EOLI ICA4-CT-2002-10012
Efficient Operation of Urban Wastewater Treatment Plant

REPORT ON FIELD-SCALE PERFORMANCE OF THE ADAPTIVE OPTIMAL CONTROL LAW

Deliverable 5.2

Deliverable Type: Report
Number: D5.2

Contractual Date of Delivery: T_0+30
Actual Date of Delivery: 20.Dic.2005

Tasks WP5-Control design&application: WP5.3-Control law validation, WP5.4-Proc.improvement eval.
Responsible: Jaime A. Moreno (UNAM)
Involved partners: UU, LBE-INRA and UNAM

By Jaime A. Moreno and Manuel J. Betancur
Insitute of Engineering (iiNGEN)
Universidad Nacional Autónoma de México (UNAM)
Ciudad Universitaria, 04510, Coyoacan, Mexico D.F.
Emails: JMorenoP@iingen.unam.mx, MBetancurB@iingen.unam.mx
Djalel Mazouni and Jérôme Harmand
Laboratory of Environmental biotechnology (LBE)
Instit. National de la recherche agronomique (INRA)
LBE INRA 11100 Narbonne, France
Emails mazouni@ensam.inra.fr, harmand@ensam.inra.fr

Abstract: This report describes the validation and the improvement assessment of the control laws designed for the WWTP models EM1 and EM2. Special attention is given to experimental results and their relation to the potential impact of the improvements in economic-related variables as Treatment time, Daily applicable load, Energy consumption, Air consumption and Tanks size.

Keywords: Activated sludge WWTP, Sequencing Batch Reactor (SBR), Optimal control

Table of Contents

1. Introduction

In this project, three types of wastewater are considered. The first one coming from a dairy industry, contaminated with organic carbon components as well as nitrogen, the second typical for an area including chemical industry, containing toxic or recalcitrant compounds, the third one a domestic wastewater which occasionally contains toxic or organic overloads. To model the problem it was agreed to use two models: the first one (denoted as EM1: EOLI Model 1) is dedicated to the carbon removal process, and the other one (denoted EM2) is dedicated to remove carbon and nitrogen (involving nitrification/denitrification). The EM1 deals with the wastewater treated by UNAM and IBTech; while the EM2 is related to the WWTP for the following partners: UU, LBE and POLIMI (+ENEA as subcontractor).

Previous deliverable D5.1 reports the Time Optimal Control laws designed for each of the EM. Now this deliverable (D5.2) reports the experimental validation and the assessment of the process's performance increase. Chapter 2 is devoted to EM1 and chapter 3 to EM2.

2. Time Optimal Control for EM1-type processes

2.1. *Methodology*

The EM1 process and its Event Driven Time Optimal Control (EDTOC) are described in deliverable D5.1. The experiments used to analyze process improvements and validation when using such EDTOC for the EM1 are described in WP1 reports. The experiments were done using a 7L lab-scale SBR (UNAM-01 in Fig. 1) following the standard conditions agreed in EOLI Mexico meeting (May 8th 2003). This means that the SBR was acclimated to such a standard conditions and operated continuously (iteratively) in Fixed Time Control

(FTC) mode before specific EDTOC experiments were done, i.e. every time an EDTOC experiment was done the reactor was assumed to be in the standard conditions.

Figure 1. UNAM-01 Lab-scale (left) and UNAM-02 Field-scale (right) SBRs

After an individual EDTOC batch experiment was finished the SBR was put again to work in standard FTC mode. The FTC batch previous to the EDTOC experiment, and the one following it, are called the "Before" and "After" kinetics, respectively. These are used to evaluate the impact and the SBR's performance changes produced by the EDTOC batch.

The amount of successfully performed experiments constitutes itself a practical validation for the EDTOC. At least three dozens of standard EDTOC kinetics were performed by WP1. Not a single time the EDTOC behaved badly, moreover it behaved as theoretically expected.

Additionally to the Standard condition EDTOC experiments, a series of SHOCK experiments was done by WP1. There the influent's toxicant concentration $S_{C,in}$ was raised, as if an unknown perturbation, to some high peak value. Such value was measured for calculation purposes but was not fed to the EDTOC algorithm, that is, it was unknown to the controller. In order to compare the performance increase and the ability to reject such a perturbation, some benchmark was needed. Unfortunately the competing FTC is not able to cope with such Shock peak loads because it lets the SBR to get strongly inhibited, or even disabled, for input concentrations in excess of 3 times the standard one (Buitrón *et al*., 2005), so the alternative was to compare the total time needed, by each strategy, to degrade the same (known) amount of known toxicant mass. This means that the perturbation is no longer an unknown perturbation for the FTC but a known parameter, so the operator dilutes the toxicant appropriately, i.e. before feeding the SBR, in order to meet the FTC standard conditions. Of course various successive **standard** FTC batches would be needed to degrade the same amount of toxicant that the EDTOC may degrade in a single **long** batch (see Fig 2).

