



INCO : International Scientific Cooperation Projects

Contract number : ICA4-CT-2002-10012

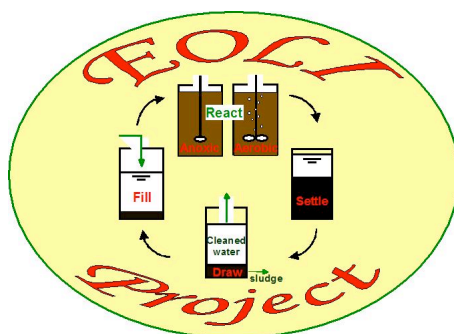
THIRD ANNUAL REPORT:

covering period from
1 November 2004 to 31 october 2005

Efficient Operation of Urban Wastewater Treatment Plant (EOLI)

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

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



Centre for Systems Engineering
and Applied Mechanics



POLITECNICO DI MILANO

Piazza Leonardo da Vinci, 32 - 20133 Milano
Tel. +39.02.2399.1 - <http://www.polimi.it>



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

COORDINATOR

Université Catholique de Louvain (UCL)
Centre for Systems Engineering and Applied Mechanics (CESAME)
Bât. Euler, Av. G. Lemaître 4-6
1348 LOUVAIN-LA-NEUVE
BELGIUM

Prof. Bernard COULIE
e-mail : rect@rect.ucl.ac.be
TEL : +32-10-478805
FAX : +32-10-473803

CONTRACTORS

Institut National de la Recherche Agronomique (INRA)
Laboratoire de Biotechnologie de l'Environnement (LBE)
2, Avenue des Etangs
11100 NARBONNE
FRANCE

Mr. Loïc GAUMÉ
e-mail : gaume@ensam.inra.fr
TEL : +33-4-99612440
FAX : +33-4-67612882

Groupe de Recherches et d'Animations pour le Développement,
l'Innovation et l'Enseignement en Technologie (GRADIENT)
UTC - Département Génie Chimique
Rue Personne de Roberval - Centre de Recherche Royallieu -
BP 20.529
60205 COMPIÈGNE
FRANCE

Dr. Michel CORDONNIER
e-mail : michel.cordonnier@utc.fr
TEL : +33-3-44234555
FAX : +33-3-44234560

Politecnico di Milano (POLIMI)
Dipartimento di Ingegneria Idraulica, Ambientale e del
Rilevamento (DIAR)
Piazza Leonardo da Vinci 32
I-20133 MILANO
ITALY

Prof. Giulio BALLIO
e-mail : rettore@rettore.rett.polimi.it
TEL : +39-022-3992250
FAX : +39-022-3992106

Società di Progettazione Elettronica e Software S.C.R.L. - SPES
Via Broganelli 84
60044 FABRIANO
ITALY

Mr. Davide MANCINI
e-mail : davide.mancini@spes-scril.com
TEL : +39-0732-625158
FAX : +39-0732-227526

Universidad Nacional Autónoma de México (UNAM)
Instituto de Ingeniería (IINGEN)
Circuito Interior, Ciudad Universitaria
04510 MEXICO D.F.
MEXICO

Dr. Juan Ramon DE LA FUENTE
e-mail : amondrag@servidor.unam.mx
TEL : +52-55-55521281
FAX :

Universidad de la República Oriental del Uruguay (UU)
Instituto de Ingeniería Eléctrica - Facultad de Ingeniería (FING)
Julio Herrera y Reissig 565
11200 MONTEVIDEO
URUGUAY

Dr. Rafael GUARGA
e-mail :
TEL : +59-82-4084901
FAX :

IBTech S.A. de CV
Poseidon 7
03940 MEXICO D.F.
MEXICO

Mr. Jorge E. LOPEZ HERNANDEZ
e-mail : Jorge_lopez@ibtech.com.mx
TEL : +52-55-56614811
FAX : +52-55-56617495

SUMMARY

Over the third year of the EOLI project, 7 scientific work packages have been active:

- WP1 : process experiments
- WP3 : hardware sensor development
- WP4 : software sensor development
- WP5 : control design and application
- WP6 : development of the Fault Detection and Isolation (FDI) system
- WP7 : supervision system development
- WP8 : validation and integration.

Within WP1, POLIMI, LBE, UNAM and UU have been performing experiments on laboratory scale Sequencing Batch Reactors (SBR's), in order to provide data and tests for the WP2, WP3, WP4, WP5, WP6 and WP7. The SBR's are instrumented to measure on-line the following process variables: temperature, DO, airflow rate, redox potential and pH. More specifically, UNAM studies SBRs dedicated to the treatment of wastewaters that have toxic compounds (typical, chlorophenol in the present instance) and the start-up of the field-scale plant was accomplished; LBE reactor is dedicated to the treatment of lactic acid based wastewater from the food industry with a specific objective to study of sludge level and purges automatization; POLIMI studies SBR's applied to the carbon and nutrients removal; and the SBR's of the UU treats dairy industry wastewaters.

Within WP3 (hardware sensor development), GRADIENT has designed an on-line spectrophotometer, based the results of the off-line device obtained in the six previous months. It was built by the Secomam company and called STAC. After some calibration and validation assays, it was integrated in May for the on-line monitoring system of the SBR in the LBE-INRA in Narbonne. POLIMI has developed five titrimetric pH-stat and pH/DO-stat procedures (MODEs) for the evaluation of fundamental parameters related to both the nitrification and denitrification processes. All MODEs were experimentally validated by using the off-line titrator (MARTINA, developed in cooperation with ENEA) on sludge samples drawn from the lab-scale POLINI-SBR. Then, in cooperation with SPES, these procedures were implemented on the on-line titrator (TITAAN) which was first tested and debugged on the pilot-scale ENEA-SBR and then shipped to Narbonne to be integrated in the monitoring system of the pilot-scale LBE-SBR.

WP4 is concerned with the design of software sensors, i.e. tools that allow to provide on-line values of key process components that are not accessible for on-line measurement. The software sensors under development are concerned with the on-line estimation of substrate and biomass concentrations from the on-line measurements of dissolved oxygen and nitrogen oxide in presence of uncertainty in the kinetics. New calibration methods for the software sensors have been developed that have been tested in numerical simulations and with real-life data.

WP5 is dedicated to the design and implementation of feedback controllers. At UNAM, the control software developed (BIOREC, acronym for BIOREactor Control) was modified (rewritten) in order to comply with the specification given by SPES. The goal was to provide capabilities for integration, i.e. for using the same control software in different hardware platforms and in different high level software configurations. Concurrently, other important improvements were made to the BIOREC software, i.e. to include the temperature effects in the Events Software-Sensor (ESS) for the ED-TOC. This same software architecture allows using the exact same software code to operate different SBRs

using different hardware platforms, just by changing the I/O software-module according to the specific hardware. The activities of the LBE-INRA with respect to WP5 for the third year were dedicated to the evaluation and validation of the optimal control strategies developed for INRA SBR reactor.

The activities of WP6 over the third year were carried in collaboration with WP4 and WP1 taking into account the following tasks :

- to get a redundancy relation which is necessary to solve a FDI issue with analytical methods ;
- to establish the causal model for the POLIMI reactor, participants of WP6 established a communication with POLIMI ;
- to propose together with POLIMI a possible solution to the excessive Nitrite outflow problem described as part of the deliverable D1.4 of WP1.

Although the EOLI supervision system (WP7) can be said to be "open" in the sense it can basically be applied to any SBR process, it has been specifically developed for two distinct processes (pilot processes of partners #2 and #6) and the application of the system to another process would require a minimum of adaptation. The first implemented system consists in the hardware and software modules implemented by SPES. This system basically interacts with the plant, performs data acquisition and store these data in two distinct databases (a local one and a - possibly decentralized - one). Within the framework of the project, the local database is at the LBE, INRA, Narbonne, France while the decentralized one is at SPES location, Fabriano, Italy. In the second instance, the activities are part of the objectives WP7.3 Integration of the supervision module and WP4 Implementation and Evaluation of the Supervision Module for the UNAM SBR field scale pilot plant and consists basically on the Development of the real-time BioReC (BioReactor Control) software in order to implement the safely automation of the field-pilot SBR.

During the third year of the project the major objective of the WP8 was the integration and validation of the EOLI supervision system on multiple plants. The EOLI supervision system was tested and validated at the two pilot SBR plants engaged in the project: the one located at the INRA-LBE facilities and the other one provided by the ENEA and located at the site of a full scale plant. During the third year both plants were equipped with the EOLI hardware and software main frame. With the aim to validate the EOLI system under other architectures for the integration different from the one developed in the project, UNAM and UU own systems for the monitoring and control have been modified in order to adapt them to run and to test some EOLI software modules at two lab plants (UU) and at the full scale plant built up by IBTech, sending the data to the EOLI remote server. The EOLI remote control centre consists therefore of the lab and pilot scale plants enrolled in the EOLI system, i.e. both lab plants at UU, two pilot plants (one at INRA and one at ENEA), and one full scale plant at IBTech in Mexico. The data from these plants are available at the remote server.

This third year report is organized as follows. The first part is dedicated to the scientific work carried out during the third year of the project by all project participants. It is followed (part 2) by a description of the management aspects of the project. The cost statement of the third year is presented in a separate report. Then in the third part, individual partner reports are presented. The last part deals with annexes and the data sheet for the annual report.

1 SCIENTIFIC REPORT

1.1 Introduction

This report describes the progress of activities in the third year of the EOLI project. The report is compiled on the basis of the individual partner annual reports and the WP reports provided by the Task leaders.

1.2 Methodology, activity and results per work packages

1.2.1 Process experiments (WP1)

Involved partners: POLIMI, LBE-INRA, UNAM, UU, IBTECH

Methodology

During the third year, laboratory-scale and one field scale pilot reactors have been used. Four lab-scale pilot reactors have been used LBE (200 L), POLIMI (30 L), UNAM (10 L) and UU (two 20 L). Ibtech with UNAM had started to operate a field scale reactor of 1000 L.

Activities

The specific activities are described in the table 1. Summarized individual contributions of each partner are the following (more details are found in annexes WP1 POLIMI, LBE, UNAM, UU and IBTECH individual reports).

POLIMI. Within the objectives of WP1, the POLIMI experimentation has included the operation and monitoring of the lab scale POLIMI-SBR and of the pilot scale ENEA-SBR.

The experimentation on the POLIMI-SBR has included the following main activities:

a) the lab scale SBR fed on synthetic sewage was kept into operation and monitored. The SBR sludge was used to perform biomass activity tests to elucidate environmental conditions which may lead to nitrites build up. Various loading conditions were experimented. Several sludge inoculums were required to recover nitrites oxidation capacity; b) batch activity tests were performed with the MARTINA instrument to assess the activity of ammonium and nitrites oxidizers at various pH, DO, ammonium concentration and aeration patterns; main goal of these tests was to evidence factors which can favor ammonium oxidizers (AOB) over nitrite oxidizers (NOB), thus unbalancing the nitrification process. The elucidations of environmental conditions, which can lead to the main abnormal condition observed during the POLIMI-SBR operation, are of interest for early fault detection (WP6), to develop appropriate control strategies (WP 5) and supervision algorithms (WP7), c) batch biosorption tests were performed to confirm that this process is irrelevant for the POLIMI SBR, as assumed in the model developed within the WP2. d) the denitrification activity of the sludge of the POLIMI SBR was monitored regularly by pH-stat titration tests with the MARTINA sensor (see WP3 report).

The experimentation on the ENEA-SBR has included the following main activities: a) operation of a pilot SBR placed at the full-scale plant of Trebbo di Reno (Bologna) at different loadings, cycle durations and operating temperature; b) off-line tests operated with the manually operated titration unit (MARTINA) to simulate the modes of operation of the automatic titration unit (TITAN), and, specifically (WP3); c) monitoring of the maximum SBR nitrification activity; d) evaluation of the SBR efficiency in nitrogen removal with maximum nitrification activity measurements.

LBE. Experiments and Results of the third year related to the WP1 realized at the LBE-INRA, Narbonne, France. During the last year, and in order to validate and evaluate the whole EOLI system developed in the project for the Narbonne's SBR, two kinds of measurements were done: Low Frequency measurement (LF) and High Frequency measurement (HF). For the low frequency measurement, around twice a week, the influent and the outlet effluent were characterised by measuring CDO, TKN, nitrites and nitrates. TSS and VSS in the reactor were also measured. This set of measurements was dedicated to the long-term evaluation of the different control and supervision algorithms applied to the reactor. The high frequency measurement, between two and ten samples per SBR cycle, was used for: evaluate the control strategies; model validation; on-line sensor calibration and validation. These measurements were globally COD, nitrites and nitrates inside the reactor and during the reaction phases. The schedule of the experiments is shown in table 1. In this section we give a brief discussion of the results obtained for each experiment. Each experiment is described in detail in the relative deliverables and in the next section of this report. See for instance D5.1 and D5.2 for the control strategies named CS2 and CS3 ; WP6 report for supervision algorithms, WP3 report for TITAN and UV sensor.

UNAM. The activities of the partner 6 (UNAM) concerning the WP1 of the EOLI project, developed during the period November 2004-October 2005 were focused in the evaluation of the Event Driven Time Optimal Control developed in the UNAM. The ED-TOC strategy was evaluated against the introduction of shock loads and compared to a usual strategy. The long-term stability of system under the standard conditions was also evaluated for the degradation of 4CP. In order to evaluate the process improvement with the application of the optimal control law two sets of experiments were tested: The evaluation of the optimal control strategy against the shock loads and in during the long-term operation of system. The evaluation of the evolution of the microorganisms community in the acclimation and the long-term stability of the system was carried out using molecular biology techniques. The toxicity of the treated wastewater using the ED-TOC strategy was also determined.

UU. During the third year of experimentation the main objectives were 1.-The optimal control law (OCL) developed by Narbonne was implemented for Reactor M. A series of experiments was carried out in order to perform the EOLI defined experiments to test the reactor performance under the OCL. 2.- to evaluate the maximum loading capacity of Reactor M, and the denitrification capacity of a second anoxic phase for Reactor F. 3.- Another series of respirometric batch experiments was intended to better determine the kinetic parameters of Reactor M, and denitrifying kinetics of Reactor F. 4.- Adsorption capacity of Reactor M sludge was investigated in batch tests. 5.- Influence of air flow rate and source of the inoculated biomass on the settling capacity of sludge from Reactor M were evaluated. 6. Study the stability of the microbial composition of the reactors by molecular biology methods (T-RFLP). The start-up of the field-scale plant was accomplished to degrade 4CP.

IBTECH. The activities of IBTech during this third year were conducted under close collaboration with the UNAM team, since the main objective was to construct the pilot plant according the engineering design basis based on UNAM specifications. Regarding WP1, from November 2004 to October 2005 various meetings were held between IBTech and the UNAM team in order to discuss technical aspects referring to the construction of the pilot plant, particularly those aspects which were relevant to the controlling system. IBTech provided technical assistance to UNAM team in the procurement of equipment. In

fact IBTech was in charge of all equipment procurement activities, including equipment inspection at manufacturer's site before delivery. Apart from that, various meetings were carried out at UNAM's offices in Mexico with the UNAM team (WP1, WP6) in order to: Coordinate equipment delivery at the construction site, Check pilot plant construction progress, To define the adequate equipment supplier, To coordinate supplier access to restrained UNAM facilities, To transport the pilot plant to the final location where it will be used for the experiments, To start up the pilot plant, Operation of the pilot plant. The pilot plant is finished and ready to be used for the experiments that were conducted by UNAM team. The plant was already checked concerning hydraulic, electrical, mechanical and control systems.

