EOLI
Efficient Operation of Urban Wastewater Treatment Plants

Deliverable D1.2
Report on evaluation of the process improvement with the application of the optimal control law: shock loads and the long-term stability of system (UU)

WP1. Process experiments
Responsible: Germán Buitrón (UNAM)
Involved partners UU

By
Adrián Ferrari (UU)
Soledad Gutiérrez (UU)

Contract Number ICA4-CT-2002-10012

Table of Contents

Report on evaluation of the process improvement with the application of the optimal control law: shock loads and the long-term stability of system

1. Introduction

This deliverable provides results of the evaluation of the process improvement with the application of the control strategy by the comparison with a non optimal (conventional) strategy and the evaluation of the influence of shock loads on the reactor stability for both optimal and non optimal strategies.

In a conventional strategy, step duration and sequence are fixed. A conventional strategy was evaluated for the operation of an SBR reactor treating dairy wastewater. A control law (CL) was developed by INRA and it is based on a phenomenological model. Result of this CL application for a target effluent quality gives a step time plan for a set biomass concentration and a known or measurable feed composition.

The optimal control law was implemented for a laboratory scale reactor. At UU, Reactor M fed with synthetic dairy effluent was employed to test the CL.

Standard reactor operation was characterized by an F/M ratio of 0.5 kgDQO/kgSSV/d. Shock load was performed by feeding the Reactor with more concentrated influent resulting in a F/M ratio of 0.75 kgDQO/kgSSV/d.

2. Methods

From March to July 2004, reactor M operated in order to acquire data for model calibration and validation, employing a set step time previously defined by Eoli protocol (set called **RM1**). Then, in order to establish the best operation achievable based on experimental knowledge under a conventional strategy, changes in operating conditions were successively evaluated. Experiences related with aeration required time, poor denitrification efficiency and microbial population dynamics were conducted. Finally, a new set of operating conditions called **RM2** was implemented.

The conventional strategy **RM2** under evaluation has been conducted (more than 120 cycles) before the implementation of CL, and after a re-inoculation of Reactor M allowing reaching its steady state which was practically completed in 3 weeks (42 cycles). Five standard conditions and three shock loads were evaluated by on line and off line measurements.

The CL was evaluated during 180 cycles, and in selected 5 cycles by off line measurements. The progresive plan carried out for the CL operation of the reactor was the following:

- Standard condition: 28 cycles.
- Shock load condition: 2 cycles.
- Standard condition: 26 cycles.
- Shock load condition: 1 cycle.
- Standard condition: 130 cycles

2.1 *Desirable effluent quality*

The following table defines the desirable effluent quality:

Parameter	Set point
COD (mg/l)	200
TKN (mg/l)	10
NOx (mg/l)	5

Table 1 - Set points for effluent quality

2.2 *Conventional strategy*

Typical strategy employed for SBR operation before control law implementation is described in the following diagrams (Table 2 and Figure 1). The mean biomass concentration during this period was 1000 mg/l:

Stage	Duration
Anoxic Fill	~ 10 min.
Anoxic	~ 50 min.
Aerobic	6 hours
Settle	1 -2 hour
Draw	~ 10 min.
Idle	~ 2-3 hours 50 min.