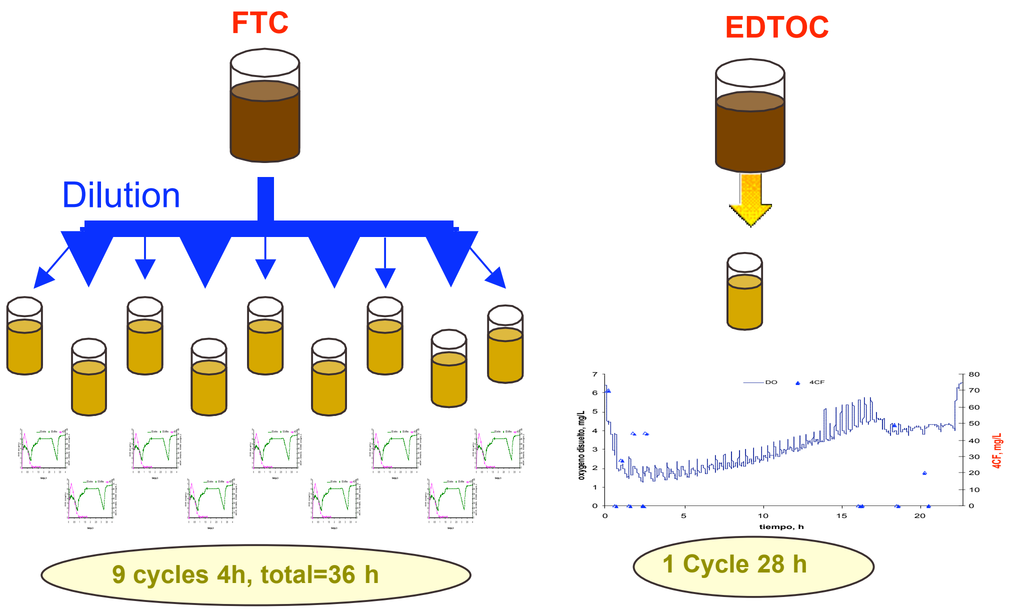

Figure 2. Dilution needed in order to compare EDTOC Vs.FTC degrading the same amount (12g) of 4CP

Long term EDTOC experiments, that is to run the SBR under EDTOC strategy continuously (iteratively), to assess biomass impact (activity, settling, ..), are in progress by WP1.

A second, field-scale SBR (UNAM-02 in Fig. 1) is under construction, now almost finished. Once IBTech delivers it to UNAM then WP1 plans to perform experiments to scale the SBR-UNAM-01 lab-scale results to field-scale ones.

2.2. *Results and Discussion*

The EDTOC strategy was validated both in simulations (using EM1 delivered by WP2 using WP1 data) and experimentally (using experiments performed by WP1). No stability problems were ever encountered when standard conditions for the experiment were kept.

WP1 results show an important reduction in treating time (almost -50%), meaning that, for a given daily load rate, it is possible to design smaller, more economical, SBRs or, equivalently, that more toxicant mass can be treated per time unit in a given size SBR. It also means that less energy in stirring and air pumping is needed. Additionally good robustness to unknown influent's perturbations, i.e. toxicant concentration shocks (high peak unknown values), was verified (in excess of twenty times the standard or, equivalently, +20000%).

Figure 3 show the typical kinetics, for a single batch, using the standard 350mg4CP/L influent's toxicant concentration, under the two different control strategies.

