INCO : International Scientific Cooperation Projects (1998-2002)

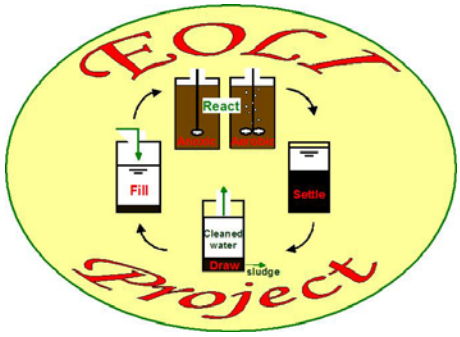
Contract number: ICA4-CT-2002-10012

WP5 at UNAM
REPORT covering period from 1 November 2004 to 1 May 2005

Efficient Operation of Urban Wastewater Treatment Plant (EOLI)

Project homepage : http://www.auto.ucl.ac.be/EOLI/

Keywords : wastewater treatment (WWT), aerobic digestion, sequencing batch reactor (SBR), monitoring, control system



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TITLE : Efficient Operation of Urban Wastewater Treatment Plant (EOLI)

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SUMMARY

UNAM:

Within WP5 UNAM studies the aerobic SBR uses for treating toxic wastewaters. In previous periods a control strategy was developed, the Event Driven Time Optimal Control (EDTOC), which demonstrated being able to solve the desired optimizing criteria, for the given restrictions, both in standard and shock lab-scale experiments.

During the reported period the assessment of the practical advantages of the EDTOC, over the traditional FTC operation mode, was done; Deliverables D5.1 and D5.2 were delivered; Following the WPs interactions policy WP5 has also performed various additional tasks:

- The redesign of the control software and instrumentation for both, a lab-scale and a field-scale, Sequencing Batch Reactors (SBRs) was done following the EOLI-WP8 integration criteria given by SPES six months ago, during the last meeting at Milan, in order to allow for total integration. Modbus protocol tests were performed in the field-scale SBR platform to assure that WP6 and WP7 results could be smoothly integrated, when delivered, to the WP5 modules already working.
- Advice and guidelines to commissioning the field-scale SBR were given to IBTech. Although officially WP5 is over by now, we plan to collaborate with WP1 and IBTech in order to perform experiments and to do last minute improvements when testing the new field-scale SBR, as soon as it is delivered.
- The possibility of using a WP3 hardware spectrophotometer sensor for the substrate concentration was studied. Unfortunately the sensor is not yet ready for such a kind of use as its sampling period is too slow and, besides, it still lacks the full automated capabilities to immerse it inside a real-time feed-back control loop.

INRA-LBE:

Reports Nothing to report.

UU:

Nothing reported.

1 SCIENTIFIC REPORT

1.1 Introduction

This report describes the progress of activities in WP5 for the EOLI project. It includes a description of the methodology followed, activities conducted in the reporting period and outputs realised for the scientific work package involved.

At UNAM, the biodegradation of a toxic compound by naturally occurring microorganisms is investigated. In accordance with WP1 a laboratory-scale reactor was designed and assembled, early at the beginning of the project, to allow WP1,2 experiments to be conducted. In order to perform a comparative study various control strategies were implemented, specifically the traditional Fixed Time Control (FTC) and the new Event Driven Time Optimal Control (EDTOC). The comparison showed the advantages of the EDTOC.

1.2 Methodology, activity, WPs interactions and results of WP5

1.2.1. Methodology

The EDTOC was studied to evaluate its possibilities and its limitations for controlling a SBR for degrading toxic wastewater. Same settings as for Eoli-Model 1 (EM1) operation conditions were followed in the first part of the study, i.e. degradation of synthetic WW with 4CP. A second series of experiments was conducted using a mixture of real WW, coming from the University's WWTP, and Phenol.

A lab-scale SBR was used to perform an experimental comparative analysis between FTC and EDTOC strategies.

A field-scale SBR is going to be used next to evaluate the EDTOC strategy with a mixture of real and synthetic wastewaters in a long term operation basis.

The original programming made for the lab-scale SBR was modified in order to allow its use in any of the hardware platforms following the EOLI integration criteria. It has been successfully tested in both the lab-scale (UNAM-01) and in the first essays of the field-scale (UNAM-02) SBRs.