Table 2.- Conventional strategy cycle phase duration

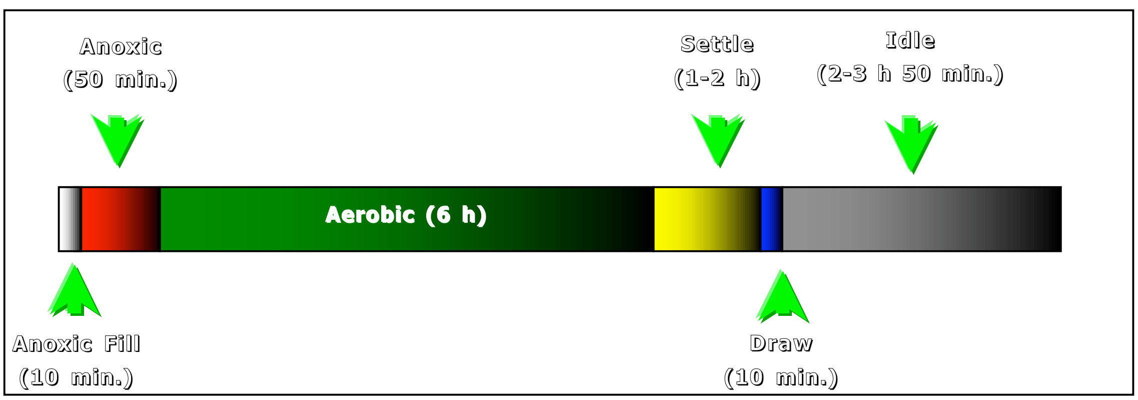


Figure 1.- Conventional phase scheme

2.3 Control strategy

The SBR operation under the CL, was characterized by the following work scheme (Table 5 and figures 2 and 3) for a mean VSS concentration of ~ 1500 mg/L:

Stage	Duration	
	Standard	Shock Load
Fill	Instantaneous	
1st Aerobic	~ 35 min.	~ 135 min.
Anóxic	~ 100 min.	~ 175 min.
2nd Aerobic	100 min.	105 min.
Settle	2 hours	
Draw	~ 5 min.	
Idle	~ 6 hours	3 hours