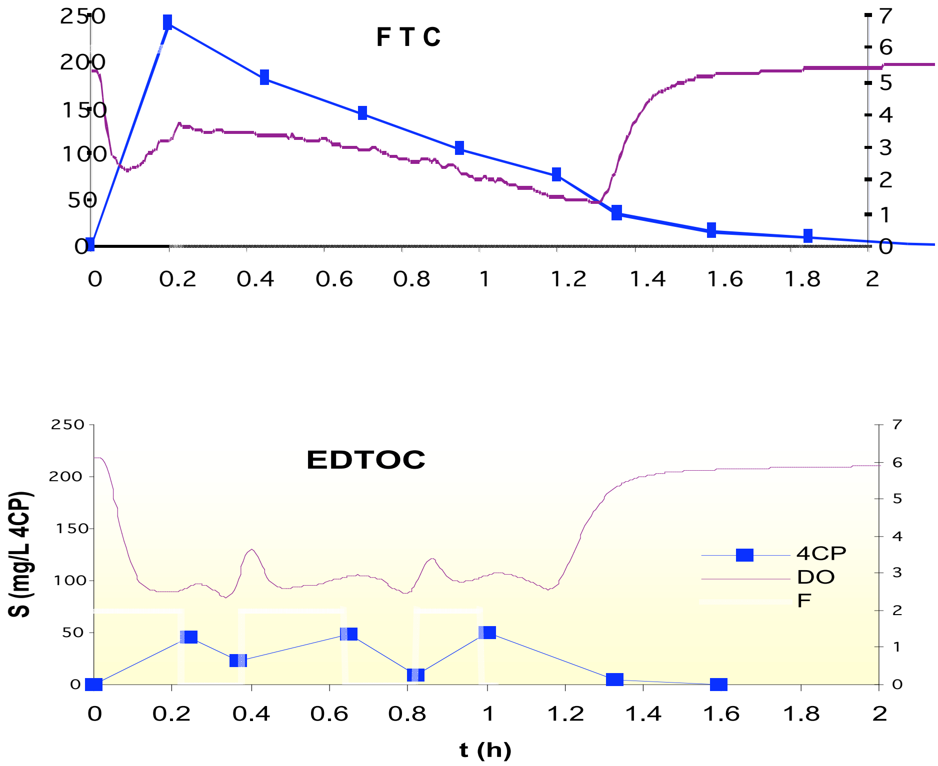

Figure 3. Typical Standard kinetics for degrading 4L of 350mg4CP/L: Only the fill&react phases are shown.
a) FTC: Fixed Time Control; b) EDTOC: Event Driven Time Optimal Control

2.2.1 **Reaction time**

Fig. 4 compares the total treating time needed to degrade 4L of influent to the given 4CP concentration, where 350 mg4CP/L is considered as the standard one. For the FTC pre-dilution was needed in order to obtain the most effective treating time possible. Without pre-dilution the FTC can not treat concentrations in excess of three times the standard one (treating time goes to infinity), while the EDTOC was able to treat twenty times the standard concentration without problems. Time saving is about (almost) 50%.

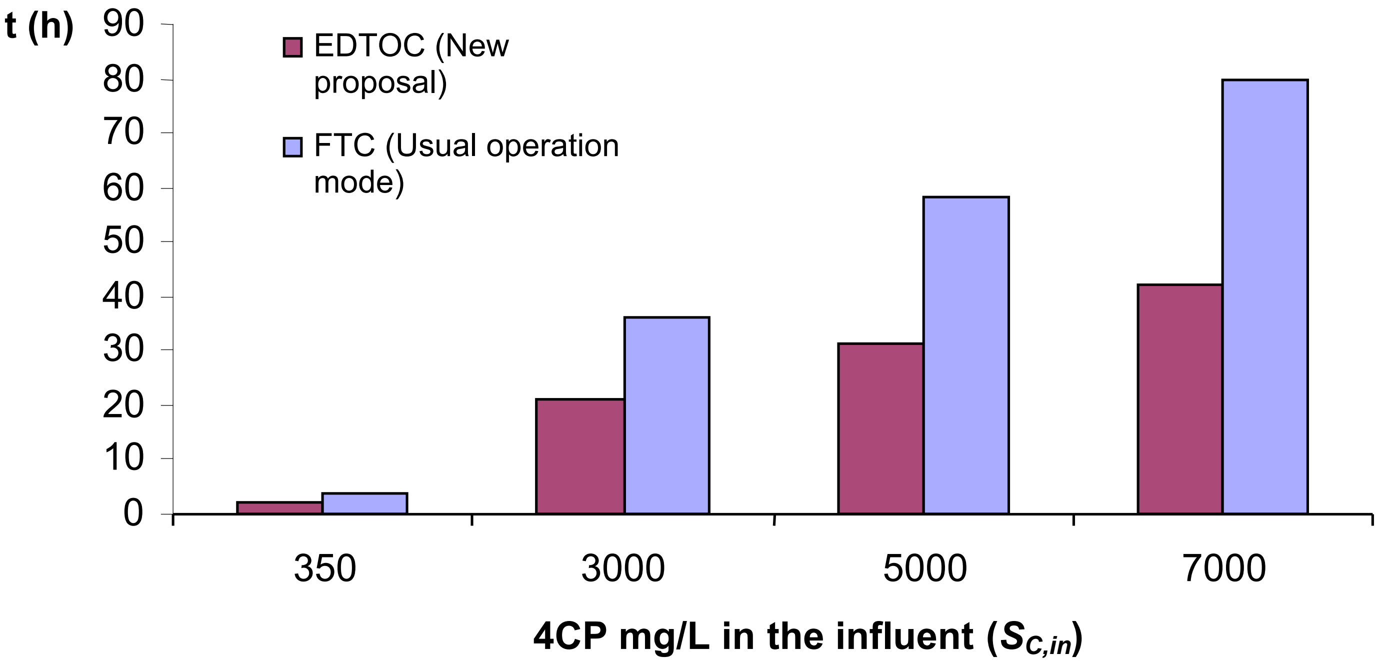

Figure 4. Total treating time Comparison for standard (350 mg4CP/L) and Shock conditions