Results

Task & Objectives	Progress towards achieving objectives (Outputs)
<i>Task 1.3 Evaluation of the optimal control strategy</i>	The evaluation of the optimal control strategy under shock loads was completed at UNAM and UU.
<i>Task 1.4 and 1.5 Evaluation of the FDI and supervision algorithms</i>	D1.4, D1.5 and D1.6 present the results of this tasks.
No	Deliverables
<i>D1.1 to D1.7</i>	All the deliverables concerning WP1 were done

1.2.3 Hardware sensor development (WP3)

Involved partners : GRADIENT, POLIMI, UNAM, SPES

Methodology

The main objectives of GRADIENT are:

- Develop a deconvolution model capable of estimating nitrate, nitrite and COD in mixture from UV-Spectra
- Modify an existing an spectrophotometer in order to estimate, on-line and at low cost, the evolution of nitrate, nitrite and COD during SBR cycles
- Implement the on-line spectrophotometer on the pilot scale bioreactor.

To realize these objectives, GRADIENT has designed an on-line spectrophotometer, based the results of the off-line device obtained in the six previous months. After some calibration and validation assays, it was integrated in May for the on-line monitoring system of the SBR in the LBE-INRA in Narbonne.

The main objectives of POLIMI experimentation are:

- Develop and operate an automated on-line combined pH/DOstat titration unit for monitoring a pilot-scale SBR, in cooperation with ENEA as subcontractor
- Develop and enhance the applicability of pH/DOstat titration for on-line monitoring of nitrification and denitrification in SBRs.

To cope with these objectives, POLIMI developed 5 titrimetric pH-stat and pH/DO-stat Modes for the evaluation of nitrification and denitrification parameters. All Modes were experimentally validated by using the off-line titrator (MARTINA) on POLINI-SBR sludge samples. Then, in cooperation with SPES, these procedures were implemented on the on-line titrator (TITAAN) which was first tested and debugged on the pilot-scale ENEA-SBR and then shipped to Narbonne (July 2005) to be integrated in the monitoring system of the pilot-scale LBE-SBR.

The main objective of SPES was the debugging of the on-line titrator TITAAN and its installation at the LBE-LBE to integrate it into the overall reactor monitoring system.

The main objective of UNAM is the use of spectrophotometric techniques to determine on-line measurements of concentrations during biodegradation of toxic (aromatic) substances.

Activities

GRADIENT activities have focused on the optimization of the UV-spectra deconvolution models and on the development of a low-cost on-line spectrophotometer based on an existing one (SECOMAM). The activities were: (1) Optimization of the deconvolution models; this task consisted in comparing different deconvolution models to discriminate between nitrate, nitrite and COD in a UV-spectrum. The UV-PRO software was then compared to types of PLS regression; results revealed that it is somewhat better than PLS regression to fit experimental data. (2) Implementation of the on-line spectrophotometer: SECOMAM company modified an existing on-line spectrophotometer (STAC) to be adapted to a SBR; the on-line spectrophotometer was implemented into the bioreactor in Narbonne (INRA) and integrated with the data acquisition system; a filtering system (60 μm) was placed prior to the spectrophotometer. (3) The UV-PRO and PLS deconvolution models were calibrated and validated on the INRA-Narbonne bioreactor. Once again, the UV-PRO software has better fitted the experimental data and was able to estimate correctly but not perfectly on-line nitrate, nitrite and COD during cycles. Improvements are under study.

The activities performed at POLIMI, Milano were the following: (1) DO-stat titration tests were compared to classical closed respirometry by performing parallel respirometric tests which allowed assessing operational differences and constraints for practical applications. (2) Further pH-stat titration tests were performed in order to achieve operational information to implement MODE 5 on the TITAAN. The activities performed at ENEA, Bologna were the following and were performed in cooperation with SPES: (1) Field tests were performed for TITAAN debugging; (2) more pH/DO-stat tests were performed to simulate some of the modes of operation of the TITAAN. Activities performed at LBE, Narbonne (F) were the following and were performed in cooperation with SPES: (1) The TITAAN was installed and put into operation on the LBE-SBR. (2) TITAAN was operated according to MODE 1 and allowed to follow the nitrification activity of the LBE-SBR. (3) TITAAN results were compared with information collected with the other monitoring systems.

The POLIMI Ph.D. student spent the last 6 months of the project in Narbonne at LBE where he followed the integration of TITAAN on the LBE-SBR monitoring systems.

A meeting was organized in Narbonne with POLIMI, SPES and GRADIENT at mid-July to discuss and finalize the implementation of both sensors in the SRB pilot plant.

The activities performed at UNAM consisted of two experiments aiming at reaching the objective described before:

- o The first experiment was performed simply to test the technique under no oxygen limiting conditions, *i.e.* no metabolite formation, in which case only one base spectrum is needed for the SD technique.
- o The second experiment was done to test the SD technique when metabolite is formed and oxygen is limiting. In fact, a useful result in this sense was that indeed this metabolite is formed when oxygen concentration remains low within the reactor. After acclimation

using the variable time strategy, two experiments were performed with 1000 and 500 mL/min airflow.

Results

Task & Objectives	Progress towards achieving objectives (Outputs)
<i>Task 3.1. Development of an on-line combined DOstat and pHstat titration biosensor</i> - Develop an automated combined titration DOstat & pHstat biosensor to be used on-line.	<i>Deliverable D3.2 Development of an automated DOstat and pHstat titration biosensor for process control</i> - An off-line combined pH-DO-stat titrator (MARTINA) was constructed (POLIMI with cooperation of SPES) - The on-line pH/DOstat titrator (named TITAAN) was built and tested on a pilot-scale SBR reactor in Bologna, in cooperation with ENEA, as a subcontractor and then shipped and installed at the LBE-SBR in Narbonne to be integrated in the reactor monitoring system. - Five modes of operation were defined and a operational protocol was issued and fully evaluated by the off-line titrator. - Of the five Modes of operations, Mode 1 and 3 were tested on the on-line titrator.
<i>Task 3.2. Development of a simplified low-cost on-line UV-spectrophotometric sensor</i> - To evaluate the performance of a lab-scale commercial UV-spectrophotometric sensor to estimate the behaviours of the SBRs for three different wastewaters - To develop the UV-databases specific to the tested wastewaters. - To simplify the existing on-line pilot-scale sensor to obtain a low-cost adapted sensor to be used with the investigated effluents. - To validate the UV-databases with the on-line pilot-scale sensor.	<i>Deliverable D3.3 Development of an simplified low-cost on-line UV spectrometric sensor</i> - UV sensor was tested using 3 target wastewaters, in cooperation of scientist from UNAM of UU. For each wastewaters, SBRs were successively fed with adapted microbial population. - UV-models were built for each wastewater with the off-line spectrophotometer - A commercial on-line spectrophotometer was purchased with external fundings - For the OECD and the UNAM wastewaters, the commercial on-line UV sensor is currently adapted, based on the off-line results, in cooperation of the SECOMAM company. The first prototype of an affordable sensor will be available in December 2004
<i>Task 3.3. Implementation of the on-line combined DOstat and pHstat titration biosensor on pilot plant</i>	- In July 2005, the TITAAN was installed on the LBE_INRA SBR reactor and integrated in the reactor monitoring system. - In May 2005, the STAC was installed on the LBE INRA SBR reactor. After some calibration and validation assays, it was integrated to on-line monitoring system of the SBR.

1.2.4. Software Sensor Development (WP4)

Involved participant : UCL, LBE

Methodology

WP4 is concerned with the design of software sensors, i.e. tools that allow to provide on-line values of key process components that are not accessible for on-line measurement. The software sensors under development are concerned with the on-line estimation of substrate and biomass concentrations from the on-line measurements of dissolved oxygen and nitrogen oxide in presence of uncertainty in the kinetics.

Activities

The design of software sensors has been first concentrating on the on-line estimation of biomass and substrate concentrations mainly in the context of the toxic compounds treatment plant described by model EM1 under the assumption (in line with the statistical

analysis of the model parameters) of poor knowledge of the kinetics parameters of the biomass growth (Haldane model). The approach considered for the EOLI project is a combination of an asymptotic observer with an adaptive observer that provides both state and parameter on-line estimates. So far, the mathematical analysis of the developed software sensors has been performed and these are tested in numerical simulations.

Another type of observers that include exclusively asymptotic observers have been designed for the LBE plan on the basis of model EM2b. These software sensors ignore the knowledge of the kinetics expression. They have been validated on real-life data.

Finally new tuning rules have been developed, analysed and tested in order to force rapid convergence of the software sensors, a key issue related to the limited time operation of the (fed-)batch processes involved in EOLI. The approach is based on an optimisation routine that computes values of the design parameters for the software sensors that minimize the Integral of the Time-weighted error of the Squared observation Error (ITSE).

Results

Task & Objectives	Progress towards achieving objectives (Outputs)
<i>Task 4.1 Software sensor specifications</i> Report the state-of-the-art of practically usable software sensors. Create from these characteristics a list of specifications for monitoring systems. Specify the characteristics of the robust software sensors to be developed based on the available hardware sensors and those to be developed within the project	- software sensor specifications for in terms of measurement and model constraints as well as in terms of application needs have been collected for each SBR process; - Uncertainty of the models has been evaluated on the basis of the WP2 results
<i>Task 4.2 Software sensor design</i> • Based on process configuration and process model, design of mass balance based observers for the prediction of time evolution of the unmeasured process components (including biomass) in the effluent and influent whenever needed and of key process parameters (such as specific growth rates and kinetic parameters) with minimal impact of uncertainties and reporting of fault residues and confidence intervals. • Incorporation of recalibration procedures based on on-line and off-line measurements and on fault residues and confidence interval measures. • Validation of software sensors with extensive simulations and confrontations with off-line data.	<i>Deliverable 4.1</i> - Design of combined adaptive and asymptotic observers for EM1 - Design of asymptotic observers for EM2 - Design of tuning rules based on ITSE criterion to guarantee fast estimation convergence - Test of the performance of the designed software sensors via extensive numerical simulations. - Validation of the observers on real-life data from the EOLI plants
<i>Task 4.3 Software sensors validation</i> Evaluation and validation of the performance of the software sensors via tests performed in lab-scale and full-scale conditions.	<i>Deliverable 4.2</i> - Validation of the observers on the EOLI plants

1.2.5. Control Design and Application (WP5)

Participants: LBE-INRA, UNAM, UU

Introduction

At UNAM, the biodegradation of a toxic compound by naturally occurring microorganisms is investigated. 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 (ED-TOC), which demonstrated being able to solve the desired optimizing criteria (minimum treating time), for the given restrictions, both under Standard conditions and under Shock load conditions. The comparison showed the

advantages of the ED-TOC. A lab-scale reactor (EOLI-UNAM-01) was used to obtain the first results. A second SBR (EOLI-UNAM-02), field scaled, is already built and is being commissioned. The activities of the LBE-INRA were dedicated to the evaluation and validation of the optimal control strategies developed for INRA SBR reactor.

Methodology and activities

a) At UNAM

During the reported period the assessment of the practical advantages of the ED-TOC (fed-batch operation mode), over the traditional Fixed Time Control (FTC) (batch operation mode), was done using three different approaches: 1) Simulation studies, 2) Theoretical assessment, and 3) Experimental tests using the lab-scale bioreactor. They all show real improvements in process and economic variables.

Standard condition long term experiments: More than 160 cycles were performed in continuous operation of the ED-TOC strategy under Standard conditions. In all the batches the ED-TOC behaved correctly. Results were reproducible and stable. No side effects for the biomass were detected because of operating it, constantly, near its maximum capabilities.

Shock load experiments: Shock toxicant loads, including an increase of the substrate concentration in the influent from the nominal value (350 mg4CP/L) up to 20 times such a value (7000 mg4CP/L), was performed to evaluate the improvement of ED-TOC operation over FTC. The results prove that the perturbation is rejected almost completely and that, even under such shock load conditions, the total treating time is less than the one needed using the previously known control strategies.

Moreover ED-TOC provides a savings potential over FTC of at least 25% in air consumption, at least 25% in stirring energy consumption, and almost 50% in reaction time. The daily applicable load incremented in excess of 63%.

Following the WP interaction policy, various additional tasks were performed:

Integration (Software/Hardware): The original software code programming (BIOREC) made for the lab-scale SBR was modified: 1) To allow its use in any of the hardware platforms, following the WP8 integration criteria; 2) The user interface, the control algorithm and the I/O functions are modular; 3) No code changes for simulation and control are required, so that the validation of software changes are simple. 4) It includes temperature effects in the Events Software-Sensor (ESS) for the ED-TOC, required by the field-scale SBR. It was first validated in simulation and then in both lab-scale (EOLI-UNAM-01) and field-scale (EOLI-UNAM-02) SBRs.

Field Scale SBR starting-up process: The field-scale SBR-UNAM-02 is now practically finished. The control software is already fully operational and validated and the I/O hardware has been thoroughly tested. The first ED-TOC batch was already performed successfully on 29 Sept 2005.

The possibility of using a WP3 hardware spectrophotometer sensor for the substrate concentration was studied. On-line integration seems not possible at this time.

b) At LBE-INRA

For the LBE reactor, 3 control strategies were developed and evaluated CS1, CS2 and CS3. In the last year of the project only CS2 and CS3 were evaluated. The main objective of these control laws is to minimize to total reaction time with the constraint to maintain high nitrification activity. The function of CS2 was to avoid a long non aerated phase by

introducing an aerobic phase between the settling and the anoxic phase. The switching instants were computed such that the total reaction time is minimal. This strategy was tested and evaluated during February, March, and April. This control is not always possible because, under some initial conditions, the process cannot be started with aerobic phase. In this case the strategy CS3 is applied. This strategy consists in changing the volume added in the reactor to change the initial concentration. With this strategy, the reactor is filled progressively with small volumes where the phases fill-anoxic-aerobic are sequentially applied until the reactor is full. Then settling and withdraw phases are applied.

Short term effect: Experimental results with CS2 and CS3 show that the dissolved oxygen is a good indicator of the reaction time: when the oxygen reaches the saturation values the reaction is finished. For CS2, it is shown that when it is possible to apply aerobic-anoxic-aerobic sequence, the reaction time is smaller than the reaction time of a cycle with anoxic-aerobic sequence. The improvement depends on the initial concentration.

Long term effect: First, recall that with CS1 the nitrification activity was lost in 3 weeks and with the standard operating mode the activity was continuously decreasing. With CS2 the nitrification activity was maintained for long period, the nitrification was full and all the nitrogen was converted into nitrites, but the reaction was very slow and the nitrification activity was low. When we applied the CS3, and using the on line monitoring TITAAN, we observed an increase of the nitrification activity.

Our conclusion comparing all the strategies is that to minimize the reaction time and maintain a high nitrification activity the best way is to use a small sequences fill-anoxic-aerobic or fill-aerobic-anoxic-aerobic where the initial concentration are not very high and the duration of each phase is not very long. This strategy avoids a long non aerated period and a long endogenous period where the bacteria decay rate is too high. The time minimization is granted using the algorithm developed in CS2 and it gives the sub-optimal switching instances. We observed also that this operating mode is not favorable for the filamentous bacteria growth.