Table 5.- CL cycle phase duration

<u>CL Standard operation:</u>

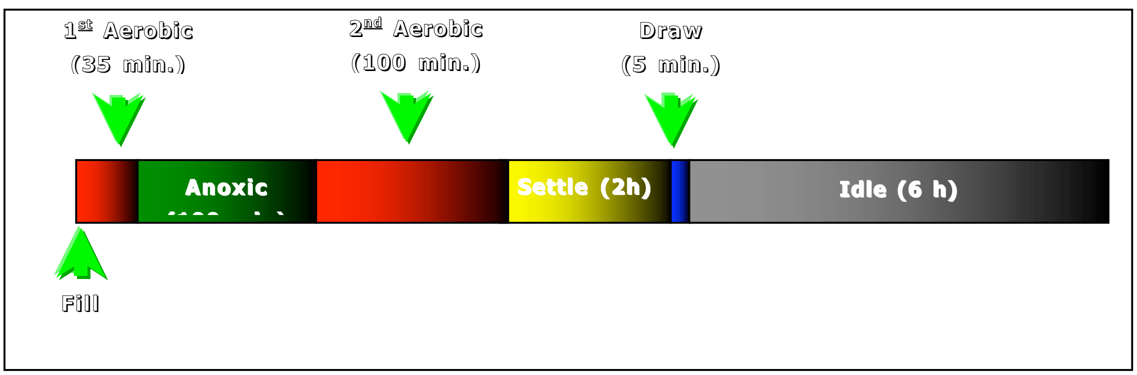


Figure 2.- CL standard operation scheme

<u>CL Shock Load operation:</u>

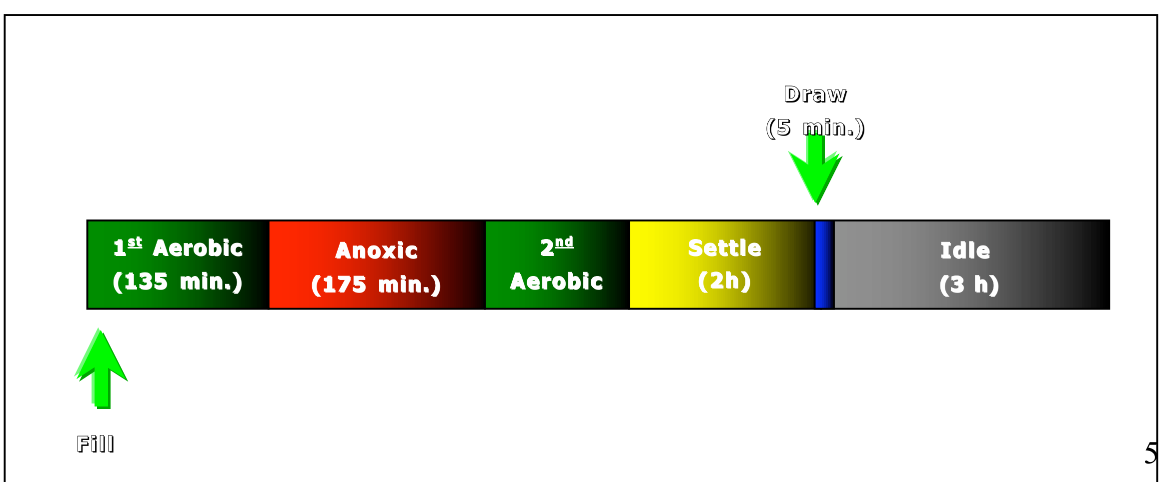


Figure 3.- CL Shock load operation scheme

3. Results

3.1 Conventional strategy

Reactor performance and effluent quality for standard conditions are resumed in the following tables (3 and 4):

Substrate Removal Efficiency (%)		Min.	Máx.	Average
	COD	91.6	97.2	95.3
	TKN	86.8	92.6	89.1
	Total - N	92.9	96.8	94.9
Air Flow Rate (NLpm)		4.5		
Air consumption (NL)		1620		
Effluent Sludge Content (mgSSV/L)		[217 – 1136]		

Table 3.- Conventional strategy standard condition performance

Parameter	Min.	Máx.	Average
COD (mg/l)	71	140	100
TKN (mgN/l)	4.7	6.6	6
Total – N (mgN/l)	4.7	13.2	7

Table 4.- Average effluent quality for standard condition with conventional strategy

As it is shown by the previous data, the SBR reactor presented good performance with this conventional strategy [average substrate removal efficiencies $\geq \sim$ 90% (COD, TKN and Total - N) and an acceptable effluent quality].
Effluent sludge content was high due to sludge bulking, frequently observed in Reactor M.

3.2 Control law strategy

The reactor performance and effluent quality are shown in tables 6 and 7.

Substrate Removal Efficiency (%)	COD	Standard Condition	92, 97
		Shock Load Condition	97, 98
	TKN	Standard Condition	91, 94
		Shock Load Condition	91, 95

	Total - N	**Standard Condition**	**94, 97**
		Shock Load Condition	**97, 99**
Air Flow Rate (NLpm)		**4.5**	
Air consumption (NL)		**Standard Condition**	**608**
		Shock Load Condition	**1080**
Effluent Sludge Content (mgSSV/L)		**[142 – 1540] (bulking phenomena)**	

Table 6 - Global performance of the reactor under control law strategy. Removal efficiency of 2 cycles is reported.

Parameter	Standard	Shock load
COD (mg/l)	**89, 225**	**85, 148**
TKN (mgN/l)	**3.7, 4.1**	**4, 8.2**
Total – N (mgN/l)	**4.4, 4.1**	**4, 8.2**

Table 7.- Average effluent quality with CL.

As it is shown by the previous data (Table 7) , the SBR reactor presented good performance under the CL strategy [average substrate removal efficiencies ≥ ~ 90% (COD, TKN and Total - N) and acceptable effluent quality (only one standard condition presents a light deviation (COD) respect to the desirable effluent quality set – points)], for both standard and shock load cases. Effluent quality under CL operation is comparable to the effluent quality under conventional operation.