1.2.2. Activities

In the first year period a laboratory-scale pilot reactor was instrumented and the necessary control software developed (it was called BIOREC, acronym for BIOREeactor Control). This was needed in order to allow WP1 to perform process experiments, very early in the project, to provide experimental data to WP2 for parameter identification of the dynamical model. At that time there was yet no clear definition of the details for the Integration policy, so such a solution was somewhat isolated and custom made to fulfill WP1-EOLI-project scheduling needs. Now, in the reported period, such software was modified (rewritten) in order to comply with specification given by SPES. The goal is to provide integration, i.e. the capability of

using the same control software in different hardware platforms and in different high level software configurations. Concurrently other important improvements were made to the EDTOC software, i.e. to include the temperature effects in the Events Software-Sensor (the field-scale SBR will not have a temperature control as the lab-scale does).

The software structure, for controlling UNAM-01 and UNAM-02 SBRs, was modified in such a way that the user interface, the control algorithm and the I/O functions are modular. UNAM-01 (see Fig. 1) hardware is made of National-Instruments plug-in cards, running in an IBM-type PC (Windows). UNAM-02 (see Fig. 02) hardware is much more robust as it is designed to be portable (Fig. 03) and industrial use resistant. I/O functions are performed via a remote Module (Beckhoff BK-9000 series) and communications run over a Modbus TCP protocol. This allows multiple users to access the I/O modules and allows also interaction between software modules running in different machines with different languages and even different operating systems. For example it would be possible to have a Fault Detection System running in a microprocessor and communicating directly to the BK-9000 I/O modules and, at the same time, the EDTOC control software may be running in a PC-based system, using the same I/O modules and interacting with the Fault detection system or even with any other additional system as a supervision one.

Figure 1. UNAM-01 Lab-sacle SBR instrumented with National-Instruments I/O

Figure 2. UNAM-02 Field-sacle SBR instrumented with BK-9000 Beckhoff I/O

Figure 3. UNAM-02 Field-scale portable SBR

This same software architecture allows using the exact same code to operate different SBR in different platforms, just by changing the I/O software-module according to the specific hardware. A configuration "Hardware Type" parameter tells the general I/O routine which platform is being used, as follows:

- "Hardware Type" = 0
  The system runs in simulation mode. A virtual SBR is simulated and the I/O uses the virtual signals as if they were the real ones. This mode is extremely useful to test software changes and validate them before attempting to test them in the real SBR. No additional integration is possible for this setting.

- "Hardware Type" = 1
  The I/O hardware is a National-Instruments plug-in hardware, as used for lab-scale reactor UNAM-01. There is only one Dissolved Oxygen probe and only one inflow pump. No additional integration is possible for this setting.

- "Hardware Type" = 2
  The I/O hardware is a BK-9000 Beckhoff arrangement, as used for field-scale reactor UNAM-02. There are two Dissolved Oxygen probes and two inflow pumps (Variable and Fixed fast inflow). Additional Integration under Modbus protocol is possible for this setting.

- "Hardware Type" = 3
  The I/O hardware may be a SPES hardware. Unfortunately the XML specs are not yet delivered so the particular I/O module could not be yet programmed, but the total EOLI integration under this protocol should be possible for this setting. BIOREC control module and User interface module are written in LabView. They will keep their local utilities (as they are needed for the other hardware types), but will rely completely in SPES architecture to operate when this mode is chosen.

Note that another advantage of having preserved EOLI integration policy for all platforms (Commercial external to EOLI and SPES generated for EOLI) consists of the possibility of writing changes to the, or a new, control strategy and then testing it first in a simulator for validation. Then, without changing a single code-line it can be run, and validated again, in the lab-scale SBR. If everything is ok it can then be scaled up to the field-scale SBR, again without changing a single code-line.

A set of experiments using both standard and shock toxicant loads was performed by WP1 in order to evaluate the improvement of EDTOC operation over FTC. The data was analyzed and the D5.2 deliverable was written to report the results.

Advice and guidelines to finishing building and commissioning the field-scale SBR-UNAM-02 were given to IBTech, in accordance with WP1 and WP5 personnel at UNAM. The reactor is now practically finished but minor adjustments and calibration of all instruments are still missing.

