The paper deals with the real application of a strategy, based on process control automation and remote on-line supervision, for the wastewater treatment in a piedmont. Seven existing small wastewater treatment plants were selected to be upgraded and to be included into a network remotely supervised. A consolidated bending point based alternating process was applied for the biological treatment. Further, the potentialities of the process control automation were enhanced by the appropriate design of the whole plant. The examination of a case study included into the network shows the real stable high performances of the plant in terms of total nitrogen removal. Moreover, the power requirements are significantly reduced according to a correct energy policy.

Key words | design strategy, full scale, piedmont, process control automation, wastewater treatment

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INTRODUCTION

At the moment, more than 6,000 wastewater treatment plants (WWTPs) with treatment capacity under 10,000 population equivalent (PE) are operating in Italy (APAT 2005). The debate on the destiny of these structures is of great topicality. In fact both the scientists and the policy-makers are divided between those who want to dismiss these plants and those who prefer the decentralised treatment in small systems, retrofitting the existing facilities, if possible. However, in mountain or in remote areas the first option is often not viable. Here, in fact, the low density of population and the nature of the territory make difficult the construction and the following maintenance of long sewers system and, consequently, the collection to large WWTPs. Therefore, in these cases the choices of the policy makers are addressed towards the most suitable technologies which allow the minimization of the costs, keeping

anyway high the quality standard of the treated effluents, so to meet the recent law limits and environmental needs.

Designing small plants in rural or remote areas require three main peculiarities: (1) easy operation and maintenance (O&M); (2) low capital and operating costs; (3) enhanced nutrient removal capacity. These guidelines can be implemented by remote controlling and process control automation (Hong *et al.* 2005). The automatically controlled alternate cycles (AC) process (Battistoni *et al.* 2003a,b, 2007; Fatone *et al.* 2005) meets these guidelines and has widely proved their suitability for small communities.

In this paper the real case of the Cuneo province (north-west of Italy) is presented and discussed. In that area the public utility (ACDA) in charge of the water and wastewater treatment and management decided to upgrade its existing small treatment systems, so as to improve the quality of

the service to the citizens and for the environmental protection. Two main criteria have been adopted to carry out this renovation: process control automation and remote on-line supervising. The paper is structured according to three main parts: firstly the characteristics of the small plants included into the network are outlined; then the strategies for the upgrading are described and discussed; finally the operation of a real plant included in the network is briefly illustrated in order to show the results achieved following the before mentioned strategy.

MATERIALS AND METHODS

The network of small plants

The ACDA is in charge of the management of 87 plants for 47 municipalities and an overall resident population of 158,700 inhabitants. The density of population in these zones is low and people are used to live in small towns that have their own wastewater systems. In 2005 ACDA selected 7 existing small WWTPs to be upgraded by the alternate cycles process and be included into a network remotely supervised from the Cuneo headquarter. The sources of wastewater in the catchments areas are mainly municipal, but in some cases also industrial wastewater from small local factories are discharged into the sewers system (Table 1).

Besides the Cuneo province, this scenario can well represent numerous places where small industries, sometimes with seasonal productions, are spread on the territory

and rely on the municipal facilities for the treatment of wastewater and non hazardous liquid wastes. In consequence of these features, the influent variability/fluctuation is high and needs processes flexible enough to guarantee always high removal performances.

The structures of hardware and software

The aeration of the biological reactors of all the WWTPs has been, or is going to be, upgraded adopting alternate cycles system. Further, the hardware for a plant-wide control is included in the upgrading operations. Therefore, the hardware structure is organized into two levels: the first controls the alternate cycles process; the second regulates the utilities used for the biological process.

In particular, the first level of hardware concerns the installed on-line signals (dissolved oxygen (DO) and oxidation reduction potential (ORP) used to manage the intermittent aeration. The analog signals (4–20 mA) are transferred to the analog-digital (A/D) converter and then sent to the industrial PC (called "node card"), which is connected with the second level hardware. On the other hand, the second level hardware manages the electro-mechanics employed by the alternating process. Principally, this second level guarantees the switching on of the blowers in the aerobic phase, contemporary to the switching off of the submerged mixers, and vice versa in the anoxic phases.