As a result of control law implementation, cumulative air consumption is appreciably reduced. Total cycle time duration for standard operation under CL (6 hours) is lower than conventional cycle (9 hours). Shock load cycle time under CL is similar to the conventional cycle duration

3.2.1 Individual cycle data analysis

Standard cycle

COD and NO_x (N-NO_2 + N-NO_3) concentration profiles of two standard cycles are shown in figures 4 and 5 presented below :

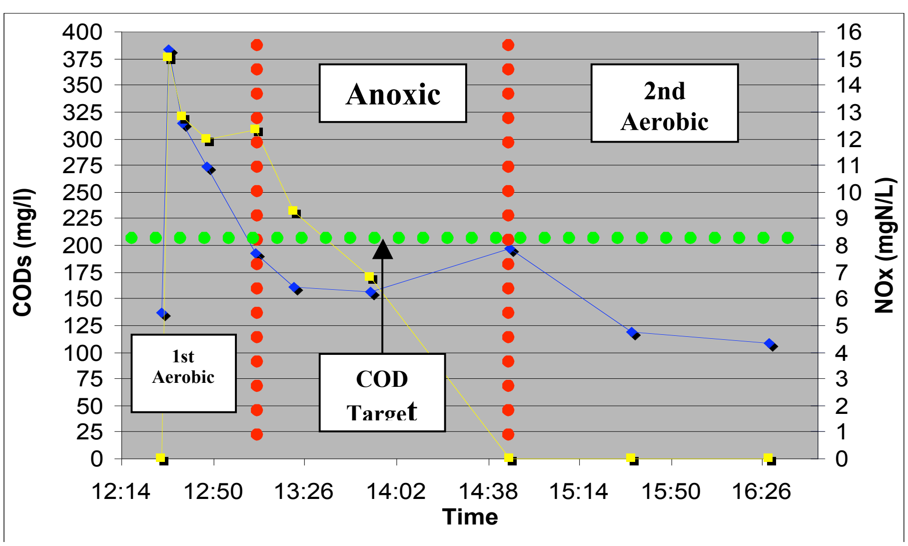


Figure 4. COD and NOx profiles for a standard CL cycle.

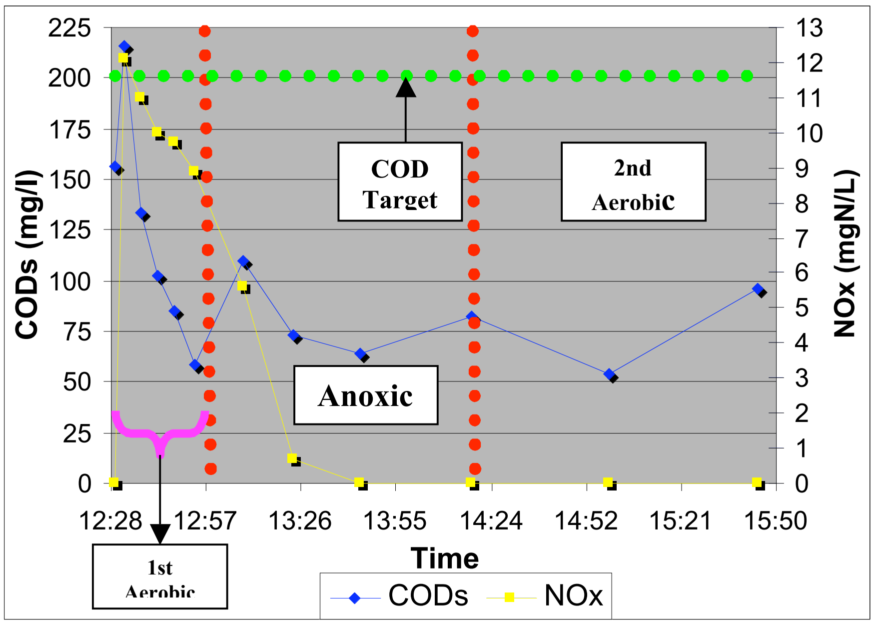


Figure 5. COD and NOx profiles for a standard CL cycle.