1.2.3. Results

The last remaining milestone was achieved using lab-scale results:

- Validation of optimal control law with real improvements in process and economic variables: **T0+30**

Deliverables are presented in the annexes, using lab-scale results:

- D5.1 Control laws based on software sensors for optimising the performance of SBRs. (annex 1) **T0+27**
- D5.2 Report on full-scale performance of the adaptive optimal control law. (annex 2) **T0+30**

Note: Once IBTECH delivers the field-scale SBR in operating conditions, and then once WP1 is able to perform the planned experiments, the scaling of the WP5 last milestone and deliverables to field-scale will be easily made for the final report.

Table 1. WP5 status and Progress towards achieving objectives

WP5 Task & Objectives	Progress towards achieving objectives (Outputs)
Task 5.1 *Status: Fulfilled* Specification of control variables and optimisation objectives	5.1.1 UNAM: Optimization objective is defined as treating the whole batch in the minimum possible time. Measured variables are Dissolved Oxygen and Volume level in the SBR tank, the controlled variable is the "reaction rate" and the manipulated variable is the input inflow. Filling and reacting phases are modeled and considered for optimization, Settling and Drawing phases are not.
Task 5.2 *Status: Fulfilled* Design of optimal and adaptive suboptimal control laws.	5.2.1 UNAM: A control law called Event Driven Time Optimal Control strategy (EDTOC) was proposed and implemented. The EDTOC strategy finds a variable, the Oxygen Mass Uptake Rate (OMUR), related to the reaction rate. Such variable can be estimated in real time by using the dissolved oxygen in the reactor and its volume. The influent flow rate is controlled in such a manner that the OMUR stays near to the maximal value and hence also the reaction rate stays near its maximum possible value at all times. Indirectly, using such OMUR the SBR is controlled to maintain the toxic concentration oscillating in a gap during the SBR filling. Every time it tries to leave this gap, an event is issued and the EDTOC then switches the influent flow on/off, to prevent it. This procedure will work regardless of the influent toxic concentration value and despite changes in most of the SBR parameters. Only the mass transfer coefficient and the dissolved oxygen concentration at saturation are needed to estimate the OMUR, and they do not even need to be precisely known.
Task 5.3 *Status: Fulfilled* Control law validation	5.3.1 UNAM: 3 different approaches to validation are taken. First simulation using both MATLAB and LABVIEW. Results are satisfactory. Second experimental tests. Results are also satisfactory. And third, theoretical proof of almost-optimality, convergence and robustness.
Task 5.4 *Status: lab-scale Fulfilled* Process improvement evaluation	5.4.1 UNAM: Single experimental batch tests have been made to evaluate process improvement. Test include perturbation of the substrate concentration in the influent going from nominal value 350 mg4CP/L up to 20 times such a value (7000 mg4CP/L) with results that allow to state that the perturbation is rejected completely and that, even under this conditions, the total treating time is less than using the previously known control strategies.

1.3 Problems encountered

No serious technical problems were encountered in the activities scheduled for the last year of the project.

1.4 Publications

1. Betancur, M.J.; Moreno, J.A. and Buitrón, G. (2004). Event-driven control for treating toxicants in aerobic sequencing batch bioreactors. *Proceedings of the 9th International Symposium on Computer Applications in Biotechnology (CAB9), CDROM file 1074*, 28-31 March 2004. Nancy, France.

2. Betancur, M.J.; Moreno J.A. and Buitrón, G. (2004). Practical Optimal Control For Fed-Batch Bioreactors. *Preprints of NOLCOS 2004 (Nonlinear Control Applications, Sep* 2004), pp 1517-1522, Stuttgart, Germany

3. Betancur, M.J; Titica, M; Moreno, J.A.; Dochain, D. and Guay, M. (2004). Event Software Sensor and Adaptive Extremum Seeking alternatives for optimizing a class of fed-batch bioreactors. *Proceedings of DYCOPS 2004*, Cambridge, Massachusetts, USA

4. Buitrón, G.; Moreno, J. A.; Betancur, M. J. and Moreno, I. (2004). Aerobic treatment of toxic wastewater: problems, solutions, and open questions. *Proceedings of the 3rd IWA Specialised Conference on Sequencing Batch Reactor Technology-SBR3*, 22-26 February 2004, Noosa, Australia

5. Buitrón, G.; Moreno-Andrade, I.; Betancur, M.J. and Moreno, J.A. (2004). Application of the event-driven time optimal control strategy for the degradation of inhibitory wastewater in a discontinuous bioreactor. *Proceedings in CD of the 4th World Water Congress, IWA.* 19-24/09/2004. Marrakech, Morocco, Paper ID 28156.