Results

Task & Objectives	Progress towards achieving objectives (Outputs)
<i>Task 5.1. Specification of control variables and optimisation objectives</i>	Optimization objective is defined as treating every single 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 feed flow. Filling and reacting phases are modeled and considered for optimization. Settling and Drawing phases are not.
<i>Task 5.2 Design of optimal and adaptive suboptimal control laws</i>	A control law called "Event Driven Time Optimal Control" (ED-TOC) was proposed and implemented. By using the dissolved oxygen concentration value and the volume level value, the ED-TOC estimates, in real-time, the Oxygen Mass Uptake Rate (OMUR), related to the reaction rate. The influent flow rate is then controlled in such a manner that the OMUR stays near to the maximal value.
<i>Task 5.3 Control law validation</i>	3 different approaches for validation are taken. 1. Simulation using both MATLAB and LABVIEW. Results are satisfactory; 2. Experimental tests. Results are also satisfactory; 3. Theoretical proof of almost-optimality, convergence and robustness.
<i>Task 5.4 Process improvement evaluation</i>	Single experimental batch tests have been made to evaluate process improvement. Tests include perturbation of the substrate concentration in the influent going from the 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 almost completely and that, even under such shock load conditions, the total treating time is less than the one needed using the previously known control strategies.

1.2.6. Development of the Fault Diagnosis and Isolation (FDI) System (WP6)

Participants : UCL, LBE-INRA, UNAM, POLIMI

Activities

Taking into account the goals of WP6 and the second annual report in which the selection of actuators and sensors together with the feasible algorithms to solve the fault detection and isolation issues was discussed and the data issues to match the analytical model given by WP2 with the abnormal condition in the POLIMI reactor was pointed out, efforts during the third year [Nov-04, Oct-05] were concentrated in the following activities :

1. Extension of the detection method for actuator fault using Dynamic Principal Component Analysis with no stationary signals and its application to the case of a industrial valve.
2. Tuning of the parameters in the identification algorithm to detect a damage in the time constant of the DOx sensor.
3. Identification of the DOx Sensor Model & Filter Design for the POLIMI instrumentation.
4. Evaluation of cyclic data, specifically before and after excessive Nitrite outflow for POLIMI reactor.
5. Discussion about the specific analysis of abnormal conditions reported by POLIMI after the meeting in Uruguay.
6. Extraction of features and training of classification algorithms using in-situ respiration rate for the process fault detection in SBR at UNAM and POLIMI.
7. Extraction of features and training of classification algorithms using *in-situ* respiration rate.

The activities were carried in collaboration with WP4 and WP1 taking into account the following tasks :

- To get a redundancy relation which is necessary to solve a FDI issue with analytical methods, the deliverable D4.1 of WP4 was considered. The idea was to estimate the internal behavior of the EM1 reactor and from them to build the required redundancy.
- To establish the causal model for the POLIMI reactor, participants of WP6 established a communication with POLIMI. A collaboration work between E. Ficara and D. Wimberger in Milan was carried on. The data reported in WP1 for the POLIMI reactor were analysis together and some subsequently work was established.
- To propose together with POLIMI a possible solution to the excessive Nitrite outflow problem described as part of the deliverable D1.4 of WP1.

The rest of the activities this year was made collaborating with the UNAM participants.

Results

Results & Task Objectives	Progress towards achieving objectives
WP6.1 <i>Specifications of the FDI system</i>	• The FDI system assumes four components fault: 1) Damage in the sensor of DOx membrane, 2) Three different damages in a generic valve with control 3) Fault in the aeration system 4) Set of ab-normal conditions in the process EM1 during reaction time. • The specific abnormal conditions in the process are: deviations of the parameters K_i and K_s in model EM1 from the normal values given in WP2-D2.3; incomplete reaction cycle when a open loop control is implemented. • The nitrites build up issue was analyzed and recommendations for the monitoring of the

	process are given; however any specific FDI algorithm has been designed. This activities allowed the achievement of the first milestone of WP6: Specifications of a diagnostic system for SBR considering practical situations
<i>WP6.2 FDI System Design</i>	• A fault detection algorithm for a damage in the DOx membrane has been tested and adjusted by simulations. • An improvement of the DPCA has been proposed to detect fault when the variables do not satisfy the stationary condition and its has been applied specifically to the actuator fault selected in WP6.1 (servo-valve). • The analysis of the monitorability of the process by the model EM1 given in WP2-D2.3 concluded that the structure is very sensitive, even by simulations with only measurements of DOx. Only some part of the cycles and subset of variables of the process can be monitored. • A fault in the aeration system of the reactor can be detected estimating the parameter K_{La} online, each cycle of the process. • The existence of substrate at the end of the reaction cycle is considered as a fault in the process and can be detected on-line using the pattern of the DOx. • Considering the pattern recognition methods for abnormal conditions as the only way to supervise the evolution of the reactor during a set of cycles, characteristics extraction of the respiration rate estimation is proposed. Specifically a set of features of the respiration rate to classify normal deviations of K_i and K_s parameter are selected. Simulated data has validated the novel procedure. All these activities integrate the second milestone of the WP6 A set of validated (on the basis of simulation) FDI routines which guaranties the protection of the biomass in the SBR and are reported in D6.1 Diagnosis algorithms for robustly detecting and isolating of a number of sensor, actuator and process faults for discontinuous SBR.
<i>WP6.3 FDI Validation</i>	• The detection algorithm for damages in the membrane of the DOx sensor has been validated by simulation. • The detection of substrate as an abnormal condition at the end of the reaction cycle has been tested by simulation and with data off line. The implementation of the supervision system at the UNAM generates an alarm signal in the screen of the operator if this condition occurs. • Since there is not a way to emulate fault without a physical damage of the valve. The novel DPCA algorithm for the detection of the three faults in the valve was only tested using the software delivered as part of the EC Project DAMADICS. • The algorithm of parameters deviations detector from the normal conditions required extra effort, since only set of data exists for the lab-scale pilot plant. At this moment, the parameters K_i and K_s of the field scale reactor are not available. • The feasible tests of the algorithms has been done. For the rest of cases extra components are required to generate real irreversible physical damages in the equipment. These activities integrate the third milestone of WP6 Validation of the diagnosis algorithms at field scale pilot plant and tuning of the system before the integration and are reported in the deliverables D1.4 Report on the evaluation of the FDI System and D6.1
<i>WP6.4 FDI Integration</i>	The integration of the diagnosis algorithms within the supervision system has been made partially. Routines for the protection of hardware (2) and biomass (4) have been integrated in the supervision system of UNAM and are reported in the deliverable D1.6 Documentation for the implementation, the tuning and the use of the FDI and supervision system.

1.2.7. Supervision Sysem Development (WP7)

Participants : LBE-INRA, UNAM

Activities

Introduction

This document presents the implementation, the evaluation and the validation of the DSS developed for the EOLI solution. Although this system can be said to be "open" in the sense it can basically be applied to any SBR process, it has been specifically developed for two distinct processes (pilot processes of partners #2 and #6) and the application of the system to another process would require a minimum of adaptation. The system aims at detecting and classifying a number of abnormal, but expected, situations and afterwards at advising operators with a number of actions to be taken.

The report is split into two distinct parts with respect to the work that has been realized within the EOLI WP7 at the LBE-INRA, Narbonne, France, on the one hand and at the UNAM lab, Mexico City, Mexico, on the other hand.

Results

Tasks and objectives	Progress towards achieving objectives (outputs)
<i>WP7.2 Supervision system design</i> - Using a simple optic sensor available on the market, development and validation of a new monitoring strategy to maintain the appropriate sludge quantity into the system at the end of each time cycle. <i>WP7.3 Integration of the supervision module</i> - Connect the control and diagnosis algorithms within the software platform monitored by the supervision system. <i>WP7.4 Implementation and evaluation of the supervision system</i> - Evaluate the system in the presence of disturbances and actuator or sensor failures in lab-scale and field-scale conditions.	- The DSS initially developed for the management of the reaction phase was extended to deal with the sludge management. The system is based on a systematic detection of a too high sludge level after settling. In addition, the biomass withdraw has been automated in order to minimize human actions (for details, please refer to Deliverables D7.2). - In close cooperation with the partner in charge of the integration, the system was integrated and implemented on the pilot plant. Details about this step are given in the deliverables D8.i. - The last six month were devoted to the evaluation and to the validation of the integrated system on the pilot plant. It is now fully operational. The details about the evaluation are given in D1.5.

Pilot plant at the LBE-INRA (J. Harmand, D. Mazouni, N. Fiocchi)

The implemented system consists in the hardware and software modules implemented by SPES. This system basically interacts with the plant, performs data acquisition and store these data in two distinct databases (a local one and a - possibly decentralized - one). Within the framework of the project, the local database is at the LBE, INRA, Narbonne, France while the decentralized one is at SPES location, Fabriano, Italy. The local database stores a shorter time period of data than the decentralized database which stores the totality of available data. As explained above and depending on the actual instrumentation available on the process, beside this independent running system, either the Matlab modules described in the deliverables D7.1 to D7.4 or the additional modules described hereabove run now on-line being able to analyze each cycle to decide whether the system operates in standard mode or not, and if not, from which mode from the database it is actually the closest. For details about the technical approaches used to classify such situations in the case 1, please refer to the deliverables D7.1 to D7.3. For details about its validation, refer to

D7.4. Hereabove, we present the system that has been developed for i) the supervision in the case #2 and ii) for the automatic management of the sludge for the optimization of the SBR operations. Details are given in the annex.

Pilot plant at the UNAM lab (Report of activities of UNAM in WP7, May05 to Sep05 by Manuel Betancur)

The reported activities are part of the objectives WP7.3 Integration of the supervision module and WP4 Implementation and Evaluation of the Supervision Module for the UNAM SBR field scale pilot plant and consists basically on the Development of the real-time BioReC (BioReactor Control) software in order to implement the safely automation of the field-pilot SBR. It was written using the LABVIEW high level language and interfaced with the process I/O Beckhoff modules via the MODBUS open protocol.

The design and implementation of the fault detection and isolation routines to satisfy with a set of safety features which are classified as hardware and variables monitoring of the process. The routines have been tested emulating abnormal conditions in the field scale SBR at the UNAM.

Hardware supervision and monitoring :

- Actuator command and status report. Each time the controller systems commands an actuator to change its state a report is issued to the online-events file. Another report is issued also the moment the actuator does indeed change its state as expected. Devices: Air Blower, Stirrer, Influent pump, Effluent pump, and Purge valve.
- Actuator error detection. If the actuator fails to respond to the command issued by the controller (except if Manual operation mode is selected) for more than 10 seconds then an alarm is issued to the operator and a report is issued to the online-events file. This feature is implemented for the following actuators: Influent pump, Effluent pump.

An additional module allowing the monitoring of the limits of the process was developed and evaluated during the last six months. Details of this routine are given in the Annex.

1.2.8 Validation and integration (WP8)

Involved partners : UCL, LBE-INRA, POLIMI, Gradient, SPES, UNAM, UU, IBTech

Methodology (steps 3, 4 and 5)

- To investigate an efficient distribution of probes, sensors and of the computational resources to make possible the reduction of the monitoring and control action cost and of the number and the expertise required to the plant workers.
- To delocalise intelligence (logical and control functions) at the local sensor and actuator level over the plant, optimising the ratio cost/performance through the design of hardware and software expressly suited to match the plant needs and to reduce the presence of expert operators during the regular work of the plant.
- To integrate all the modules of hardware sensors on the one hand and of software sensors, control, FDI and DSS on the other hand into a compact hardware and software module ready to be used for the project and for the potential users.
- To evaluate the integrated monitoring and control system and its performance.

Activities

During the third year of the project the major objective of the WP8 was the integration and validation of the EOLI supervision system on multiple plants.

The EOLI supervision system was tested and validated at the two pilot SBR plants engaged in the project: the one located at the INRA-LBE facilities and the other one provided by the ENEA and located at the site of a full scale plant. During the third year both plants were equipped with the EOLI hardware and software main frame – the EOLI digital platform developed to integrate several hardware and software components produced to manage the plant- described in the deliverable D8.3 in its first release realized in prototypal versions by SPES.

With the aim to validate the EOLI system under different architectures for the integration than the one developed in the project, so that the policy for exploitation and dissemination of the results could be enforced, UNAM and UU, who during the previous two years developed their own systems for the monitoring and control, modified these systems in order to adapt them to run and to test some EOLI software modules at two lab plants (UU) and at the full scale plant built up by IbTech, sending the data to the EOLI remote server.

Starting from the beginning of November 2004, at the ENEA pilot plant a complete field test of the digital platform and its hardware and software components was performed. In this phase of the project, as far as the hardware sensor integration concerned, the biosensor titration TITAAN – developed in WP3 - was run and tested in parallel at the ENEA pilot plant: the TITAAN is managed by the main board of the EOLI digital platform in the same way of a slave board, connected by a RF link or a serial link, that's why the TITAAN is provided with the same kind of links as it is a slave board (see deliverable D8.2 for details). So its integration is attended by simply enrolling the variables needed for the management of the measurements produced into the EOLI local software, and this implies automatically the update of the database tables.

When the field test was over, in July the platform was installed at the INRA pilot plant for the integration of the other hardware sensor – the UV sensor – and of the Matlab Modules (control and supervision) and for the validation of the whole EOLI supervision system.

The UV sensor is managed by a devoted PC: the EOLI system interact with this alien PC using a software module as media. As a consequence the integration of this hardware sensor is reduced to the enrolment of the related both software module and variables, to manage the measurements produced, into the SPESGateway - the EOLI local Software (for more details see deliverable D8.4) –actions that automatically imply the update of the database tables.

At the same time, the TITAAN was shipped to Narbonne and installed at the INRA pilot plant too. At present the full integrated system is running at the pilot plant in Narbonne.

The milestone fixed at T0+29 (Field test of the hardware (electronic) main frame) and the other one fixed at T0+35 (Validation tests of the hardware and software main frame of the system) were checked with positive results.

The EOLI remote control centre was set up. The lab and pilot scale plants enrolled in the EOLI system are: two lab plants at UU, two pilot plants, one at INRA and the other one at ENEA, and one full scale plant at IbTech in Mexico. The data from these plants are available at the remote server. At the login page <http://82.190.245.149/eoli>, a public login, user name demo, password demo, is available to experience the general features and functionalities of the EOLI systems as far as the remote monitoring and control of the plants.

Results

Task & Objectives	Progress towards achieving objectives (Outputs)
<i>Task 8.2. Sensor configuration network selection</i> Objectives: Selection of the most suitable hardware + software sensor configurations, starting from the simplest one to the most complex	Experiments were running at lab (UNAM and UU) and pilot (POLIMI_ENEA and LBE) plants to validate the two sensor network configurations defined. Deliverable D8.2 was delivered in draft version
<i>Task 8.4. Hardware and Software validation</i> Objectives: Evaluation and validation of the hardware and software main frame of the system via tests performed in laboratory, pilot and full scale plants.	The EOLI integrated system was installed at the two pilot plants. Experiments were running at pilot (POLIMI-ENEA and INRA-LBE) plants to validate the EOLI supervision system and to integrate the software modules provided by other WPs and the two hardware sensors developed in WP3. Also two lab plants at UU and one full scale plant at IbTech were involved in the validation of the software modules to enforce the exploitation activity. The EOLI remote control centre was set up. All the plants mentioned above can be accessed at the login page http://82.190.245.149/eoli. Deliverable D8.3 was provided in its final version Deliverable D8.4 was provided in draft version

1.3. Problems encountered

WP1

POLIMI: part of the job has been delayed by the hard winter that slowed down the operation of the pilot plant in Bologna and delayed the shipping of TITAAN to Narbonne (it arrived at Narbonne on July 6th, while it was planned at the end of April).

UU: Poor settling capacity for Reactor M is still unsolved. Attempts to reduce it have improved the settling velocity, but more effort is still needed to overcome this problem. Long term stability could not be completely evaluated, as OD and pH probes should be purchased for this.

1.4. Publications and Papers

Betancur M.J., J.A. Moreno, I. Moreno-Andrade and G. Buitrón (2005) Practical Optimal Control of Fed-Batch Bioreactors for the Waste Water Treatment, *International Journal of Robust and Nonlinear Control*, accepted for publication.