<u>Shock load cycle</u>

COD and NO_x (N-NO_2 + N-NO_3) concentration profiles of two shock load cycles are shown in figures 6 and 7 presented below:

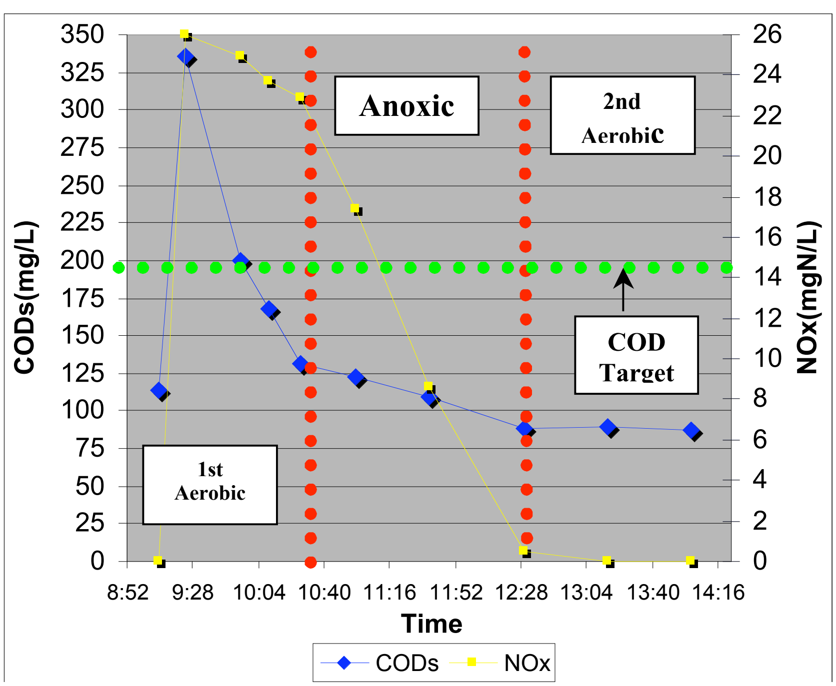


Figure 6 - COD and NOx profiles for shock load CL cycle.

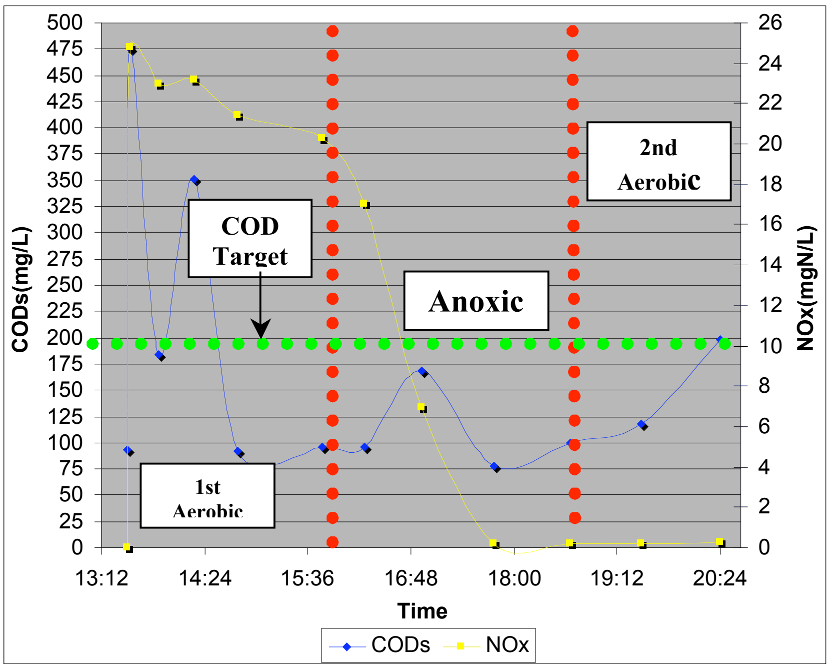


Figure 7 - COD and NOx profiles for shock load CL cycle.

Discussion

Final effluent quality is acceptable for both standard and shock load cycles under CL application.