2.2.2 **Applied load**

As a consequence of the time near optimality attained by the EDTOC an increment in the SBR's applicable load seems to be possible. Assuming long term studies produce no restrictions to operate the SBR in EDTOC mode continuously the Table 1 gives an idea of the potential increment for a given size SBR. This means that facilities already built, and currently running in FTC mode, may be upgraded with the addition of a couple of sensors (Dissolved Oxygen and Volume level) and an EDTOC controller. The potential savings, not requiring new additional WWTP facilities, for an increasing load demand are self explicatory.

Table 1. Increment in daily applicable load, comparing EDTOC Vs.FTC

$S_{C,in}$ 4CP, mg/L	Load, Kg COD/m^{3}d		Increment (%)
	FTC	EDTOC	
350	2.52	4.65	85
634		4.58	81
3000		4.11	63
5000		4.80	90
7000		4.77	89

2.2.3 **Air consumption savings**

As a consequence of the reaction time reduction attained by the EDTOC, savings in air consumption in excess of 25% are possible. Table 2 shows the potential savings.

Table 2.Savings in Air consumption, comparing EDTOC Vs.FTC

$S_{C,in}$ 4CP, mg/L	Air Volume ,m^3		Air Savings (%)
	FTC	EDTOC	
350	0.29	0.18	38
3000	2.63	1.98	25
5000	4.39	2.70	39
7000	5.85	3.87	34

2.2.4 **Stirring Energy Savings**

As a consequence of the reaction time reduction attained by the EDTOC, not only savings in air consumption are possible, but also a reduction in the energy necessary to stir the tank. Table 3 shows the potential savings, i.e. exactly the same as savings in air.

Table 3.Savings in Stirring, comparing EDTOC Vs.FTC

$S_{C,in}$ 4CP, mg/L	Energy Savings (%)
350	38
3000	25
5000	39
7000	34

2.2.5 **Shock load effects and perturbation rejection**

The standard toxicant influent's concentration was set as 350 mg4CP/L. For the FTC pre-dilution was needed in order to obtain the most effective treating time possible. Without pre-dilution the FTC can not treat concentrations in excess of three times the standard one as shows Table 4a. On the other hand the EDTOC was able to treat twenty times the standard concentration without problems (Table 4b).

Table 4a. Shock load response, using FTC, and effects in the posterior behavior of the SBR

Strategy	*4CP mg/L*	*q mg4CP/gVSS/h*	*q after experiment*	*Reference*
FTC	*350*	*53.2±15.7*	*no variation*	*this study*
	700	*34.4*	*37.5*	*Buitrón* et al., *2005**
	1050	*4.6*	*17.9*	
	1400	*0.9*	*total activity loss*	

Table 4b. Shock load response, using EDTOC, and effects in the posterior behavior of the SBR

Strategy	*4CP mg/L*	*q mg4CP/gVSS/h*	*q after experiment*	*Reference*
EDTOC	*3000*	*41.3±5.9*	*no variation*	*this study*
	5000	*49.1±0.7*		
	7000	*54.5±1.9*		

2.2.6 **Summary of Advantages and Disadvantages**

The FTC strategy does have the advantage of not requiring neither sensors nor computing equipment. A simple timer and a low-high volume-level detector will do. However its disadvantages are numerous:

- An expert should balance the risks to decide the time settings for the different phases of the SBR, as these settings are used to operate the reactor in open-loop mode for the standard conditions, i.e. without being sure that the control objectives are satisfied for every single batch, especially if the standard conditions are not exactly met.
- Even if standard conditions are satisfied the treating time is not optimal, i.e. it is bigger than the minimum time practically attainable.
- When higher than standard, inhibitory, concentrations are fed to the SBR the treating time increases more rapidly than linearly and, in fact, it tends to infinity when the biomass gets strongly inhibited. As a consequence there is no guarantee that the reaction, i.e. the most important phase of the WW treatment, is finished in the assigned time. This means there is the risk of delivering water, supposedly treated but, still containing toxicants beyond the acceptable level.
- Equalization tanks are needed in order to smooth out the eventual high peak concentration perturbations of toxicant that may arrive, from time to time, causing a Shock condition to the SBR.
- If a lower than the standard toxicant concentrations is fed then the wasted time is even bigger than in standard conditions, meaning also there is a waste in air consumption and in stirring energy. This also means that the SBR is sub-utilized because the reaction time is less than the fixed one given by the standard conditions, and with no sensors there is no way to know this is happening. A non desirable side effect is starvation. This means that the biomass will be more time deprived from food. Short term effects may not be important, but in the long run this may lead to deacclimation of the biomass, meaning that the SBR will no longer be ready to withstand a standard batch and perform as expected for such a standard condition.