6. Buitrón, G.; Moreno-Andrade, I.; Betancur, M.J. and Moreno, J.A. (2004). Biodegradación de efluentes altamente contaminados por compuestos fenólicos utilizando una estrategia de control óptima, in Spanish. *Memorias del XIV Congreso de Ingeniería Ambiental y Ciencias Ambientales.* 12-14/05/2004, Mazatlán, México.

7. Betancur, M.J.; Moreno, J.A.; Buitrón, G. and Moreno-Andrade, I. Control y mejoras en biorreactores para tratar aguas residuales tóxicas, in Spanish. *Proceedings of the Congreso Anual de la AMCA.* October 2004, D.F., México, pp. 490-495

8. Betancur, M.J.; Moreno, J.A.; Moreno-Andrade, I. and Buitrón, G. Control strategies for treating toxic wastewater using bioreactors. *Accepted in the 16th IFAC World Congress*. Prag, July 2005.

9. Moreno, J. and Dochain, D. Global observability and detectability analysis of uncertain reaction systems. *Accepted in the 16th IFAC World Congress*. Prag, July 2005.

Submitted

10. *Process to operate an aerobic bioreactor.* Mexican Institute for the Industrial Property (IMPI), 3 Feb 2005 13:19; Expedient number PA/a/2005/001368; Folio PA/E/2005/006962, in Spanish (Proceso para operar un biorreactor aerobio), Patent pending.

11. Betancur, M.J., J.A. Moreno and G. Buitrón. Practical Optimal Control of Fed-Batch Bioreactors for the Wastewater Treatment. *Submitted to: Journal of Robust and Nonlinear Control,* Mar 2005.

12. Moreno-Andrade, G. Buitrón, M.J. Betancur and J.A. Moreno. Optimal Degradation of Inhibitory Wastewaters in a Discontinuous Bioreactor. S*ubmitted to Water Research.* May 2005

13. Schaum, Alexander; Moreno, Jaime A. and Vargas, A. Global observability and detectability analysis for a class of nonlinear models of biological processes with bad inputs. *Submitted to the 2nd International Conference on Electrical and Electronics Engineering and XI Conference on Electrical Engineering (ICEEE-CIE 2005),* 7 - 9 September 2005, Mexico City, Mexico

In Preparation

14. Moreno J.A., M.J. Betancur, I. Moreno-Andrade and G. Buitrón. Event Driven Time Optimal Control for a Class of Discontinuous Bioreactors. *To be submitted to: Biotechnology and Bioengineering.* May 2005

1.5 Planning

Once IBTech delivers the field-scale SBR-UNAM-02, and after starting-it-up, evaluation and validation of the performance of the EDTOC strategy will be made, in accordance with WP1, in order to scale up the lab-scale results already obtained.

Long-term running of the lab SBR to test the biological stability of the SBR operated exclusively with the EDTOC strategy is going to be performed in accordance with WP1

2 MANAGEMENT REPORT

2.1 Meetings

Meetings with IBTECH and UNAM WP1, WP2 and WP6 participants were held when necessary, specially to give advice and guidelines for the design and construction of the field scale pilot reactor by IBTECH.

2.2 Exchanges

Alexander Schaum, master degree student from the *Institut für Systemdynamik und Regelungstechnik* of the *University of Stuttgart*, stays at UNAM from 27 January until 30 September 2005 in order to work on the topic "Observability analysis and observer design for a class of bioreactors with bad inputs"

2.3 Problems

No management problems occurred in this period.

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
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

LIST OF ANNEXES

Annex 01. WP5-D5.1 (deliverable)
D5.1 Control laws based on software sensors for optimising the performance of SBRs

Annex 02. WP5-D5.2 (deliverable)
D5.2 Report on full-scale performance of the adaptive optimal control law