The anoxic phase duration in the reactor was excessive in some cycles (~ 30 minutes in standard cycle and ~ 50 min extra time during shock load). This observation could be explained by some of the following effects:

- High N-NH_4^+ assimilation on biomass, and low nitrification extent in the reactor, neglected for the CL .
- Presence of N-NO_x removal during aerobic stage (assimilative reduction, denitrification at not sufficiently inhibitory DO levels). In figures 4 to 7 this process can be seen.

Regarding aerobic phase, the following can be observed:

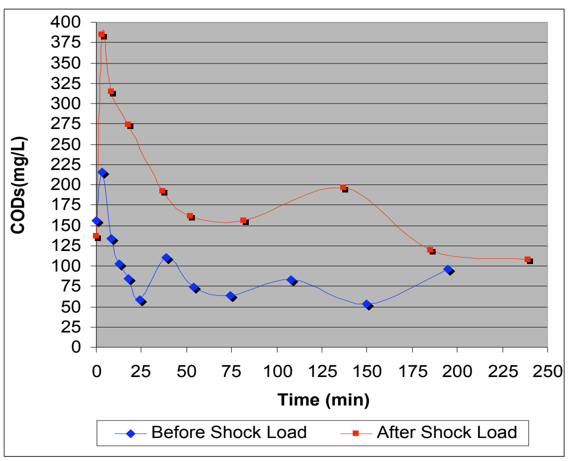
- The first aerobic stage was excessive in some standard and CL cycles (see figures 5 to 7).
- At the beginning of the second aerobic stage, COD was always under the target value. Then, this stage should not be necessary for any condition (standard and CL cycles).

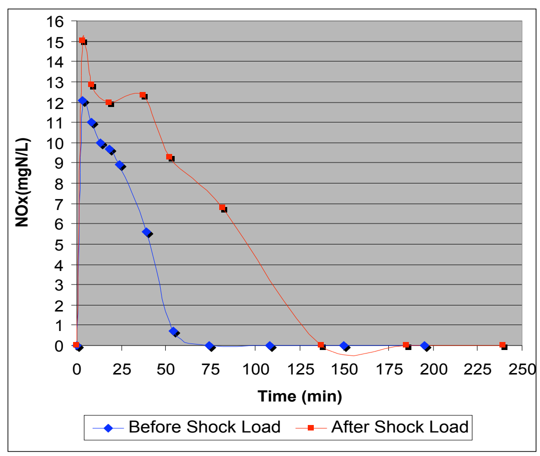
The CL could be further optimized by considering the nutrient consumption of heterotrophic biomass in the model, or simply neglecting autotrophic growth, for this high C/N ratio.

Influence of shock loads on the reactor stability

Conventional strategy No differences were appreciated in reactor operation at standard and shock loads conditions. Removal efficiencies (COD, TKN, etc.) and biomass activity remain stables at both reactor states.

Control Law Strategy: Standard cycles before and after shock load are compared. COD, total nitrogen and NOx evolution were compared and shown in the following figure 8. After shock load, denitrification and aerobic kinetics seems to be lower than before the shock, even when biomass concentration was similar (1100 mgVSS.l^{-1}) (see COD and NOx profiles). Even when the COD and NTK final concentration in the standard cycle after a shock load was under the target limit, a possible gradual accumulation could occur if the shock load duration is extended several cycles. From these results, it is not possible to conclude about the impact of a long term CL shock load operation, on the reactor performance.





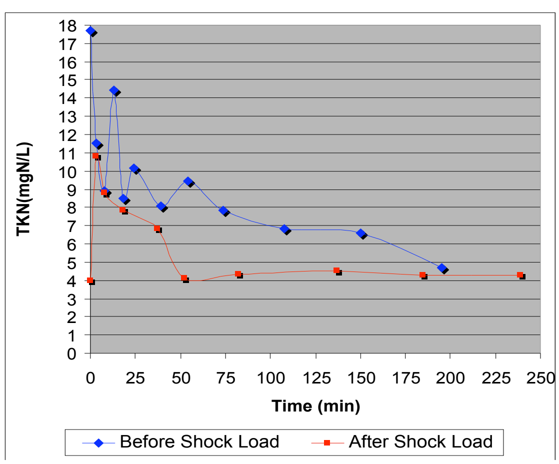


Figure 8.- COD, TKN and NOx profiles for standard cycles before and after a shock load.