On the other hand, the proposed EDTOC strategy needs instruments and a minimum computing capability. However, nowadays, the sensor technologies needed, i.e. Dissolved Oxygen and Volume level measurements, are mature, well proven, and have reached a cost/performance optimal level. Computing capability is no longer a problem either. The advantages of having such sensors integrated with the EDTOC are:

- There is no need for an expert to decide reaction times. The EDTOC control may know precisely when the reaction phase is practically finished even if other than the standard conditions are present.
- The treating time will be close to the minimum attainable time for every single batch in the standard conditions.
- When higher than standard, inhibitory, concentrations are fed to the SBR the treating time increases almost linearly and, in fact, the biomass never gets strongly inhibited. The EDTOC will take the necessary time, and only the necessary time, to guarantee that the reaction, i.e. the most important phase of the WW treatment, is finished. This means there is no risk of delivering water still containing toxicants beyond the acceptable level.
- Equalization tanks are not strictly needed, or their size may be greatly reduced, as peak inlet concentrations are fed to the reactor in such a way that no Shock is caused to the biomass.
- If a lower than the standard toxicant concentrations is fed then the treating time adjust accordingly, meaning there is no starvation nor waste in air consumption and in stirring energy.
- The EDTOC is robust to kinetic model parameters uncertainties. These parameters take no part in the solution, i.e. they are not needed by the controller. Even more, the EDTOC is robust against kinetic model structure uncertainties, i.e. the Specific biomass growth rate does not have to be close to the Haldane one. From Monod to any other model that does have a single unique maximum will do.
- The EDTOC is robust to yield model parameters uncertainties. These parameters take no part in the solution, i.e. they are not needed by the controller.

3. Time optimal control for EM2 type processes

3.1. *Methodology*

The EM2b was developed for UU and LBE SBRs. For these processes, three control strategies CS1, CS2 and CS3 (that can be combined together) were developed and tested on the LBE reactor. The first one (CS1), is a data-based approach that uses standard on-line industrial sensors. The second and third ones (CS2 and CS3) are model-based approaches that need a mathematical model as well as advanced sensors as those described in the Deliverable D5.1. Experiments for SBR improvement were carried out on the LBE pilot plant which has a working volume between 150 L and 200 L. Results are compared with the standard SBR conditions defined in the Deliverables of the Workpackage WP1.

For the evaluation, one has to distinguish between the "reaction time" and the "phase time" (effective total duration of the batch). The phase duration includes the reaction time which is not known a priori (but which can be roughly estimated if the load is approximately known) and an extra time to ensure that the reactions will be completely finished at the end of the phase time. In standard conditions, the phase time are fixed a priory by an expert with respect to the average values of the influent concentrations and the reactor volume.

The evaluation of the data-based approach (CS1) was realized by comparing the total phase time obtained with the standard mode (fixed phase time) and with the optimised mode (based on the data delivered by a set of standard industrial on-line sensors). The evaluation of the model-based approaches (CS2 and CS3) were done by comparing the effective reaction time with the standard total phase time using the standard mode (fixed phase time).

3.1.1 **First control strategy CS1**

It is well known that during the batch process reaction phases, significant information can be extracted from the dissolved oxygen, Redox and pH curves. The tracking of these process variables during batch operation presents some typical patterns that can be used to detect the end of the biodegradation processes. These patterns have a great potential for on-line control. The control strategy studied in the sequel consists in beginning by a given phase, for example by the anoxic phase, and then by detecting the "end of this phase" and thus to switch immediately to the next phase.

In the literature, monitoring methods for both nitrification and denitrification have been suggested, simply based on the patterns of DO, pH and ORP signals. (refer to D8.2 for details):

For the **denitrification process** the end-point of the reaction can be detected by:

1) the "nitrate knee" in the ORP profile

2) the "nitrate-apex" (i.e. the maximum), in the pH profile.

While for the **nitrification process,** the end-point can be detected by observing:

1) the "ammonia valley" in the pH profile

2) the bending point in the ORP profile

3) the "DO flex" or "break-point" that is the typical change in the slope of the DO profile.

In order to detect on-line these critical points, the on-line measurements of pH, DO and ORP are analysed. The switching from one phase to the next one is realized 5 minutes later than the effective point has been detected in order to insure that the point detected is really due to the end of the reaction and not to a noise in the measured signals.