Betancur M.J., J.A. Moreno, I. Moreno-Andrade and G. Buitrón (2005). Control strategies for treating toxic wastewater using bioreactors, 16th IFAC World Congress. 4-8/07/2005, Praha, Czech Republic.

Betancur M.J., I. Moreno-Andrade, J.A. Moreno, D. Dochain and G. Buitrón (2005). Modeling for the optimal biodegradation of toxic wastewater in a discontinuous reactor. *4th IWA Activated Sludge Population Dynamics Specialist Conference. Microbial Population Dynamics in Biological Wastewater Treatment (ASPD4)*, 17-20/07/2005. Queensland, Australia.

Betancur M., D. Mazouni, J. Harmand and J. Moreno (2006). Optimal control of biological SBR's for the treatment of dairy and toxic wastewater, *5th MATHMOD VIENNA, IMACS Symposium on Mathematical Modelling*, Vienna, 8-10 février 2006.

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- Ignatova, M., J. Harmand, M. Herveau, D. Mazouni and D. Dochain (2005). A comparison of simple mass-balance models for the control of biological sequencing batch reactors used for carbon and nitrogen removal, *In preparation*.
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- Mazouni, D., M. Ignatova and J. Harmand (2005) "A multi model approach for the monitoring of carbon and nitrogen concentrations during the aerobic phase of a biological SBR", *IFAC 2005 World Congress*, July, 4-8 2005, Prague, Czech republic.
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1.5. Planning

WP1

Both laboratory and field-scale plants are going to be operated in order to finish the data acquisition for the long term stability. At UNAM the mixing capacity of the field scale plant is going to be determined.

At UU : Reactor M and F: control law with a minimum feeding period will be tested. Reactor F: Environmental aspects related with nitrite build-up will be evaluated, in order to compare with POLIMI results

WP3

The TITAAN and STAC sensors will be used for monitoring the SBR reactor in Narbonne. In particular, the models used by the STAC will be refined with increasing the number of SBR cycles. The TITAAN prototype will be switched to the automatic configuration. A series of toxicity tests with typical toxicants (as ATU and chlorophenol) has been planned and Modes 3 to 5 will be tested on the prototype.

At UU : Reactors M and F: control law will be tested on both reactors with the filling phase duration reduced.

WP5

At UNAM: Validation of the control law on the field-scale SBR will be made.

At LBE-INRA: 1) Optimisation of the SBR by management of the durations and the orders of anoxic and aerobic phase. 2) Effect of the filling volume on the SBR phases.

At UU : Experiments on sludge settling ultrasonic measurements will be repeated for sludges of different industrial sources.

WP6

The WP6 will concentrate to design the user guide which helps the responsible of a plant to configure the process and take actions in abnormal conditions. This task will allow to generate the D6.2

WP8

Integration procedures will implement other TITAAN's modes of operation (Mode 2 and 3 at least).

2 MANAGEMENT REPORT

2.1 Project organisation

2.1.1 Administrative structure

The project coordination was discussed at the Kick-off meeting held in November 2002 in Narbonne, France (Figure 2). The CESAME-UCL acts as the overall project coordinator with links to the partners. It was agreed that the overall project coordinator (CESAME-UCL), coordinates all administrative and technical activities including financial flows and cost statements. Within CESAME, Prof. Denis Dochain acts overall project manager, while Mrs. Isabelle Hisette carries out the administrative aspects of the management of the project.

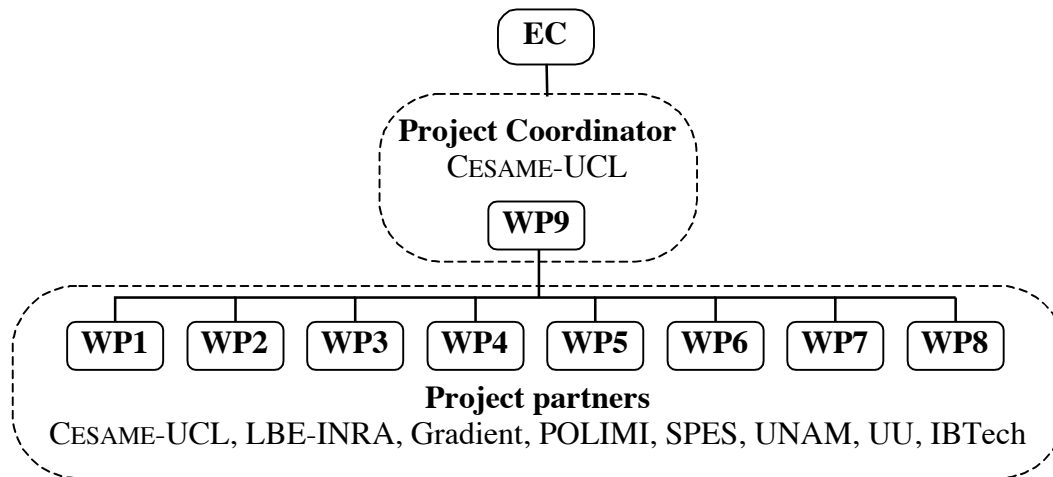


Figure 2. Coordination structure for EOLI

The writing, compilation and editing of the progress and scientific reports are coordinated by the task leaders (see Table 1), which in turn submit the compiled reports to the overall coordinator for final editing.

Table 1. WP Task leaders

Task	Title	Task leader
WP1	Process experiments	Germán Buitrón, UNAM
WP2	Model selection and parameter identification	Rafael Canetti, UU
WP3	Hardware sensors development	<i>André Pauss, GRADIENT</i> *
WP4	Software sensors development	Denis Dochain, UCL
WP5	Control design and application	Jaime Moreno, UNAM
WP6	Fault Detection and Isolation (FDI) system	Cristina Verde, UNAM
WP7	Supervision system development	Jérôme Harmand, INRA
WP8	Validation and integration	Paolo Ratini, SPES
WP9	Project coordination	Denis Dochain, UCL

2.1.2 Communication

During the period under review, e-mail and fax connections between partners facilitated regular exchange of information, data, reports and management information.

* replaces Alberto Rozzi, POLIMI

A project website (<http://www.auto.ucl.ac.be/EOLI/>) is operational with a specific section for project communication between partners (only accessible by the project partners). The main objective of the website is to disseminate information about the project and project outputs to the research and development community.

More precisely, this web site contains the following information:

- Public area: information that is accessible for public
 - Welcome page: introduction of the project;
 - Scope of project: general objectives of the project;
 - Partners: all institutions implying in the project with the contacting persons;
 - Publications: all papers that are made during/within the project;
 - News: any actual news involving the project;
 - Event: meetings;
 - Links: partners' web sites, EC web site.
- Restricted area: password is needed (reserved for members)
 - General documents: technical annexes, member addresses, data format (agreeing format to exchange data between partners), INCO reporting guide, EC financial report form;
 - Meetings reports: all documents presented in EOLI meetings
 - Achieved results with respect to deliverables
 - Progress reports: including the first annual report

Moreover, in order to further guarantee the successful operation of each WP and the coordination between WP's during this year where all the WP have been active, each WP leader was preparing a monthly activity report based on the activities within his/her Work Package. These reports have been sent every month to the project coordinator from the mid-term meeting.

2.1 Meetings

The second annual EOLI meeting was held in Milano (Italy) on November, 22nd –24th, 2004. The third year mid-year meeting took place in Montevideo (Uruguay) on May 5th-7th, 2005. Tables 2 and 3 provide an overview of the information related to the project meetings organized during the reporting period and planned for the following years, respectively.

Table 2. Project meetings during the third year of the project

Period	Place	Purpose	Participants	Results
November 22 nd -24 th , 2004	Milano, Italy	Second annual meeting	All project partners	Second annual report, minutes of the meeting
May 9 th -11 th , 2005	Montevideo, Uruguay	mid-year meeting	All project partners	minutes of the meeting
October 17 th -19 th , 2005	Mexico City, Mexico	Third annual meeting	All project partners	Third annual report, minutes of the meeting

Table 3. Planned meetings for the following year

Period	Place	Purpose
April 2006	Narbonne, France	Final project meeting

During the third year of the project, many meetings took place with the objective to increase the cooperation among the different groups with a particular concern for the integration activities of WP8. Meetings with IBTECH and UNAM WP1, WP2 and WP6 participants were held when necessary, specially to give advice and guidelines for the construction and the commissioning of the field scale pilot reactor (EOLI-UNAM-02) by IBTECH. On January 24th 25th and 26th, Jérôme Harmand and Djalel Mazouni had a meeting in Milano with SPES and POLMI to prepare the integration with SPES platform and TITAAN. On February 2nd and 3rd, GRADIENT group had a meeting in Narbonne to prepare the integration of the UV sensor (Gradient 's Hardware sensor).. He is working also on the supervision algorithm. From May 15th to 30th, Miriem Bekri from Gradient came to Narbonne for the start up of the UV sensor (Gradient hardware sensor). From July 6th to 18th SPES people were in Narbonne for the installation of the SPES platform and TITAAN. On July 13th, there has been a meeting in Narbonne with André Pauss and Olivier Schoefs from Gradient, Roberto Canziani and Nicola Fiocchi from POLIMI, Paolo Ratini from SPES, Jerome Harmand, Michel Torrijos, Jean Claude Bouvier and Djalel Mazouni from LBE-INRA. The object of the meeting was reporting the actual stat and planning experiment for validation and integration of the whole system.

2.3 Exchanges

On May 2nd, Nicola Fiocchi, came to Narbonne for 7 monts for the start up and the evaluation of TITAAN Alexander Schaum, master degree student from the Institut für Systemdynamik und Regelungstechnik of the University of Stuttgart, stayed 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"

2.4 Problems

No specific problem has been encountered over the third year in the management of EOLI.

3 INDIVIDUAL PARTNER REPORTS

3.1 CESAME-UCL

Participating staff

Name	Background	Activities in EOLI
Prof. Denis Dochain	Biotechnological/ chemical process control scientist	WP 4, 8 and 9
Mr. Cédric Henri	Chemical engineering scientist	WP 4, 8 and 9
Mrs. Isabelle Hisette	Secretary	WP 9

Activities

In the third year of the project, the activities were carried out within the software sensor development (WP4), the validation and integration (WP8) and the project coordination (WP9).

Software sensor development (WP4)

Motivation

This activity in the third year has been mainly dedicated to the development of appropriate tuning rules that will fit to the specific features of time limitation of batch and fed-batch reactor operation.

If we consider the following state space model of order n :

$$\frac{dx}{dt} = f(x, u) \quad (1)$$

where the measured variables y are related to the state variables x and the inputs u by:

$$y = h(x, u) \quad (2)$$

the general structure of a state observer can be written as:

$$\frac{d\hat{x}}{dt} = f(\hat{x}, u) + K(\hat{x})(y - \hat{y}) \quad (3)$$

where $\hat{x}$ and $\hat{y}$ are the on-line estimates of x and y given by:

$$\hat{y} = h(\hat{x}) \quad (4)$$

with $K(\hat{x})$ the observer gain.

It is well known that the design of classical observers consists of choosing an appropriate gain, $K(\hat{x})$, such that the error dynamics has some desired properties (Dochain, 2003a). In the case of the extended Luenberger observer (ELO), the objective is to select $K(\hat{x})$ such that the linearised error dynamics around the process dynamics observation error e ($e = x - \hat{x}$) is asymptotically stable.

ITSE Observers

On the other hand the problem of choosing the appropriate gain $K(\hat{x})$ for ITSE observers becomes an optimisation problem. It consists on finding $K(\hat{x})$ that minimizes the following objective function J :

$$J = \int_0^T t e^2(t) dt \quad (5)$$

With T being an appropriate window of time. In this way the design of the observer includes minimization of the observation error together with better convergence rates.

First of all the ITSE observer was tested for a simple CSTR process with Monod kinetics (Dochain, 2003b).

The model dynamics is described by the following equations:

$$\frac{dS}{dt} = -k_1 \mu X + D S_{in} - D S \quad (5)$$

$$\frac{dX}{dt} = \mu X - D X \quad (6)$$

With k_1 , μ , D and S_{in} being the yield coefficient, the specific growth rate (h^{-1}), the dilution rate (h^{-1}) and the influent substrate concentration (gL^{-1}) respectively.

$\mu = \frac{\mu_{max} S}{K_S + S}$ being a Monod kinetics with μ_{max} the maximum specific growth rate (h^{-1}) and K_S the saturation constant (gL^{-1}).

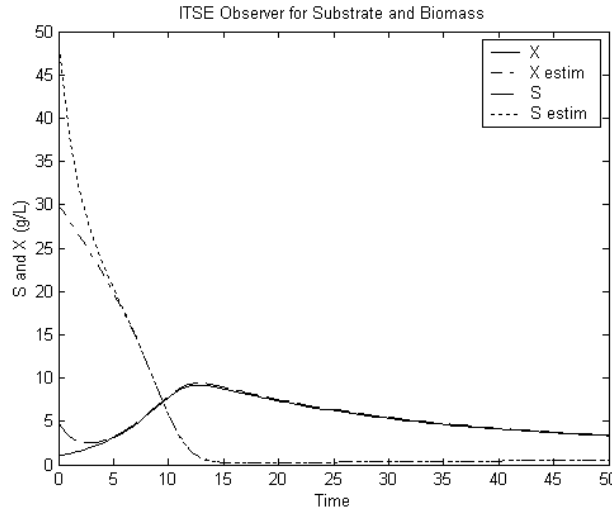


Fig 1. ITSE observer for biomass (X) and substrate (S) concentrations for a simple CSTR process

The observer equations become:

$$\frac{d\hat{S}}{dt} = -k_1 \mu_{max} \frac{\hat{S}}{K_S + \hat{S}} \hat{X} + D S_{in} - D \hat{S} + K_1 (S - \hat{S}) \quad (7)$$

$$\frac{d\hat{X}}{dt} = \mu_{\max} \frac{\hat{S}}{K_s + \hat{S}} \hat{X} - D \hat{X} + K_2 (S - \hat{S}) \quad (8)$$

Considering the value of the parameters included in Deliverable 2.3 and the following initial values $X(0)=1$ (gL⁻¹), $\hat{X}(0)=5$ (gL⁻¹), $S(0)=30$ (gL⁻¹) and $\hat{S}(0)=50$ (gL⁻¹) the ITSE observer performs as it can be seen in Figure 1

The ITSE performance was then compared with an ELO observer with gains K_1 and K_2 selected as indicated in (Dochain, 2003b) with $\lambda_1 = \lambda_2 = -0.1$ being the selected poles of the error dynamics (see Figure 2).

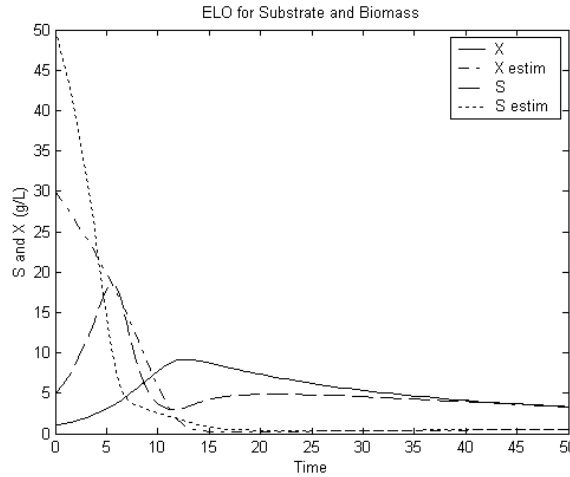


Fig. 2. Extended Luenberger Observer for biomass (X) and substrate (S) concentrations for a simple CSTR process

It can be noticed that the ITSE observer performs better than ELO with very good convergence properties.