3.2.2 Long term CL experiences

In order to evaluate the long term CL effectiveness on the reactor performance (reactor M), both standard and shock load experiences were carried out in this sense.

The SBR operation in this stage was characterized by the following work scheme (Table 8) for a mean VSS concentration of ~ **3000 – 3200 mg/L**. For this higher biomass concentration, a higher air flow rate was required to maintain the oxic conditions during aerobic stagge.

Stage	Duration	
	Standard	Shock Load
Fill	Instantaneous	
1st Aerobic	~ 7 min.	~ 30 min.
Anóxic	~ 45 min.	~ 70 min.
2nd Aerobic	~ 45 min.	~ 90 min.
Settle	2 hours	
Draw	~ 5 min.	
Idle	~ 8 hours 15 minutes	~ 6 hours 45 minutes

Table 8.- Cycle phase duration at long term CL experiences

The VSS concentracion in this case (~ 3000 – 3200 mgSSV/L) were higher than previous stages (~ 1500 mgSSV/L) of CL implementation at reactor M. This difference is due to the addition of Urea in reactor influent (~ 5 mgN/L) in the last case (long term stability studies), to eliminate the TKN limitation present during the cycle up to that moment, to improve the settling properties of the sludge.

The standard CL condition was established during 60 cycles before the corresponding analisys by on line and off line measurements. For the shock load CL condition, the reactor was operated for 15 cycles before similar evaluation.

In table 9, the critical performance parametes of reactor are summarized for each configuration (standard and shock load).

Substrate Removal Efficiency (%)	**COD**	**Standard Condition**	**~ 100**
		Shock Load Condition	
	TKN	**Standard Condition**	
		Shock Load Condition	
	Total - N	**Standard Condition**	
		Shock Load Condition	
Air Flow Rate (NLpm)		**16**	
Air consumption (NL)		**Standard Condition**	**800**
		Shock Load Condition	**1920**

Table 9.- Global performance of the reactor after a long term control law strategy.

If this performance is compared with the conventional strategy , the following can be seen

- Great reduction in total reaction time (see Tables 2 and 8), without sacrifice in substrate removal efficiencies.
- Great reduction in total air consumption for standard conditions (800 vs. 1620 NL for long term CL and conventional strategy respectively).
- Increase in total air consumption for shock load conditions (1920 vs. 1620 NL for long term CL and conventional strategy respectively).

4. Conclusion

The application of the CL reduced the total cycle time from nine to six hours for standard condition, and total air consumption is reduced in ~ 60%, with comparable effluent quality. In CL shock load cycle, air consumption is also shorted with respect to the conventional one, even when total cycle duration is similar. For all conditions (standard and shock load CL cycles), the total aerobic phase duration was excessive. The total anoxic time was excessive only in some cycles. Nitrogen assimilation for biomass growth is the main mechanism of TKN removal for this wastewater with a particularly high C/N ratio. A CL based in a model which specially considers this process could be necessary to optimize the cycle phase for this effluent.

Reactor global performance after a shock load (1 – 2 cycles) didn't show signs of instability as normal effluent quality was obtained. Even when the COD and NTK final concentration in the standard cycle after a shock load was under the target limit, a possible gradual accumulation could occur if the shock load duration is extended several cycles.
The carried out long term CL experiments did show a stable operation with a good reactor performance, reaching in an appreciable minor total reaction time respect to conventional strategy. Moreover, the global air consumption in long term CL experiences was more than 50% lower than conventional strategy for standard condition.