3.1.2 **Second control strategy CS2 and CS3.**

The second and third control strategies are described in the Deliverable D5.1. Their first aim is to reduce the reaction time by modifying the batch sequences switching instants. Ideally, using on-line sensors, these control strategy could be applied in closed-loop and should give the best possible solution (obtain the minimal reaction phase in order to ensure that the actual concentrations in COD, ammonium nitrogen and Nitrite+Nitrate concentrations at the end of the batch operation are under the normative limits for these). In this case, given initial conditions of the batch, the idea is i) first to generate optimal trajectories and ii) second to track these optimal trajectories using the available on-line sensors. However, these strategies could not be actually implemented on-line (understand in closed-loop) because the sample times of the available advanced sensors (see the detailed descriptions of the developed hardware sensors in the Deliverables of the Workpackage 3) are greater than the gains in the reaction time it is expected to obtain when the control strategy is applied. It is why the actual evaluation of the effectiveness of CS2 and CS3 was rather done by comparing the reaction time using the model (theoretical reaction time using a validated model) and the ones obtained in practice using experimental data when the open-loop controls were applied instead of their closed-loop versions. The end of the reaction in the experimental case was detected off-line using a posteriori the DO profile. The second aim for these control methods was to maintain a high nitrification activity for long term functioning. This could be realized, as it was observed, by altering anoxic and aerobic phases.

In the case where the ratio C/N is not too high the optimal solution corresponds to the standard solution i.e. anoxic-aerobic and no optimisation is applied. However, there is a significative gain in applying the optimal solution as soon as the influent to be treated contains a large amount of nitrogen. In any case, the proposed solution is to decrease the volume treated per cycle and increase the number of cycles per day. The aim of this strategy is to alternate more quickly the aerobic and the anoxic phases. Instead of applying 2 long cycles with 25L of influent, 5 small cycles of 10L of influent were applied.

Two operation conditions were evaluated using the algorithm developed in the Deliverable D5.1 in order to evaluate two different cases:

1) A first operation mode with initial conditions where the optimal solution correspond to a sequence of aerobic-anoxic-aerobic. In this period two cycles per day were applied with 25 L of influent for each cycle.

2) A second operation mode consists to evaluate initial conditions such that the optimal sequence corresponds to a anoxic-aerobic phase. In this period 5 cycles where applied with 10L of influent for each one. The switching instants were determined using the optimal algorithm described in the Deliverable D5.1

Table5 comparison between the control strategies

Control	Phases sequences	Switching instances	Variable used	Comment
standard	(fill-Anoxic-aerobic)^2-settling	Fixed by operator	Time	Phases advised and fixed by an expert
CS1	(fill-Anoxic-aerobic)^3-settling	detected on-line	DO, ORP, pH	easy, simple and uses standard sensors
CS1	(fill-aerobic-anoxic-aerobic)^2-settling	Result from the optimization algorithm	COD, NO3, NTK	Altering aerated and not aerated phases
CS3	(fill-aerobic-anoxic)^5-settling	Result from the optimization algorithm	COD, NO3, NTK	Altering aerated and not aerated phases

The notation (fill-aerobic-anoxic)^n-settling means that the sequence between brackets is repeated n times.

3.2. *Results and Discussion*

3.2.1 **Results of CS1 strategy**

The control strategy CS1 was applied continuously during three weeks. During the first cycles, it was tested with the standard conditions. Then, the influent volume and the airflow rate were changed to test the reliability and the robustness of this method. During the last weeks, standard conditions were maintained to validate the control in the long term.

Some comparisons of the phase durations between standard operations and CS1 are given in the table 6. The first cycle and the last one are not controlled and the phase durations were fixed. In any case, the initial concentration of COD is about 700 mg/l. The reaction is considered to be finished if the concentration becomes less then 50 mg/l.

The first series of cycles worked perfectly. With the detection of the critical points, the total cycle time was reduced from 11 hours to less than 6 hours. In the outlet, the COD was consumed and the nitrogen converted into nitrates. The change of the initial conditions makes the reactions faster or slower. The switching instants depend on the end of the reaction which is easily detected with the above mentioned bending points.

Table 6 Phases duration comparison using CS1

Cycle	Volume (L)	Anoxic phase Duration	Aerobic phase Duration	Total cycle time reduction	Final Concentrations mg/l (CODs, NO2, NO3		
24-01-2004 standard	25	2 h	9 h		42	0	37
05-02-2004 CS1	30	32’	5h21’	53.5%	43	0	31
09-02-2004 CS1	25	25’	5h23’	49.7%	32	12	14
10-02-2004 CS1	27	31’	5h42’	56.5%	27	18	15
13-02-2004 CS1	24	22’	4h08’	40.1%	31	24	17

With this control strategy, it is clear that by decreasing the total cycle time the loading rate is increased (in other words, a greater volume of wastewater is treated per day). For long time application, this overload degrades the performance of the purification. In particular, as can be seen in table 6, the nitrification activity was degraded in the second and the third week. Some nitrates were detected even with a longer aerobic phase. In fact, because of the overloads, the Heterotrophic cells grow rapidly and the ratio between Heterotrophic cells and Autotrophic cells increases (which is equivalent to a washout of nitrifying organisms).