According to the alternate cycles (AC) automatic control algorithm (Battistoni & Chemitec 1999), the intermittent aeration of the bioreactor is automatically controlled through a strategy based on the control of bending points in the on-line profiles of dissolved oxygen (DO) and oxidation reduction potential (ORP) (Wareham *et al.* 1993; Zipper *et al.* 1998). Aeration is switched off (and submerged mixers are switched on) when the ammonia break point is detected, and is switched on when the nitrate flex is detected. In this way, the lengths of the aerobic and anoxic phases are controlled to be just sufficient for complete nitrification and denitrification, respectively. However, the bending points are not always easy to be identified. Ammonia break point on the ORP curve appears only when the DO is subject to a sharp rise from a low level to a significantly higher one at the end of nitrification. Similar difficulties may also be found with DO bending points

Table 1 | Plants included into the network

WWTP Town	Road distance WWTP-Cuneo (km)	DWF* (m³ d⁻¹)	LCOD municipal (kg COD d⁻¹)	LCOD industrial (kg COD d⁻¹)
Garessio	78	9,500	1,800	840 (47%)
Ceva	49	1,200	720	0 (0%)
Beinette	10	1,860	480	264 (55%)
Busca	17	2,100	720	120 (17%)
Centallo	15	2,140	648	120 (19%)
Dronero	19	2,400	888	72 (8%)
Chiusa di Pesio	15	833	336	0 (0%)

*Dry Weather Flow.

Table 2 | Setpoints included in the secondary branches of the algorithm

	Aerobic phase		Anoxic phase	
	MAX	MIN	MAX	MIN
DO	X	*	*	
ORP	X		*	X
Time-length	*	X	X	*

*Start the calculations
X Switch between aerated/non aerated phases.

(Olsson *et al.* 2005). Furthermore, Paul *et al.* (1998) demonstrated that bending points are not identifiable under particular conditions like over-aeration, under or over-loading, which can be almost common for real wastewater treatment system, especially for small treatment capacities. Finally, with a bending point based strategy, nitrification and denitrification come to their ends in the aerobic and anoxic phase, respectively. This is not necessarily an optimal strategy. For an intermittently aerated continuous system, high effluent ammonia and nitrate peaks may appear alternatively, resulting in high effluent nitrogen concentration, when the plant is over loaded with nitrogen. Therefore, the complete control algorithm has been provided with secondary branches which are based on setpoints of the time lengths of the aerobic and anoxic phases and of the absolute values of DO or ORP. These secondary branches represent a secondary safety level of the

automatic control and are initially set by simulations with the activated sludge model, then they are adjusted after the initial trials operations of the plant, so to reach the assessment which best fits the particular case study. Table 2 shows the setpoints which could be set to complete the automatic control of the process.

Besides the time-length set points which are usually set on the basis of the actual nitrification and denitrification rates (determinable by respirometry tests) and the process simulations, for the initial DO and ORP set-points some usual choices are made on the basis of the influent characteristics and their relation to the biological process (Table 3).

Furthermore, the blowers are equipped with frequency regulator in order to adjust the air supply to the actual influent demand, according to the fluctuations of the influent loadings.

Although the control algorithm can dispose of different safety levels, a software that can validate its reliability has also been engineered and installed in the full scale plants. It carries out the statistical analysis of all the cycles performed and gives, as output, both the end-reason (bending point detection, DO or ORP or time setpoint) for the phase-switch and the lengths of the phases (average, minimal, maximal) (Battistoni *et al.* 2003*a,b*). This software is used, besides the classical mass balances, to make a detailed

Table 3 | Usual initial choices for the main setpoints

	Plant under-loaded		Plant over-loaded	
	MAX	MIN	MAX	MIN
DO aerobic phase	6–7 mg/L (reason: oxygen saturation levels may be reached before the ammonia exhaustion)	0.3–1 mg/L	3–4 mg/L (reason: these values can be reached only in night-times, when the loading is lower)	0.3–1 mg/L
ORP anoxic phase	100–250 mV (reason: the ammonia breakpoint may occur in a wide range of ORP)	−50– −150 mV (reason: the nitrate knee may occur in a wide range of ORP, but the cycles are rather high)	0–100 mV	~ −200 mV (reason: the denitrification can be very fast and low ORP may occur before the nitrates exhaustion)
Time-length	According to actual nitrification and denitrification rates		According to actual nitrification and denitrification rates	

diagnosis of the process behavior so to, eventually, adjust the setpoints or intervene directly on site.