Application to model EM2b

Recall that the dynamics of the process in Narbonne are given by the following mass balance equations (model EM2b) :

Anoxic phase

$$\frac{dX_h}{dt} = \mu_{hN} X_h \quad (9)$$

$$\frac{dS_C}{dt} = -k_1 \mu_{hN} X_h \quad (10)$$

$$\frac{dS_{NO}}{dt} = -k_2 \mu_{hN} X_h \quad (11)$$

$$\frac{dS_{NH}}{dt} = k_3 r_N \quad (12)$$

$$\frac{dS_N}{dt} = -r_N \quad (13)$$

Aerobic phase

$$\frac{dX_h}{dt} = \mu_h X_h \quad (14)$$

$$\frac{dX_a}{dt} = \mu_a X_a \quad (15)$$

$$\frac{dS_c}{dt} = -k_4 \mu_h X_h \quad (16)$$

$$\frac{dS_o}{dt} = -k_5 \mu_h X_h - k_6 \mu_a X_a + k_L a (S_{O_{\max}} - S_o) \quad (17)$$

$$\frac{dS_{NO}}{dt} = k_7 \mu_a X_a \quad (18)$$

$$\frac{dS_{NH}}{dt} = k_3 r_N - k_8 \mu_a X_a \quad (19)$$

$$\frac{dS_N}{dt} = -r_N \quad (20)$$

Where S_c , S_{NH} , S_{NO} , S_N , S_o , X_h and X_a are the biodegradable substrate concentration (carbon, mgCOD/L), the ammonia nitrogen concentration (mgN/L), the nitrate and nitrite concentration (mgN/L), the soluble organic nitrogen (mgN/L), the concentration of the dissolved oxygen (DO) in the water (mg/L) and the concentration of the digester biomasses (heterotrophs and autotrophs)(mgVSS/L), respectively.

$$\text{And } k_1 = \frac{1}{Y_{hN}}; k_2 = \frac{1 - Y_{HN}}{2.86 Y_{HN}}; k_4 = \frac{1}{Y_h}; k_5 = \frac{1 - Y_h}{Y_h}; k_6 = \frac{\beta_1}{Y_a}; k_7 = \frac{\beta_2}{Y_a}; k_8 = \frac{1}{Y_a}$$

and the following kinetic expressions:

$$\mu_{hN} = \mu_{hN \max} \frac{S_c - S_{c \min}}{K_{C1} + S_c - S_{c \min}} \frac{S_{NO}}{K_{NO} + S_{NO}} \quad (21)$$

$$r_N = \mu_0 (S_N - S_{N \min}) \quad (22)$$

$$\mu_h = \mu_{h \max} \frac{S_c - S_{c \min}}{K_{Ch} + S_c - S_{c \min}} \frac{S_o}{K_{Oh} + S_o} \quad (23)$$

$$\mu_a = \mu_{a \max} \frac{S_{NH}}{K_{NHa} + S_{NH}} \frac{S_o}{K_{Oa} + S_o} \quad (24)$$

ITSE Observer for the Anoxic Phase

In order to illustrate the performance of the ITSE observer in the SBR, we first proceed with the anoxic phase.

In a first step and taking into account that the system of equations (9)-(11) is not observable with only one measurement (S_{NO}) (the observability matrix constructed from the Jacobian of system (9)-(11) is of rank 2), we start by developing an asymptotic observer for S_c as follows :

$$\text{Let } Z = \frac{-k_2}{k_1} S_c + S_{NO} \quad (26)$$

Then the asymptotic observer which is independent from the specific kinetics is written as follows :

$$\frac{d\hat{Z}}{dt} = 0 \quad \text{and} \quad \hat{S}_C = \frac{-k_1}{k_2} (\hat{Z} - S_{NO}) \quad (27)$$

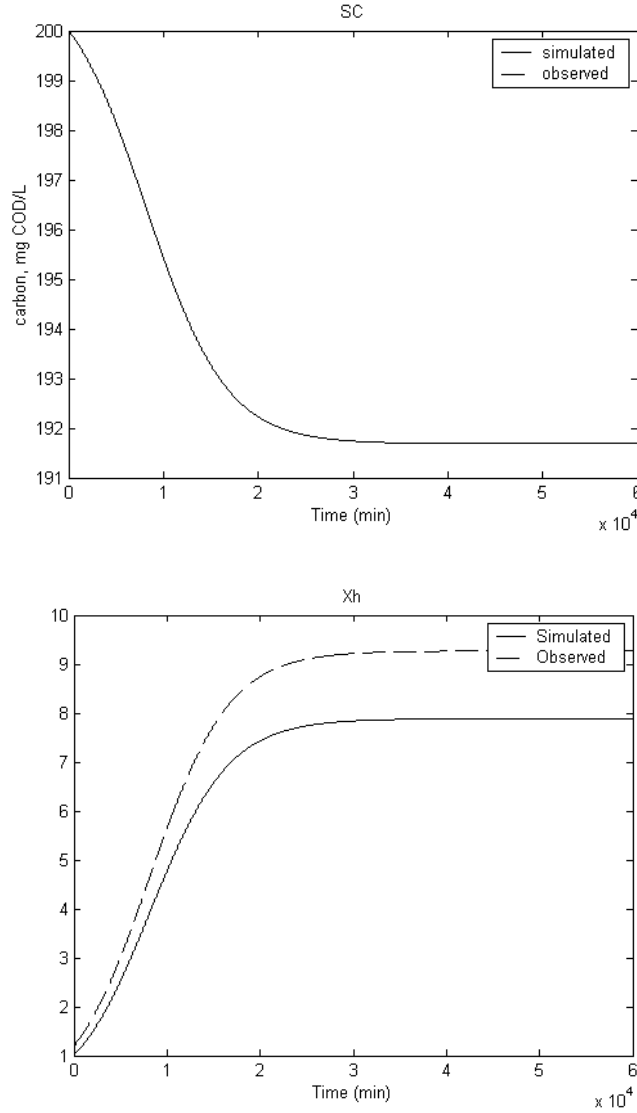


Fig. 3. ITSE Observer for S_c and X_h during the anoxic phase of the wastewater treatment process with a 20% error in the initial condition of X_h

Then, by considering the already determined $\hat{S}_C$ in a second step, we developed the following observer :

$$\frac{d\hat{X}_h}{dt} = \hat{\mu}_{hN} \hat{X}_h + K_1 (\hat{S}_{NO} - S_{NO}) \quad (28)$$

$$\frac{d\hat{S}_{NO}}{dt} = -k_2 \hat{\mu}_{hN} \hat{X}_h + K_2 (\hat{S}_{NO} - S_{NO}) \quad (29)$$

with

$$\hat{\mu}_{hN} = \mu_{hN \max} \frac{\hat{S}_C - S_{C \min}}{K_{C1} + \hat{S}_C - S_{C \min}} \frac{\hat{S}_{NO}}{K_{NO} + \hat{S}_{NO}} \quad (30)$$

Considering the parameter values of Deliverable 2.3 and the following initial values: $X_h(0)=1$; $\hat{X}_h(0)=1.2$; $S_C(0)=S_C(0)=200$ (carbon, mg COD/L); $S_{NO}(0)=\hat{S}_{NO}(0)=0.5$ (mg N/L) which correspond to a 20% error in the initial observed value of X_h . The ITSE observer performs as shown in Figure 3.

As it can be seen in Figure 3, the ITSE is biased for X_h observation. In fact it happens that X_h can be poorly observed from S_{NO} measurements. The observability test shows that the observability matrix constructed from the Jacobian of system equations (1) and (3) is of rank 2 if and only if $\mu_{hN} \gg 0$ which is not at all the case. This is also the reason why the equivalent ELO performs in a very unstable way. It can be proved that the gain K_1 of the ELO has μ_{hN} in a denominator.

ITSE Observer for the Anoxic and Aerobic Phase

In a first step we begun by developing an asymptotic observer for X_a as follows :

$$\text{Let } Z = k_7 X_a - S_{NO} \quad (31)$$

Then the asymptotic observer which is independent from the specific kinetics is written as follows :

$$\frac{d\hat{Z}}{dt} = 0 \quad \text{and} \quad \hat{X}_a = \frac{1}{k_7} (\hat{Z} + S_{NO}) \quad (32)$$

By considering the estimated value of $\hat{X}_a$ given by the asymptotic observer, the observer for the other state variables considering that S_O , S_{NO} and S_{NH} are measured variables is given by the following set of equations :

$$\frac{d\hat{S}_N}{dt} = -\hat{r}_N + K_1 (\hat{S}_{NH} - S_{NH}) \quad (33)$$

$$\frac{d\hat{S}_{NH}}{dt} = k_3 \hat{r}_N - k_8 \hat{\mu}_a \hat{X}_a + K_2 (\hat{S}_{NH} - \hat{S}_{NH}) \quad (34)$$

$$\frac{d\hat{X}_h}{dt} = \hat{\mu}_h \hat{X}_h + K_3 (\hat{S}_O - S_O) \quad (35)$$

$$\frac{d\hat{S}_C}{dt} = -k_4 \hat{\mu}_h \hat{X}_h + K_4 (\hat{S}_O - S_O) \quad (36)$$

$$\frac{d\hat{S}_O}{dt} = -k_5 \hat{\mu}_h \hat{X}_h - k_6 \hat{\mu}_a \hat{X}_a + k_L a (S_{O \max} - \hat{S}_O) + K_5 (\hat{S}_O - S_O) \quad (37)$$

and the following kinetic expressions:

$$\hat{\mu}_{hN} = \mu_{hN \max} \frac{\hat{S}_C - S_{C \min}}{K_{C1} + \hat{S}_C - S_{C \min}} \frac{\hat{S}_{NO}}{K_{NO} + \hat{S}_{NO}} \quad (38)$$

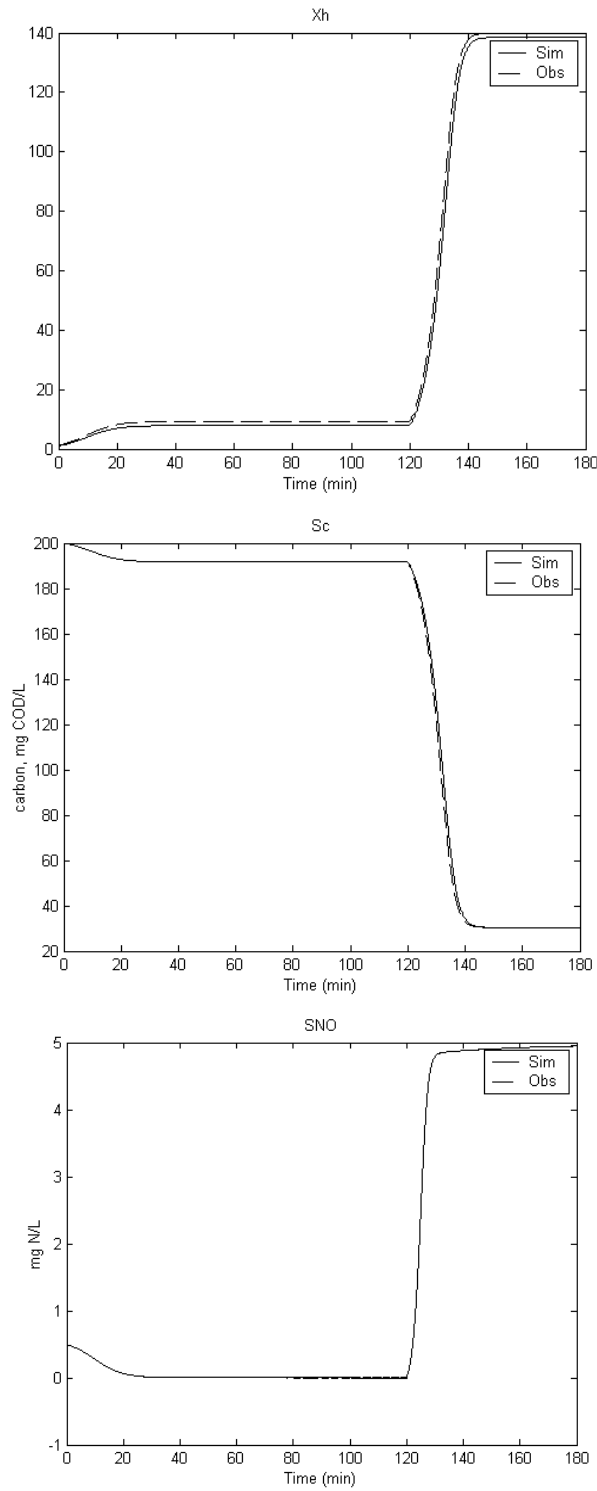


Fig. 4. ITSE Observer for S_c , X_h and S_{NO} during the anoxic and aerobic phase of the wastewater treatment process with a 20% error in the initial condition of $X_{h,}$, $S_{NH,}$, S_N , X_a and S_O

$$\hat{r}_N = \mu_0 (\hat{S}_N - S_{N\min}) \quad (39)$$

$$\hat{\mu}_h = \mu_{h \max} \frac{\hat{S}_C - S_{C \min}}{K_{Ch} + \hat{S}_C - S_{C \min}} \frac{\hat{S}_O}{K_{Oh} + \hat{S}_O} \quad (40)$$

$$\hat{\mu}_a = \mu_{a \max} \frac{\hat{S}_{NH}}{K_{NH} + \hat{S}_{NH}} \frac{\hat{S}_O}{K_{Oa} + \hat{S}_O} \quad (41)$$

Taking into account that S_{NO} is a measured variable we shall only consider that:

$$\frac{d\hat{S}_{NO}}{dt} = k_7 \hat{\mu}_a \hat{X}_a \quad (42)$$

Considering the value of the parameters included in (Betancur et al, 2003) and the following initial values: $X_h(0)=1$; $\hat{X}_h(0)=1.2$; $S_C(0)=\hat{S}_C(0)=200$; $S_{NO}(0)=\hat{S}_{NO}(0)=0.5$; $S_{NH}(0)=0.1$; $\hat{S}_{NH}(0)=0.12$; $S_N(0)=20$; $\hat{S}_N(0)=24$; $X_a(0)=1$; $\hat{X}_a(0)=1.2$; $S_O(0)=0.010$; $\hat{S}_O(0)=0.012$. The ITSE observer performs as shown in Figure 4.

It is worth noting that the ITSE performs very well even with the important initial errors in some of the observed variables. Another advantage over the ELO is that the observer gains are easy to determine which is not the case for the ELO when the system is of high order.

References

- Dochain D. (2003a). State and parameter estimation in chemical and biochemical processes : a survey. *Journal of Process Control*, **13** (8), 801-818
 Dochain D. (2003b). State observers for processes with uncertain kinetics. *Int. J. Control*, **76** (15), 1483-1492

Validation and integration (WP8)

In WP8 the activity of the CESAME was mainly interms of support of transferring the developed software sensors into the FDI and supervision systems as part of the control system implemented both in Mexico and in Narbonne.