3.2.2 **Result of CS2 strategy**

The CS2 strategy was applied during three months from February 2005 to April 2005. Using the algorithm described in D5.1, the switching instants were computed off-line using the influent characterisation and the initial biomass concentrations. The phase durations were adjusted to be an entire value of the sampling time. In the following table a comparison between standard cycles and cycles with CS2 strategy is reported. The loading rate applied is about 1.2 kg COD/m^3/day while the VSS concentration is about 7±0.5g/L.

Table 7 Phases duration comparison using CS2

	Date	Anoxic time (min)	Aerobic time (min)	Total (min)
Standard	09/02/2005	32	390	422
	21/02/2005	35	410	435
	22/02/2005	30	400	430
CS2	23/02/2005	28	10+380	418
	24/02/2005	25	10+360	395
	26/02/2005	26	10+380	416
	27/02/2005	22	10+400	432
	28/02/2005	24	10+390	414

As it is shown in the table 7, the reaction durations are varying from one cycle to another because the influent concentration are not exactly the same from cycle to cycle. In order to compare the cycles before and after the use of CS2, only validated cycles of one month with standard operating mode and one month with CS2 are used. The result is given in the following table

Table 8 Average of reaction durations and time optimisation.

Loading rate average (Kg COD/m^3/day)	1.2
VSS average mg/L	7000±500
Initial CODs mg/L	4800±300
Initial NO3 mg/L	30±5
Reaction time: anoxic+aerobic (standard)	(32 ± 3) + (410 ± 15)
Reaction time: anoxic+aerobic (CS2)	(25 ± 3) + (390 ± 20)
Anoxic time reduction	13%
Total time reduction	4%

Globally, the average of the effective reaction time was reduced using CS2. The time reduction for the anoxic phase is around 13% while the total reaction time was reduced at only 4%. This happen because the long aerobic phase depends essentially of the nitrogen removal which is not eliminated in the anoxic phase. The anoxic reaction time is reduced by increasing the anoxic reaction rate. In fact, when enough carbon is available at the beginning, the first aerobic phase contributes to the NO3 production that increases the anoxic reaction rate.

3.2.3 **Result of CS3 strategy**

CS3 strategy was applied from the beginning of September 2005 and was adapted to operate the INRA SBR plant for all the time. At these operation conditions, the sub-optimal solution corresponds to a sequence of anoxic-aerobic as standard operation mode. The difference is that the switching instants are estimated using the model and validated using advanced sensors. After few days, the nitrification activity was increased significantly at more than 3 times. Improving the bacterial activities leads to minimize the reaction time.

Figure 5 presents the activities measured using TITAAN (hardware sensor developed within WP3) before and after the use of CS3. The loading rate was around 0.9kg COD/m^3/day and the VSS 5±0.5g/L.