RESULTS AND DISCUSSION

Design strategies and process control automation

Process control automation is really effective only if coupled to the appropriate design of the whole treatment system. Following some important design features are outlined.

As for the selection of the biological processes, all the plants operate the automatically controlled alternate cycles process preceded by a metabolic-based anoxic selector according to a up/down flow, that disadvantages the growth of filamentous bacteria especially with low temperature of the liquor and does not need any electro-mechanics for the mixing. The AC bioreactor can be obtained in a number of tanks types (squared, rectangular, ring-like) which is a peculiarity of great importance for retrofitting existing plants. Since different tank shapes involve different reactor configurations (one to n-CSTRs in series), it is important to know the behaviour of the alternating processes under these conditions. With concern to this topic, both empirical full scale evidences and ASM2d simulations proved that the exhaustion of ammonia or nitrates can occur in diverse CSTRs, depending on the actual influent loadings. To be effective this alternating process needs as many couples of sensors (DO-ORP) as the number of CSTRs assumed in the bioreactor. This is why at present the process control by expensive on-line nutrient sensors/analysers is not convenient, while indirect parameters (such as DO,ORP) should be preferred.

Basically, the design tried always to recover the existing structures, so to reduce the investment costs. Moreover, as for the flow-scheme, the following main criteria were used to guarantee the maximal efficiency and flexibility of management in case of ordinary and/or extra-ordinary maintenance: (1) inflow divider before the bioreactors, so to have exactly the same influent loadings to all the treatment lines; (2) biological process composed at least of two equal separate lines; (3) gradient distribution of the air diffusers in order to adequate the air supply to the demand (Fatone *et al.* 2006); (4) one secondary clarifier per biological line, large enough to guarantee the treatment of all the influent flowrate. Furthermore, in order to optimize also the power requirements: (1) frequency regulator and low specific power are used for the aeration systems; (2) much care is given to the possible infiltration of ground water into the collection system. Finally, the inexpensive and consolidated on-line sensors are installed to control and supervise the process.

The cited guidelines are also inferred from Table 4 where the main characteristics of the plants included into the network are reported.

From Table 4 it is important to point out also that the AC process can operate with a low specific tank volume ($68 - 131$ L capita^{-1}).

The on-line parameters were chosen to obtain the best on-line control of the process, anyhow according to reasonable investment costs and the low frequency of maintenance (cleanings, substitution of consumables, etc.). Table 5 shows the on line sensors installed into the plant.

From Table 4 it can be observed that: (1) DO and ORP are necessary to control the AC process and can indirectly give a

Table 4 | Main characteristics of the plants included in the network

WWTP	Treatment lines n	AC tank (m³)	Secondary settler (m³)	Specific tank volume (L capita^{-1})	Specific flowrate (L capita-1 d^{-1})	Specific power for AC tank aeration (W capita^{-1})
Garessio	2	2,300	1,570	105	432	5.0
Ceva	1	410	634	68	200	5.0
Beinette	2	812	920	131	300	4.8
Busca	2	813	1,130	116	300	6.3
Centallo	2	636	589	99	334	4.7
Dronero	2	910	1,049	114	300	4.5
Chiusa Pesio	1	285	690	102	298	5.4

Table 5 | On line sensors and meters installed into the plants

	AC bioreactor			WAS		Other on-line parameters	
	DO	ORP	MLSSAC	Qw	MLSSWAS	Q$_{in}$	Q$_{out}$
Garessio	x	x	x	x	x	x	x
Ceva	x	x	x	x		x	x
Beinette	x	x	x	x	x	x	x
Busca	x	x	x	x	x	x	x
Centallo	x	x	x	x		x	x
Dronero	x	x	x	x	x	x	x
Chiusa di Pesio	x	x	x	x		x	x

lot of information about the influent loadings and its biodegradability; (2) besides the influent and effluent, also the waste activated sludge flowrate is measured; (3) the MLSS are installed always into the AC bioreactor. In larger plants, also the MLSS into the waste activated sludge withdrawn from the secondary clarifier is measured to have a real control of the sludge age without any modification of the existing piping (i.e.: the facilities to waste the excess sludge remained in the outflow from the secondary clarifier).