Publications

- Betancur M.J., I. Moreno-Andrade, J.A. Moreno, D. Dochain and G. Buitrón (2005). Modeling for the optimal biodegradation of toxic wastewater in a discontinuous reactor. *4th IWA Activated Sludge Population Dynamics Specialist Conference. Microbial Population Dynamics in Biological Wastewater Treatment (ASPD4)*, 17-20/07/2005. Queensland, Australia.
 Fibrianto H., D. Mazouni, M. Ignatova, M. Herveau, J. Harmand and D. Dochain (2006) : "Dynamical modelling, identification and software sensors for SBR's", *5th MATHMOD VIENNA, IMACS Symposium on Mathematical Modelling*, Vienna, 8-10 février 2006.
 Ignatova, M., J. Harmand, M. Herveau, D. Mazouni and D. Dochain (2005). A comparison of simple mass-balance models for the control of biological sequencing batch reactors used for carbon and nitrogen removal, *In preparation*

3.2 LBE-INRA

Participating staff

Name	Background	Activities in EOLI
Jérôme Harmand	Process control scientist	WP2, WP3, WP5 WP7, WP8,
Michel Torrijos	Biotechnological / Bioprocess scientist	WP 1, WP7
Djalel Mazouni	Process control PhD student	WP2, WP4, WP5 WP7, WP8
Nicola Fiocchi	Sanitary Engineering PhD student	WP1, WP3, WP7, WP8

Activities

In the last year of the project, the LBE-INRA was involved in most of the work packages activities. The activities of the LBE-INRA with respect to WP1 for the third year were dedicated to the evaluation of the whole integrated system. Firstly, supervision algorithms and optimal control strategies developed, respectively within WP7 and WP5 for INRA SBR reactor, were evaluated and validated. In a second step, the hardware sensors developed within WP3 were tested, improved then validated. Finally, all the modules tested on the SBR in Narbonne were integrated together with the platform developed within WP8. The whole system, was tested and evaluated and is currently running.

With respect to WP2 a new simplified model structure for LBE SBR was proposed, evaluated and validated and some observers were evaluated within WP3. The control algorithms developed within WP5 for the LBE SBR were theoretically studied and improved. Within WP6 and WP7 some results about the monitoring of reaction phases and settleability were proposed and evaluated.

Experiments and Results of the third year

During the last year, and in order to validate and evaluate the whole EOLI system developed in the project for the Narbonne's SBR, two kinds of measurements were done : Low Frequency measurement (LF) and High Frequency measurement (HF).

For the low frequency measurement, around twice a week, the influent and the outlet effluent were characterised by measuring CDO, TKN, nitrites and nitrates. TSS and VSS in the reactor were also measured. This set of measurements was dedicated to the long-term evaluation of the different control and supervision algorithms applied to the reactor.

The high frequency measurement, between two and ten samples per SBR cycle, was used for:

- evaluate the control strategies;
- model validation;
- on-line sensor calibration and validation.

These measurements were globally COD, nitrites and nitrates inside the reactor and during the reaction phases. The schedule of the experiments is shown in table 1. In this section we give a brief description of the results obtained for each experiment. Each experiment is described in details in the related deliverables and in the next section of this report. See for

instance D5.1 and D5.2 for the control strategies named CS2 and CS3, the WP6 report for supervision algorithms and the WP3 report for TITAN and UV sensors.

Table 1 : Schedule of experiments performed during the third year of the project at LBE-INRA

Period	Measurement		other variables	Frequency	Experiment objectives	comment
	influent	effluent				
September 2004 to December 2004	COD	TSS, VSS, COD	MLR; VLR, SVI, sludge level	LF	characterize the settle ability capacity	Only carbon removal and different loading rate : from low to high
January 2005						reactor filled with new fresh sludge for carbon and nitrogen removal
February 2005 to April 2005	COD, NTK	TSS, VSS, COD, NO ₃ , NO ₂		LF and HF	model calibration and validation	some modifications with the model structures was tested
					validation of the control CS2	this control try to minimize the non aerated phase
April 2005 to June 2005	COD, NTK	TSS, VSS, COD, NO ₃ , NO ₂	K _{La} , oxygen consumption	HF	validation of the control CS2	effect of the control for long term
					supervision algorithm for high load detection	first data were collected but validation is still on the run
					UV sensor calibration	developing on line filtration system and calibrating the UV sensor
end of June 2005						reactor filled with new sludge after total degradation of the settling capacity and the nitrification activity
July 2005						Implementation of the SPES platform and software modules
August 2005 September 2005	COD, NTK	TSS, VSS, COD, NO ₃ , NO ₂		HF, LF	UV sensor validation	validation accomplished
				HF, LF	validation of the control CS3	effect of the CS3 on the nitrification activities
			pH, DO, ORP NO _x on-line	HF	TITAN validation	first data were collected validation is still on the run

System Integration

The main task was the integration of the EOLI system and to carry out the full field-scale pilot plan. The whole system integrates the most important EOLI 's softwares and hardwares developed during the three years of the project. It can be divided into three major parts :

- The main part is the hardware and software systems developed within the WP8 by SPES. They are designed to support all the modules developed within the project and the so called "basic reactor" (see below its definition). For more details refer to the deliverable D8.2.
- The second part concerns the basic reactor implemented at the beginning of the project with its conventional on-line sensors and actuators as pH, ORP and dissolved oxygen probes and all the pumps and aeration system as it is described in the first LBE-INRA annual report.
- The third part integrates the modules of all the workpackages : experimental data acquisition (WP1) ; models and simulation (WP2) ; hardware sensors and their software (WP3) ; software sensors (WP4) ; control modules (WP5) ; supervision and fault detection algorithms (WP6&7)

These three parts are linked and communicate together as described in the figure 1. The databases are connected to a remote database located at SPES head office in Fabriano (Italy). All the data acquired on the local database are sent periodically to the remote database.

At this time, at the LBE, the Part 3 integrates : two hardware sensors (TITAN and UV sensor); a control module that is able to incorporate any control algorithm; a module for simulation and model validation; and a module for supervision and monitoring.

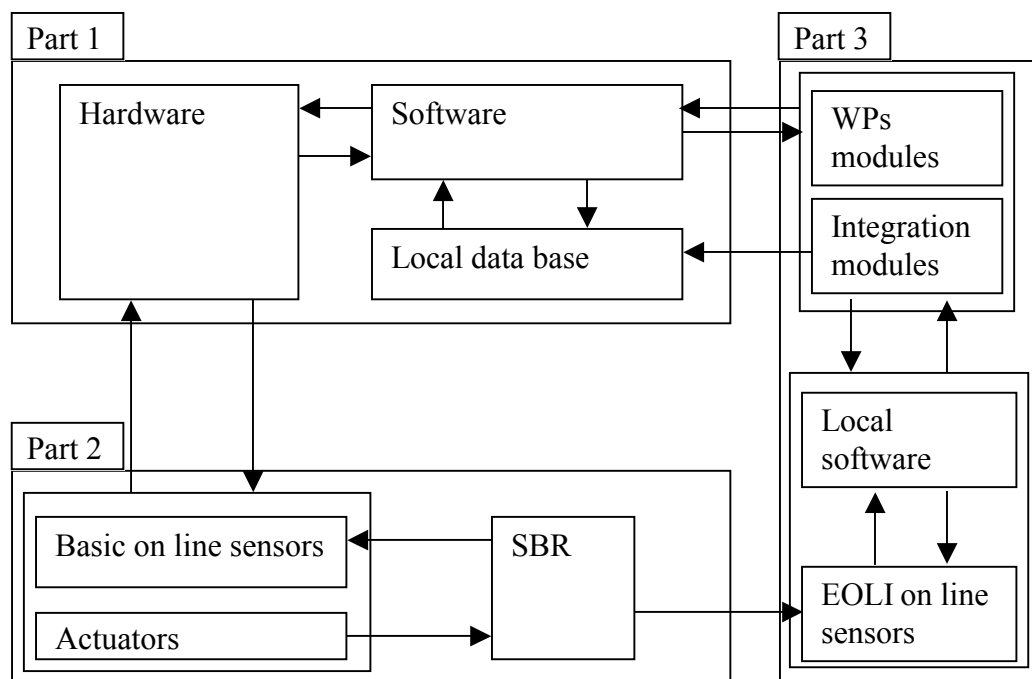


Figure 1 : Field-scale pilot plan architecture

Evaluation and validation

Model validation

During the last year, a simplified model to be used in the design of optimal control laws was developed. The details of this model are given in the paper by Mazouni, Harmand, Herveau, Ignatova and Dochain, 2005.

Software Sensor

The software sensor consists in the dynamic observer used to estimate the variables that are not measured on-line in the reactor. The derivation of the observers is strongly related to the model structure. In the paper Mazouni, Ignatova and Harmand, 2005 as well as in the LBE second annual report an extension of the EOLI model for the LBE SBR describing the dynamical behavior during the aerobic phase is presented. For this model, we derived a simple asymptotic observer estimating both soluble biodegradable carbon and nitrate + nitrite nitrogen concentrations for the aerobic phase.

The resulting observer was validated, in figures 2, by comparing the real data of three experiments and the output of the software sensor. The experiments used correspond, respectively from left to right, to the cycles of November, 04th, 06th and 12th 2003.

The output of the observer are COD on the top figures and N-NO₃+N-NO₂ on the other figures.

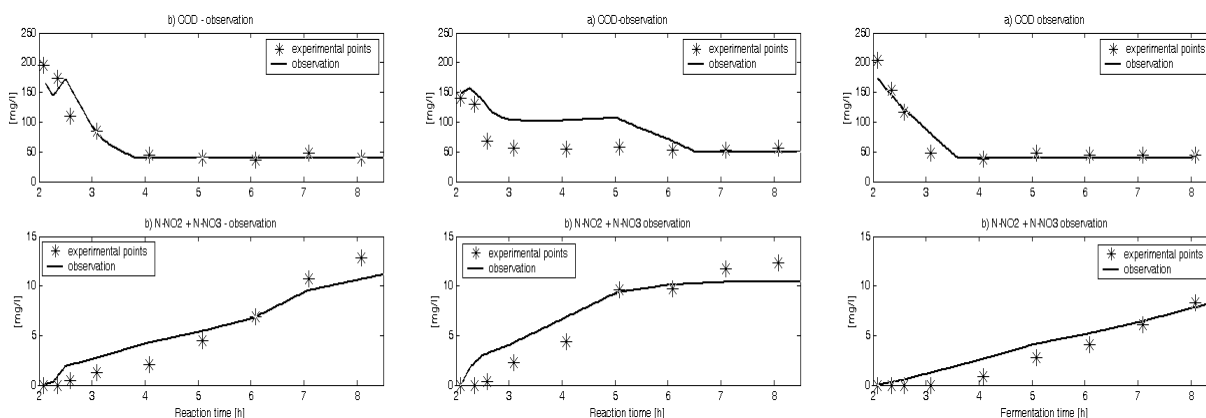


Figure 2 : software sensors validation

Hardware Sensor

Two hardware sensors developed in WP3 were evaluated at the LBE. The first one is the UV spectrum for COD, nitrites and nitrates measurement. The second one is TITAN for on-line nitrifying activity assessment and toxicity detection on the sewage.

UV sensor

For technical details and development of this sensor please refer to Gradient report of the WP3. In order to evaluate the instruments on the LBE-INRA SBR, firstly a series of

experiment were done during May-July 2005 to calibrate the sensor with Narbonne effluent and perform a robust COD, nitrites and nitrates estimation. In figure 3 a comparison between the data obtained by the UV sensor (Y-axis) and data obtained by laboratory measurement (X-axis) are given. From left to right the variables are NO₃, NO₂, COD. In Table 2 are reported the regression coefficient, the maximum error and the range of the measurement for each variable.

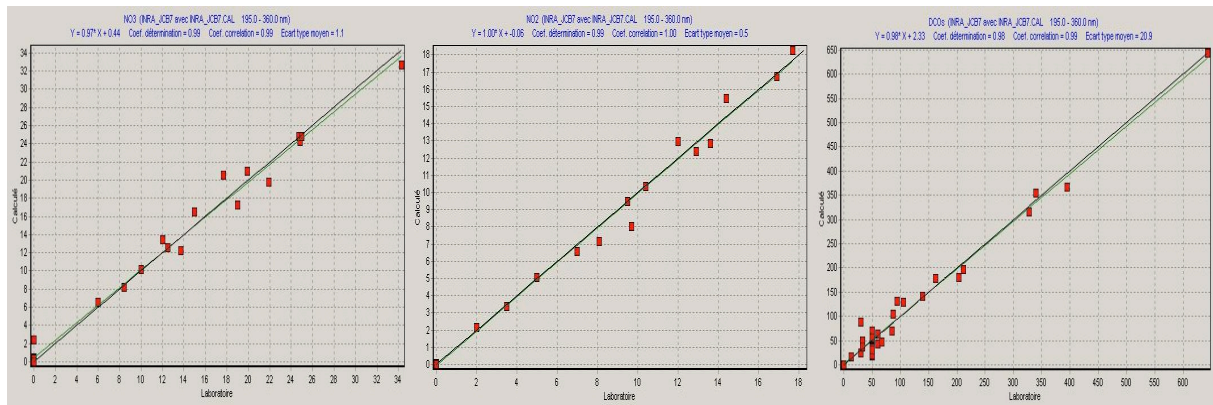


Figure 3 - UV sensor calibration

Table 2 : Calibration of the UV sensor

	NO ₃	NO ₂	COD
Regression coefficient	0.99	1	0.98
Maximum error	1.1 mg/l	0.5 mg/l	20.9 mg/l
Range	0-35 mg/l	0-35 mg/l	0-600 mg/l

In figure 4 it's reported the validation of the measurements: analysis performed with UV sensor (blue square) are compared with laboratory data analysed with the chromatographic Dionex (black triangle). The figures from left to right match with NO₃, NO₂ and COD. The data correspond to one SBR cycle that starts at the point 'a' with a quick filling followed by denitrification phase until point 'b', where the nitrification starts.

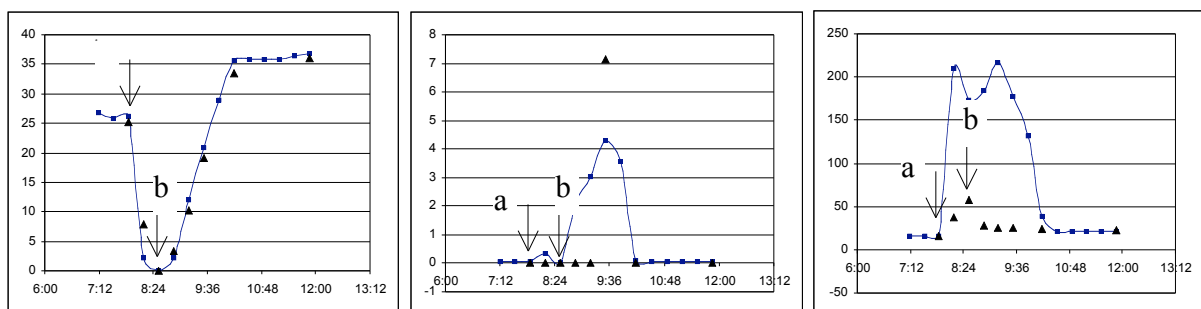


Figure 4 : Validation for one SBR cycle

On line NO_3 and NO_2 measurements fitted well with the off line measurements while the sensor present some problems to measure the COD which is not easy to detect with accuracy even with laboratory analysis. For NO_2 the values less then 2 mg/l are not detectable with the Dionex.

TITAAN

The prototype of the on-line titration unit (named TITAAN, TITration Automatic ANalyser), built by SPES on the basis of POLIMI specifications during 2004, has been placed at the Narbonne SBR pilot plant during July '05. A full description of the prototype is reported in the POLIMI and SPES WP3 EOLI 2nd year report and is omitted here. The main purpose of the implementation of the TITAAN in Narbonne was to evaluate the possibility to use the on-line titrator to detect toxicity events on nitrifying biomass due to the presence of toxic compounds in the SBR feed. Therefore we applied the Model titration bioassay to the process and, as a secondary task we performed a continuous estimation of the real nitrifying activity of the SBR sludge in presence of sewage.

We performed five titration tests with influent with high toxicity: to prepare it we added a toxic compound of reference (Allylthiourea) to the standard influent, in order to obtain in the titrator's reactor a concentration of toxic $> 10 \text{ mgATU/L}$, in order to achieve a complete inhibition of the nitrifying biomass. Results are reported in the following table 3.