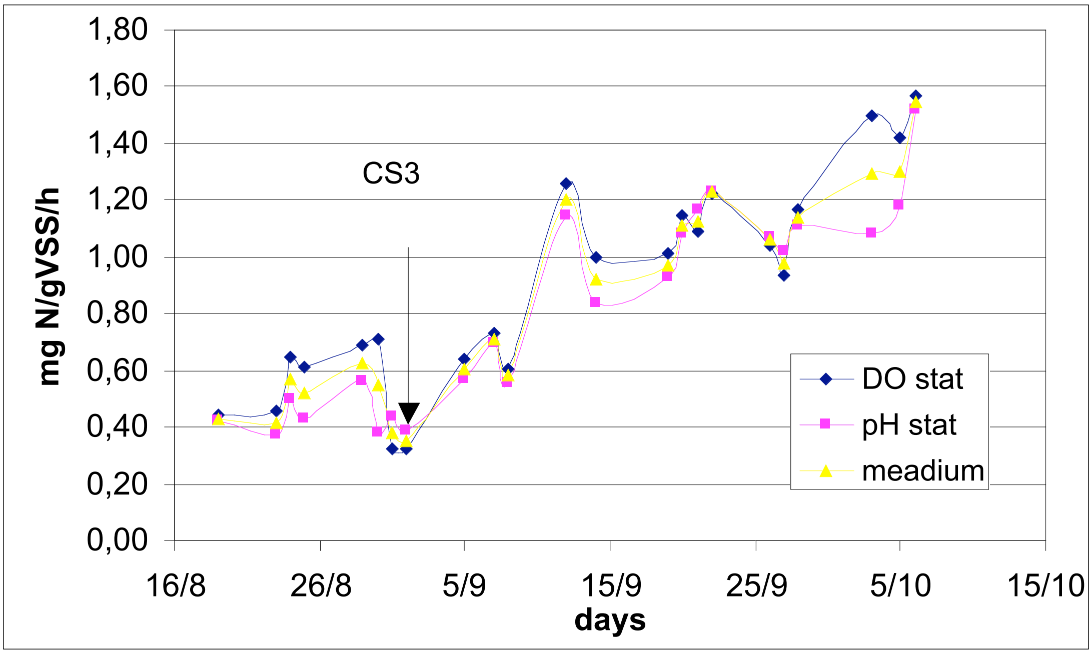

Figure 5: nitrification activity evolution before and after CS3 (measured using TITAAN)

3.2.4 **Summary of Advantages and Disadvantages**

Control laws	advantages	disadvantages
Standard operating mode	no advanced equipment used based on expertise and knowledge	high energy consumption because the reactors are oversized and not optimal does not take into account the influent characteristic variations
CS1	use of standard sensors does not need model and parameters energy and time optimisation possibility to increase the loading rate	critical points are not easily detected with noised data. Delay is generated by data filtration probes must be regularly calibrated.

		lost of nitrification activities with high loading rate
CS2	efficient for high initial concentrations (fast kinetics) minimize the reactions durations energy and time optimisation maintain nitrification activity high loading rate	Needs of mathematical model and parameters Needs advanced equipment : sensors and computing processors. needs enough carbon sources low nitrification activity but constant
CS3	long term effect are taken into account. Improve nitrification activity	need of mathematical model and parameters advanced equipments : sensors and computing processors. Low initial concentration : not global optimisation Limitation of the loading rate

Conclusions

The Event Driven Time Optimal Control (EDTOC) strategy developed solves the optimization criteria chosen for the EM1 problem and needs only sensors of well proven mature technologies. Moreover it is robust against model structure uncertainties and against uncertainties in most of the model parameters, specially the most uncertain ones. Treating time reduction of almost 50% was achieved compared to the Fixed Time Control mode, for various input toxicant concentrations, including Shock conditions as large as 20 times the standard one. As a consequence there is potential to increase Applicable Load, to reduce energy consumption and to avoid the need for big equalization tanks.

For EM2b processes, the optimization is done in two steps. Firstly, the phase durations are reduced up to the reaction duration. The gain observed with the average of the standard condition is about 50%. With the second strategy, the reactions are accelerated and the time gain estimated at about 5%. With combined strategies, the time reduction for one cycle can approach 55% when compared to the expert operation mode.

We observed for long term effect that high loading rate could decrease the nitrification activity and needs high energy for aeration. Alternating aerated and non aerated phases seems to increase and maintain the nitrification activity in the case where the loading rate is not to high. The suggested solution proposed is to optimize firstly the phases duration using the methods described in this deliverable. Then, increase the lording rate to fill the reduced time until the possible limit that saves the nitrification activities (in the INRA SBR case 1.2 KgCOD/m^3/day). Replace the remained optimized time by an Idle phase without aeration to save energy consumption used for aeration.

List of abbreviations

4CP	4-Chloro-Phenol
ASM	Activated Sludge Model
CESAME	Centre for Systems Engineering and Applied Mechanics
D1.x – D9.x	Deliverables
DO	Dissolved Oxygen Concentration
DSS	Decision Support System
EC	European Commission
EDTOC	Event Driven Time Optimal Control (New way to operate a SBR)
EM1, 2	EOLI Model 1, 2
EOLI	Efficient Operation of Urban Wastewater Treatment Plant
FDI	Fault Detection and Isolation
FTC	Fixed Timing Control (Traditional way to operate a typical SBR)
GRADIENT	Groupe de Recherches et d'Animations pour le Développement, l'Innovation et l'Enseignement en Technologie
INCO	International Scientific Cooperation Projects
INRA	Institut National de la Recherche Agronomique
LBE	Laboratoire de Biotechnologie de l'Environnement
OMUR	Oxygen Mass Uptake Rate
POLIMI	Politecnico di Milano
SBR	Sequencing Batch Reactor
SPES	Società di Progettazione Elettronica e Software
UCL	Université Catholique de Louvain
UNAM	Universidad Nacional Autónoma de México
UTC	Université Technologique de Compiègne
UU	Universidad de la República Oriental des Uruguay
WP	Work Package
WWTP	Wastewater Treatment Process

References

Buitrón G., Schoeb M.-E., Moreno-Andrade I. and Moreno J.A. (2005). Evaluation of two control strategies for a sequencing batch reactor degrading high concentration peaks of 4-chlorophenol. *Wat. Reserch*, **39**, 1015–1024.