In terms of treatment management, the operators can control the plant from their headquarter and can have, directly from the on-line curves of the parameters, gross information on the influent loadings and the behaviour of the process. This is fundamental especially for small treatment systems operating in remote areas. Here, in fact, unauthorized discharges from local small factories may occur and these events are very hard to be identified under a irregular and non on-line control of the plant. Otherwise, the only observation of the on-line signals can allow to know periodic singular events and to take adequate countermeasures. Besides the direct monitoring of the on-line profiles, the analysis of the performed cycles according to the software described in the materials and methods is used both to have a detailed remote diagnosis of the state of the treatment and to evaluate the reliability of the control performed.

Garessio WWTP: an example from the network

The Garessio WWTP is included into the ACDA network. This plant has been upgraded according to the before
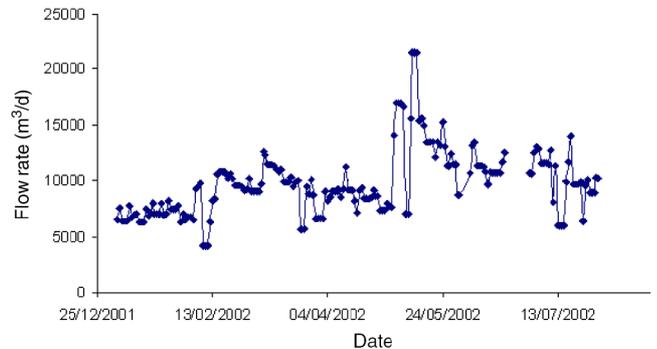
Figure 1 | The flowrate influent to the Garessio WWTP.

mentioned strategies and has been started up in April 2006. This case study is of particular significance because it is characterized by a number of particular conditions such as the high infiltration of groundwater in the sewers system and the remarkable fraction of the influent loadings coming from an industrial source. As a result, the influent flowrate is very fluctuating (Figure 1) as well as the mass loadings. Hence, a very flexible process control is required.

The operation of the Garessio WWTP is discussed taking into account two main evidences: the removal performances of the process and the statistical analysis of the cycles performed, which gives information on the real detection of the bending points (optimal condition) or the intervention of the setpoint branch of the control algorithm. Both the cited approaches contribute to evaluate the reliability of the design and control strategies.

As far as the removal efficiencies, Figure 2 shows the total nitrogen (TN) removal before and after the plant upgrading. After the upgrading, the quality of the effluent
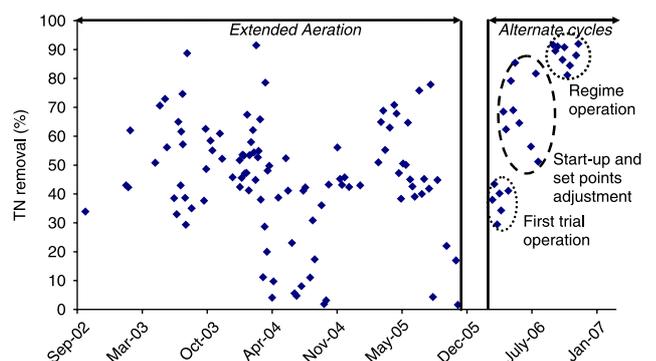

Figure 2 | Total nitrogen removal.

Table 6 | Results of the statistical analysis of the alternate cycles

		Aerobic phase End-reasons			Anoxic phase End-reasons		
	Cycles *n*	Bending point (%)	DO-ORP setpoint (%)	Time-max (%)	Bending points (%)	ORP setpoint (%)	Time-max (%)
Trials operation	54	54	1	45	56	36	8
April	95	95	1	4	96	3	1
May	93	93	6	1	99	0	1
June	81	81	17	2	95	4	1
July	66	66	28	6	91	9	0
August	93	93	6	1	96	4	0

improved clearly as shown in Figure 2, where the outflow total nitrogen over four years operation is reported.

Figure 2 shows that, after the initial trials operation, a stable high quality of the effluent was achieved, so to prove the efficiency of the upgrading strategy in such a difficult case. Moreover, thanks to the alternate cycles process that is characterized by nitrates denitrification higher than the conventional processes, energy savings of about 35% were achieved thanks to the better exploitation of the oxygen linked to the nitrates for the anoxic biodegradation of the organic matter. In fact, the power requirements passed from 1,000 to 650 kWh per day. Considering the whole network examined in this paper, the overall energy saving is estimated in at least 2000–2500 kWh per day.