Table 3 : Nitrification activity measurements by TITAAN with influent at high toxic concentration ($> 10 \text{ mgATU/L}$)

date & hour of test	actAOB [$\text{mgN-NH}_4\text{-gVSS}^{-1}\cdot\text{h}^{-1}$]		duration of the test [min]	toxicity detection
	pHstat (NaOH)	DOstat (H_2O_2)		
07/09/2005 8.30	-0.09	0.01	140	yes
08/09/2005 13.53	-0.01	0.07	140	yes
09/09/2005 11.59	-0.04	0.09	140	yes
12/09/2005 16.55	n.n.	n.n.	140	test not valuable
13/09/2005 16.09	-0.04	0.08	140	yes

We can notice that, with an exception (test 12/09/2005 16.55), the instrument was able to detect a total inhibition of the nitrifying activity, thus the message "ActAOB: yes" is provided by the TITAAN. Therefore the values of the activity collected during the tests are negligible ($< 0.1 \text{ mgN-NH}_4\text{-gVSS}^{-1}\cdot\text{h}^{-1}$). The negative values are due to some imprecision in the measure method, but they don't affect negatively the result of the tests: negative activity means negligible activity.

During the implementation of TITAAN's Mode 1 titration tests, we followed the evolution of the real SBR nitrifying activity performing bioassays with no toxicant addition. Results are reported in the following Figure 5.

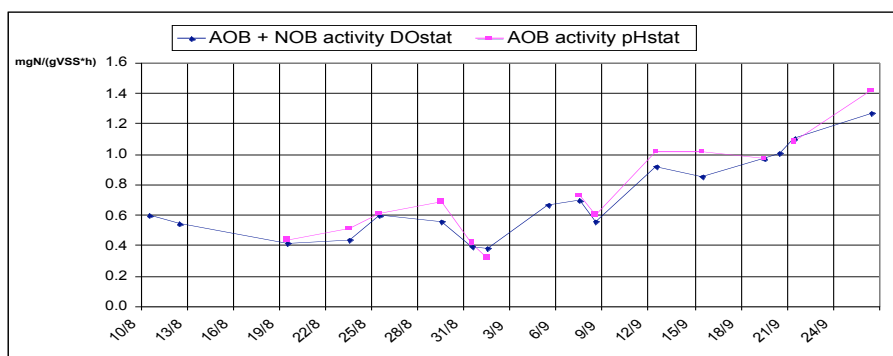


Figure 5 : Evolution of nitrifying activity for LBE SBR pilot plant estimated by on-line tests with TITAN titrator (pH/DOstat) during August – September '05

To evaluate the data collected, we compared them with the real evolution of nitrification in the SBR. A mass balance allowed us to estimate the amount of ammonia oxidized in the reactor during aerobic phase in non limiting conditions ($DO > 2$ mg/L) because the activity rates estimated by TITAN refer to not limiting conditions. We used both nitrates analytical data and data collected by the UV on-line sensor developed within WP3.

We can notice that the activity trend was quite stable after the plant re-starting (10/08); a decrease in the activity was reported at the end of August. We suppose that this nitrifiers' suffering condition was a consequence of a malfunctioning of the aeration system and of an accidental plant's surcharge happened on the 29th of August. Then at the beginning of September an improvement of the nitrification process was reported. Very probably the increase of the ammonia oxidation rate is due to the radical change in the process we operated on September the 5th when we increased the treatment cycles from 2 to 5.

As we can see in the following table xxx, the evaluation of the ammonia nitrified achieved by means of the activity rate provided by the TITAN is quite in accordance with analytical assessments (considering the errors on the measures of: NO_3^- , VSS, reactor's volume, temperature compensation) confirming the utility of the on-line activity assessment to evaluate the reactor's performance in terms of oxidation of ammonia.

Table 4 : Comparison between ammonia oxidation estimated in the reactor by means of the on-line UV sensor and the estimation made by means of pH/DOstat titration

data	act AOB pHstat (NaOH)	act AOB DOstat (H2O2)	reaction duration in SBR [h]	gVSS/ L	t °C in SBR	NO_3^- [mgN/L] UV sensor	SBR volume [L]	N-NH4 oxidized [mgN]	N-NH4 estimate [mgN] pHstat (NaOH)	N-NH4 estimate [mgN] DOstat (H2O2)	pHstat estimate - N-NH4 oxidized	DOstat estimate - N-NH4 oxidized
25-08	0.61	0.60	0.66	5.5	24.4	12.2	175	482.1	543.7	534.8	11%	10%
01-09	0.42	0.39	1.33	5.37	23.7	17.2	175	679.7	692.8	654.1	2%	-4%

05-09	x	0.67	0.66	4.77	25.3	12.2	160	440.8	x	552.6	x	20%
08-09	0.73	0.70	1.00	4.77	23.5	19.9	170	763.9	797.0	760.0	4%	-1%
12-09	1.01	0.92	0.66	4.63	24.4	15.5	180	630.0	737.6	669.3	15%	6%
15-09	1.02	0.85	0.66	4.7	24.7	18.2	160	656.5	769.0	646.5	15%	-2%
21-09	1.09	1.10	0.33	4.88	22.6	9.6	170	368.51	363.5	368.3	-1%	0%

Control validation

In D5.1 the control strategies developed within LBE SBR are described in detail. For the LBE reactor, 3 control strategies were developed and evaluated CS1, CS2 and CS3. In the last year of the project only CS2 and CS3 were evaluated. The main objectives of these control laws is to minimize to total reaction time with the constraint to maintain high nitrification activity. The function of CS2 was to avoid a long non aerated phase by introducing an aerobic phase between the settling and the anoxic phase. The switching instants were computed such that the total reaction time be minimal. This strategy was tested and evaluated during February, March, and April. This control in not always possible because under some initial conditions the process can not be started with aerobic phase. In this case the strategy CS3 is applied. This strategy consists in changing the volume added in the reactor to change the initial concentration. With this strategy, the reactor is filled progressively with small volumes where the phases fill-anoxic-aerobic are sequentially applied until the reactor is full. Then settling and withdraw phases are be applied.

Short term effect

Figure 5 shows the dissolved oxygen curves. In the left cycles with CS2 and in the right cycles with CS3. The oxygen is a good indicator of the reaction time when the oxygen reaches the saturation values it means that the reaction is finished. For CS2, it is shown that when it is possible to apply aerobic-anoxic-aerobic sequence, the reaction time is smaller than the reaction time of a cycle with anoxic-aerobic sequence. The gain depends on the initial concentration. For more detail refer to D5.1 and D5.2.

Long term effect

Firstly, we recall that with CS1 the nitrification activity was lost in 3 weeks and with the standard operating mode the activity was continuously decreasing. With CS2 strategy, the nitrification activity was maintained for long period, the nitrification was full and all the nitrogen was converted into nitrites but the reaction was very slow and the nitrification activity was low. When we applied the CS3, and using the on line monitoring by TITAN, we observed an increase of the nitrification activity. See WP3 for TITAN validation and the LBE sludge activities.

Our conclusion comparing all the strategies is that to minimize the reaction time and maintain a high nitrification activity the best way is to use a small sequences fill-anoxic-aerobic of fill-aerobic-anoxic-aerobic where the initial concentration are not very high and the duration of each phase in not very long. This strategy avoid a long non aerated period and a long endogenous period where the bacteria decay rate is too high. The time

minimisation is granted using the algorithm developed in CS2 and it gives the sub-optimal switching instances.

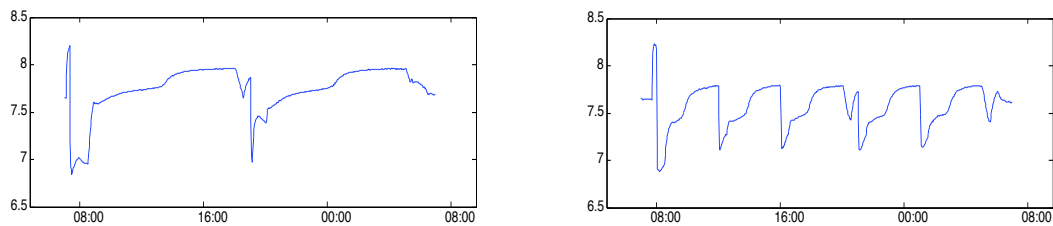


Figure 7 : pH and dissolved oxygen with CS2 and CS3

We observed also that this operating mode is not favourable for the filamentous bacteria growth. In figure 6 microscopy pictures of the LBE sludge. In the left : just before starting CS3; in the centre : 5 days later and in the right : 2 months later. We observe clearly that the filamentous disappear from the sludge.

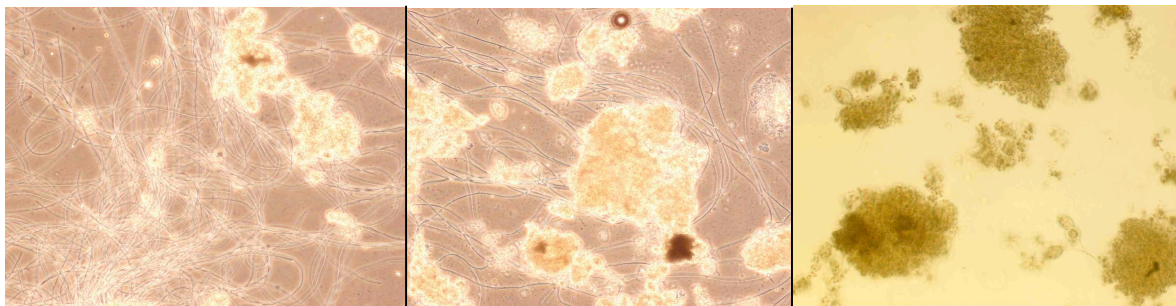


Figure 8 : Filamentous evolution in the LBE SBR

Supervision

The objective of the supervision works it to check, using the available data, if the state of the reactor is “normal” or “abnormal”. In the case it is normal the data are simply archived and if the state is classified as abnormal the supervision system decides if the problem can be automatically solved or a manual intervention is needed.

The algorithms developed within this work package concern the reaction phase, especially for carbon and nitrogen removal, and the settling phase to monitor the settleability. For more details and results please refer to WP7.

Reaction

The EOLI supervision system that has been developed has two separated subsystems. Depending on the available instrumentation, the aim of the first subsystem was to be able to answer the question "does the SBR run in standard conditions or not?". To do so, As explained in the deliverable D7.1, the structure of this first component of the DSS includes two distinct modules corresponding to the following instrumentation structures :

- Case #1 : a low instrumentation supervision module including only DO, pH and ORP probes. The details about the development, the evaluation and the validation of this system have been reported in deliverables D7.1 to D7.4.
- Case #2 : an advanced instrumentation supervision module. The algorithms used within this module as well as its integration and its evaluation are reported here above in the section "Supervision of the SBR in the case it is equipped with advanced instrumentation".

The implemented system consists in the hardware and software modules implemented by SPES. This system basically interacts with the plant, performs data acquisition and store these data in two distinct databases (a local one and a - possibly decentralized - one). The local database stores a shorter time period of data than the decentralized database which stores the totality of available data. Depending on the actual instrumentation available on the process, beside this independent running system, either the Matlab modules described in the deliverables D7.1 to D7.4 or the additional modules described hereabove run now on-line being able to analyze each cycle to decide whether the system operates in standard mode or not, and if not, from which mode from the database it is actually the closest. For details about the technical approaches used to classify such situations in the case 1, please refer to the deliverables D7.1 to D7.3. For details about its validation, refer to D7.4. Hereabove, we present the system that has been developed for the supervision in the case #2.

Taking into account the information provided by the TITAAN (cf. the deliverable D3.2) and/or by the UV sensor (cf. the deliverable D3.3) that have been developed within the framework of EOLI, the basic idea of the actual supervision system is to perform on-line a mass balance on the carbon and on the nitrogen. In other words, the idea is to verify if the actual oxygen consumption fits the theoretical oxygen needs with respect to the available knowledge about the yields of the different involved bioreactions. The mass balance which is realized is fully described in the deliverable D1.5 and it's omitted here. The system needs as inputs the dissolved oxygen concentration (measured on-line by the DO probe), the influent's TKN content and the amount of N-NO_x in the reactor at the beginning of the anoxic phase, data that can be provided both by TITAAN and UV sensor.

With the oxygen consumption data and the amount of TKN in the influent that is fed to the SBR, we can use the oxygen mass balance to detect the amount of COD_{tot} that was fed to the plant in the actual cycle, and evidence situations as over/under load of organic matter rather than nitrogen. At now the system has been tested by using analytical data rather than data provided by the hardware sensors because their validation process is still on the run. A friendly user interface has been developed (shown in Figure xxx) and data are automatically stored in the EOLI database in order to follow the evolution of the process. A series of tests with different influent COD/N ratios have been performed, and first results of

the comparison between the oxygen consumption estimated by the software and the one predicted by mass balance (based on analytical determinations) are shown in Figure 9.

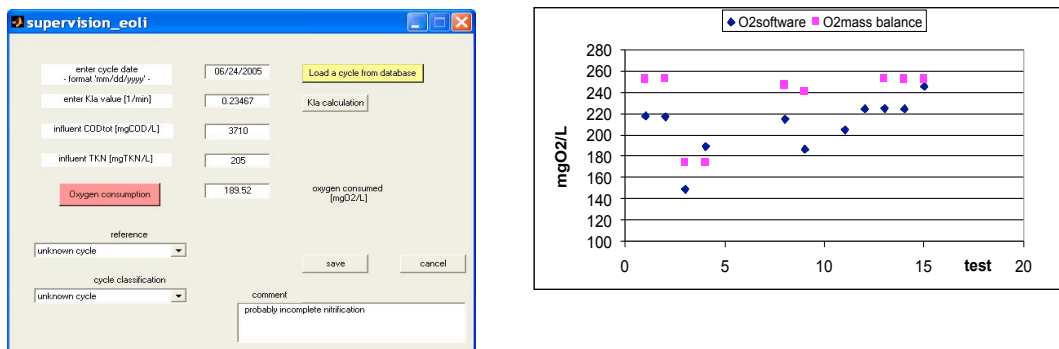


Figure 9 : User interface of the supervision system in the case 2 (left) and comparison between oxygen consumption estimated by mass balance and by the supervision software (right)

Settling

A series of experiment were carried out the characterise the settleability and define some parameters as “indicators”. This parameters may give information about the stat of the settleability.

First the influence of the TSS was studied. In the reactor, the settling kinetics was observed with a variation of TSS between 3 and 40 g/l for the LBE SBR sludge. One can observe in figure 5, left picture, that the initial velocity decreases when the TSS concentration increases. We observe also that the sludge level for a concentration between 4 and 20 g/l, after 2 hours of settling, is proportional to the TSS concentration as it is mentioned in the right picture. This parameter is the sludge volume index it is given by the equation :

$$SVI \text{ (ml/g)} = 1000 \frac{l_0 - TSS_0}{l_f}$$

where l_0 and l_f are respectively initial and final sludge level and TSS_0 the sludge concentration before settling.