As for the validation of the control system, 482 cycles performed over six months operation were analyzed finding out which branches of the control algorithm intervened to switch from the aerobic to the anoxic phase and vice versa. The results of these analyses are reported in Table 6 and can be used to explain the methodology used for the remote diagnosis of the treatment.

From Table 6 one can easily observe that the setpoints were fairly adjusted after the initial trials operation (lasted about 10 days), when the maximal length for the aerobic phase was too low for the detection of the ammonia breakpoint, and needed to be increased, as well as the minimal ORP for the anoxic phase was too high, and needed to be lowered. After the trials operation the system was able to detect the bending points and contemporary the quality of the effluent improved (see Figure 2). Singular events occurred in June and July because of the over-aeration of activated sludge, anyway the denitrification and the removal of total nitrogen was optimal. This demon-

strates the long term reliability of the control device and how a remote supervisor can on-line check the process behaviour and optimize performances and costs simply changing the setpoints.

CONCLUSIONS

Process control automation and remote on-line supervision were applied to manage and monitor the wastewater treatment in an Italian piedmont. Seven existing small wastewater treatment plants were selected for the upgrading and to be included into a network. The upgrading was carried out coupling the process control according to a bending point based alternate process to the appropriate design of the whole plant. To date, the network has been designed and in few years all the plants will be started up.

The first plant, started up at the beginning of 2006 after the up-grading, gave very important results in terms of improvement of the total nitrogen removal. To date the plant can reach the limits for discharge in sensitive areas. At the same time, the energy consumptions of the plant decreased of about 35%.

Considering the whole network, the effluent quality is expected to reach high standard as already shown from the case study. At the same time, the overall power requirements will be reduced at least of 2000–2500 kWh per day.

REFERENCES

APAT 2005 Guida per l'adeguamento, miglioramento e razionalizzazione del servizio di depurazione delle acque di scarico urbane. *In Italian*.

Battistoni, P. & Chemitec 1999 Metodo e dispositivo di controllo di un processo di trattamento biologico, a cicli alternati, di acque reflue. Italian Patent N° NR99A000018.

Battistoni, P., De Angelis, A., Boccadoro, R. & Bolzonella, D. 2003a An automatically controlled alternate oxic-anoxic process for small municipal wastewater treatment plants. *Ind. Eng. Chem. Res.* **42**(3), 509–515.

Battistoni, P., Boccadoro, R., Bolzonella, D. & Marinelli, M. 2003b An alternate oxic-anoxic process automatically controlled. Theory and practice in a real treatment plant network. *Water Sci Technol.* **48**(11–12), 337–344.

Battistoni, P., Fatone, F., Passacantando, D. & Bolzonella, D. 2007 Application of food waste disposers and alternate cycles process in small-decentralized towns: a case study. *Water Res.* **41**(4), 893–903.

Fatone, F., Bolzonella, D., Battistoni, P. & Cecchi, F. 2005 Removal of nutrients and micropollutants treating low loaded wastewaters in a membrane bioreactor operating the automatic alternate-cycles process. *Desalination* **183**, 395–405.

Fatone, F., Battistoni, P., Pavan, P. & Cecchi, F. 2006 Application of a membrane bioreactor for the treatment of low loaded wastewater for water re-use. *Water Sci. Technol.* **53**(9), 111–121.

Hong, S.-W., Choi, Y.-S., Kim, S.-J. & Kwon, G. 2005 Pilot testing an alternative on-site wastewater treatment system for small systems and its automatic control. *Water Sci. Technol.* **51**(10), 101–108.

Olsson, G., Nielsen, M. K., Yuan, Z., Lynggaard-Jensen, A. & Steyer, J. P. 2005 *Instrumentation, Control and Automation in Wastewater Systems.* Scientific and Technical Report No. 15. IWA Publishing, London.

Paul, E., Plisson-Saune, S., Mauret, M. & Cantet, J. 1998 Process state evaluation of alternating Oxic–Anoxic activated sludge using ORP, pH and DO. *Water Sci. Technol.* **38**(3), 299–306.

Wareham, D. G., Hall, K. J. & Mavinic, D. S. 1993 Real-time control of wastewater treatment systems using ORP. *Water Sci. Technol.* **28**(11/12).

Zipper, T., Fleischmann, N. & Haberl, R. 1998 Development of a new system for control and optimisation of small wastewater treatment plants using oxidation reduction potential (ORP). *Water Sci. Technol.* **38**(3), 307–314.