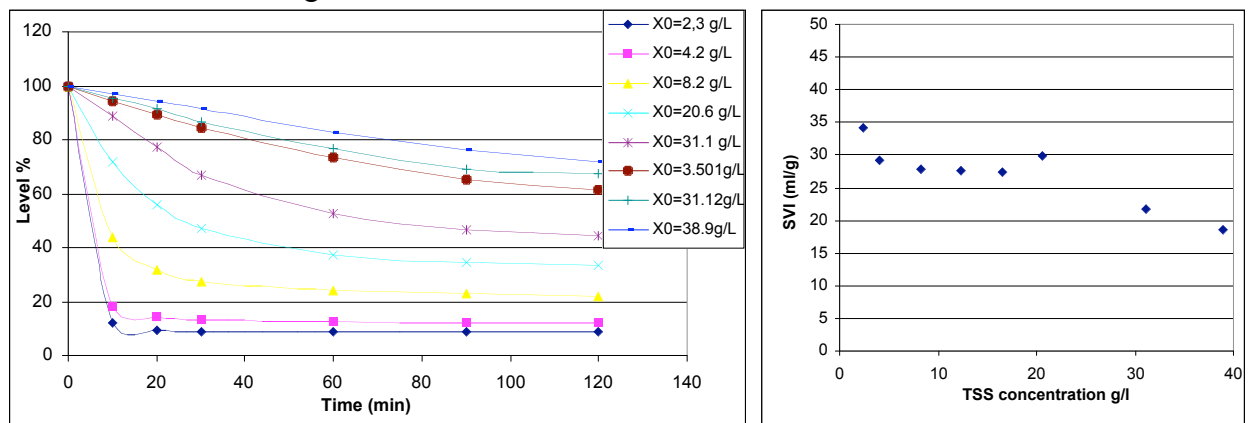


Figure 10 : TSS Influence on the settleability

Using these parameter : SVI and initial velocity we can monitor the settling phase. The problem is that the SVI can be influenced by the loading rate and other parameters and it is not always constant. A second series of experiments were carried out to characterise the evolution of the SVI within the mass loading rate and volume loading rate. Firstly, a long period of sludge adaptation was made. For long time more then three months the reactor was operated at low volume loading rate around 0.7 kg COD/m³/day. Then the loading rate was increased up to 1.2 kg COD/m³/day.

Table 5 :experiment plan for loading rate increasing

	Step 1	Step 2	Step 3
Masse loading rate kg COD/kg TSS/d	Low 0.09	Medium 0.15	High 0.4
Volume loading rate kg COD/m ³ /d	Low 0.7	High 2.4	High 2
SVI mg/g	19.6±0.5	21.7±0.9	35.14±3.3

The results of the experiments show that the sludge supports in the third step a high loading rate while SVI was very low compared to traditional waste water treatment plan which is around 120 ml/g. The second remark is that this value was constant for a fixed operating conditions of mass loading rate and volume loading rate.

So by measuring the on line sludge level and regular off line TSS the SVI and the initial settling velocity can be calculated (refer to WP7 for examples). With these parameter any bad settling can be isolated and detected. The settling phase duration or maximum TSS concentration allowed in the reactor can easily determiner using this parameters. For the supervision algorithms alarms could be activated when the SVI increases while when it is constant and the settling velocity decrease the TSS concentration need to be decreased by withdraw.

Meetings, field trips and missions

- January 24th 25th and 26th : Jerome Harmand and Djalel Mazouni had a meeting in Milano with SPES and POLMI to prepare the integration with SPES platform and TITAAN (POLIMI 's Hardware sensor).
- February 2nd and 3rd : GRADIENT group had a meting in Narbonne to prepare the integration of the UV sensor (Gradient 's Hardware sensor)
- May 2nd Nicola Fiocchi, came to Narbonne for 7 monts for the start up and the evaluation of TITAAN. He is working also on the supervision algorithm.
- May 9th to 11th Jerome Harmand, Michel Torrijos and Djalel Mazouni participate to the 3rd mid term EOLI meeting in Montevideo.
- May 15th to 30th : Miriem Bekri from Gradient came to Narbonne for the start up of the UV sensor (Gradient hardware sensor).
- July 6th to 18th SPES arrival in Narbone for the installation of the SPES platform and TITAAN.

- July 13th meeting in Narbonne with André Pauss and Olivier Schoefs from Gradient; Roberto Canziani and Nicola Fiocchi from POLIMI; Paolo Ratini from SPES; Jerome Harmand, Michel Torrijos, Jean Claude Bouvier and Djalel Mazouni from LBE INRA. The object of the meeting was reporting the actual state and planning experiment for validation and integration of the whole system.

Publications and references

- Betancur M., D. Mazouni, J. Harmand and J. Moreno (2006, to be submitted) : "Optimal control of biological SBR's for the treatment of dairy and toxic wastewater", 5th MATHMOD VIENNA, IMACS Symposium on Mathematical Modelling, Vienna, 8-10 février 2006.
- Fibrianto H., D. Mazouni, M. Ignatova, M. Herveau, J. Harmand and D. Dochain (2006, to be submitted) : "Dynamical modelling, identification and software sensors for SBR's", 5th MATHMOD VIENNA, IMACS Symposium on Mathematical Modelling, Vienna, 8-10 février 2006.
- Ignatova, M., J. Harmand, M. Herveau, D. Mazouni and D. Dochain (2005, to be submitted) "A comparison of simple mass-balance models for the control of biological sequencing batch reactors used for carbon and nitrogen removal", *Journal of Process Control*.
- Mazouni, D., J. Harmand, A. Rapaport and H. Hammouri (2005, to be submitted) "Optimal time control of switching systems : application to biological Sequencing Batch Reactors", *Optimal Control Application and Methods*.
- Mazouni, D., M. Ignatova and J. Harmand (2005) "A multi model approach for the monitoring of carbon and nitrogen concentrations during the aerobic phase of a biological SBR", IFAC 2005 World Congress, July, 4-8 2005, Prague, Czech republic.
- Ratini P., M. Pirani, S. Mariani, L. Luccarini, D. Mazouni and J. Harmand (2006, to be submitted) : *Development of an integrated system for the optimisation of SBR's*, 5th MATHMOD VIENNA, IMACS Symposium on Mathematical Modelling, Vienna, 8-10 février 2006.

3.3 Gradient

Participating staff

Name	Background	Activities in EOLI
Prof. André Paus	Biochemical scientist	WP3
Dr. Meriem Bekri	Environmental engineering scientist	WP3
Ass. Prof. Olivier Schoefs	Biotechnological engineering scientist	WP3

The group of LBE-INRA of Narbonne (Jean-Claude Bouvier, Djalel Mazouni, Jérôme Harmand), where the on-line spectrophotometer was implemented, hardly participated to the work. Their participation to the WP3 was not foreseen, but without their help the experimentations would not have been successful.

Activities

Introduction and objectives

Gradient, whose contribution started on November 2002, is concerned with WP3.2 (Development of a simplified low-cost on-line UV-spectrophotometric sensor) and WP3.3 (Pilot plant implementation).

Ultra-violet (UV) spectral analysis can be used to quantitatively monitor several compounds in water. The main objective is to develop a low-cost on-line UV spectrophotometric sensor to monitor on-line specific compounds (such as nitrate, biomass and organic nitrogen) during the operation of a Sequential Biological Reactor (SBR). The global methodology consists in:

- Evaluating the applicability of UV spectrophotometric existing sensors to quantitatively monitor target compounds water.
- Developing a simplified low-cost UV spectrophotometric sensor to monitor on-line target compounds during the operation of a SBR.
- Evaluating the performance of the developed spectrophotometric sensor on a pilot-scale SBR bioreactor; it has been decided at the meeting of Mexico to install the sensor on the INRA-LBE bioreactor.

The UV sensor has been tested with different target wastewaters (OECD, UNAM, UU and INRA-LBE wastewaters). The first one tested during the last year was the OECD effluent as defined with the group of Polimi, who is also involved in the WP3. From June to December 2004, Gloria Moreno from UNAM and Alejandra Benitez from UU used the UV spectral analysis for their respective wastewaters. The results obtained for these three effluents were presented in the last reports (May 2004 and November 2004).

The activities discussed in this report focuses on the implementation of the on-line spectrophotometer at the pilot-scale bioreactor in Narbonne (LBE-INRA) and on the results obtained.

Results and Discussion

Description and implementation of the on-line spectrophotometer

Description of the on-line spectrophotometer

The company SECOMAM developed an on-line spectrophotometer, called STAC. The STAC instrument exists in a standard version but it was modified to manage the behaviour of SBR with different wastewaters and finally with the INRA-LBE wastewater where the system will be finally installed.

The development of the STAC consists of adapting the standard analyser STAC to a resolution of 0.5 nm with 256 measurement points, from 190 to 240nm, and latter from 190 to 360, to make possible discrimination between nitrate (205 nm) and nitrite (211 nm) peaks. This adaptation was done in two steps:

- Adaptation of the monochromatic system with, in particular, a CCD detector of 256 pixels and a an adaptation of a new diffraction system,
- Development of the UV-Pro software to manage pumps, lamps, diode captor, for data storage and UV spectrum management and for the interface man-machine.

The measuring range is:

Nitrate: NO_3^- : 1 to 50 mg/L

Nitrite: NO_2^- : 1 to 50 mg/L

Organic matter: COD: 5 to 350 mg/L

The STAC instrument was implemented in the INRA-LBE bioreactor in May and has been operated continuously thereafter.

To know more about STAC instrument:

STAC (Compact Alarm System) measures the sample absorbance in the specific area of the UV spectrum, the STAC records the spectral profile of the sample, a true numerical photograph of the water quality (www.SECOMAM.com). It is constituted with 3 connected modules.

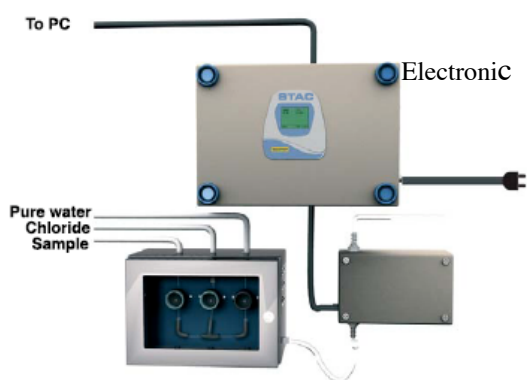
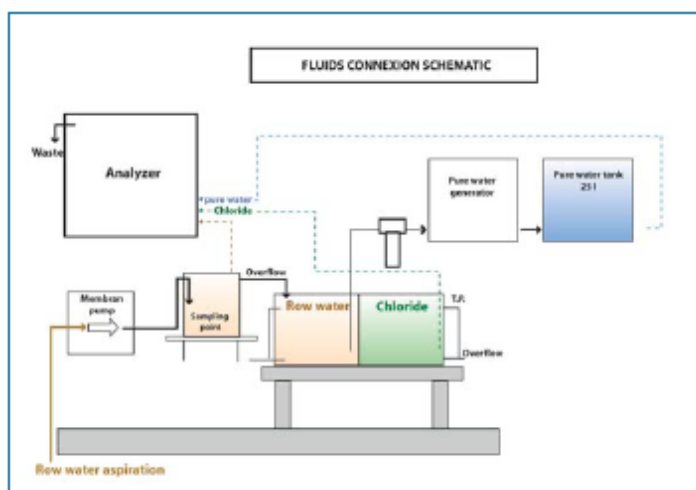


Figure 1. STAC instrument



Advantages

- Physical method with almost no consumable
- Very fast reading
- Easy and low maintenance
- Both quantitative and qualitative reading
- Built in separates enclosures with aqueous sample separated from electronics
- Fitting with most of tele-transmittable systems
- Fully automatic

Sampling

- Cuvette cleaning and sampling circuit rinsing automatic and sequential
- Automatic sampling programmable from 5 to 30 minutes
- Pinching valves and 8 mm tubing for TSS reading and filtration free

Data transfer

- 4 current loops
- RS 232
- UV PRO software for data storage and UV spectrum management

The STAC spectrophotometer is illustrated below :

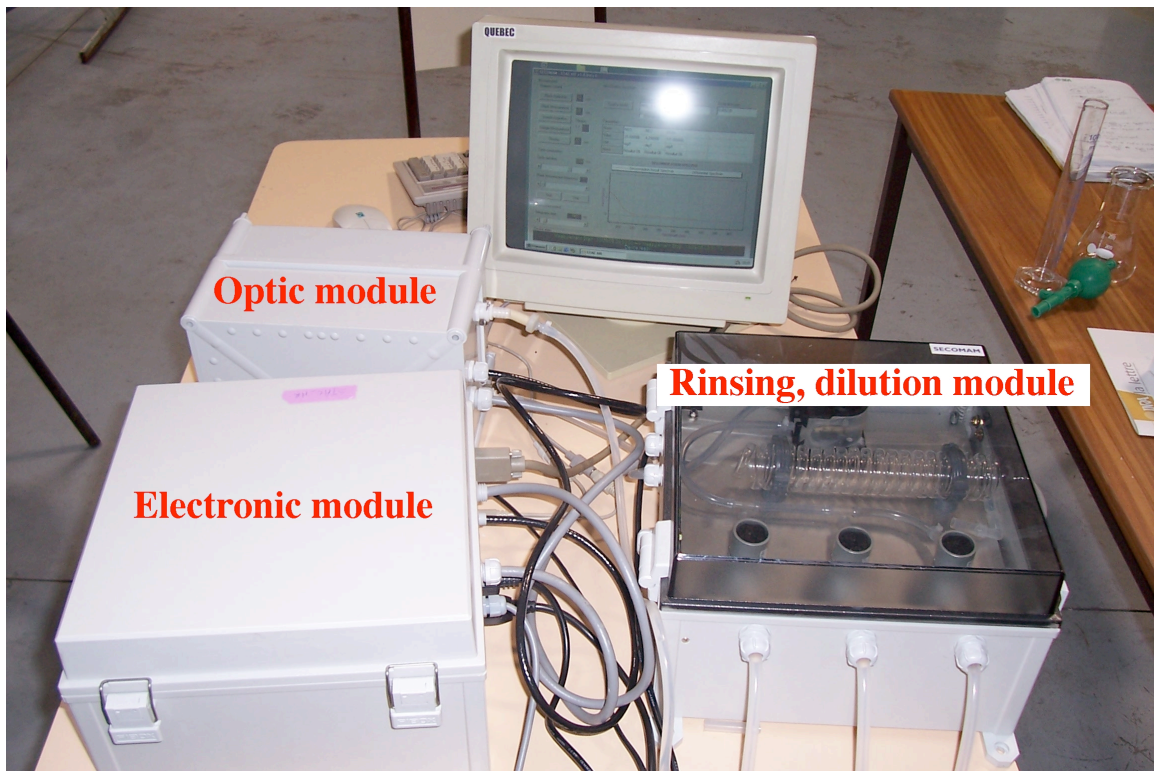


Figure 2: Overview of the STAC spectrophotometer

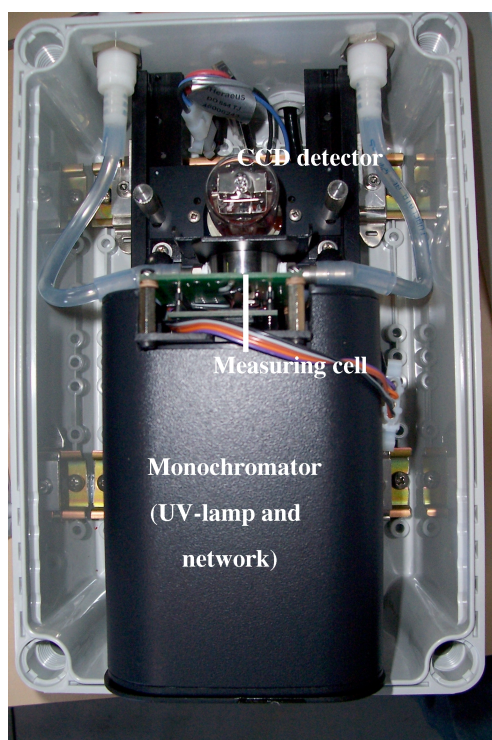


Figure 3: Optic module

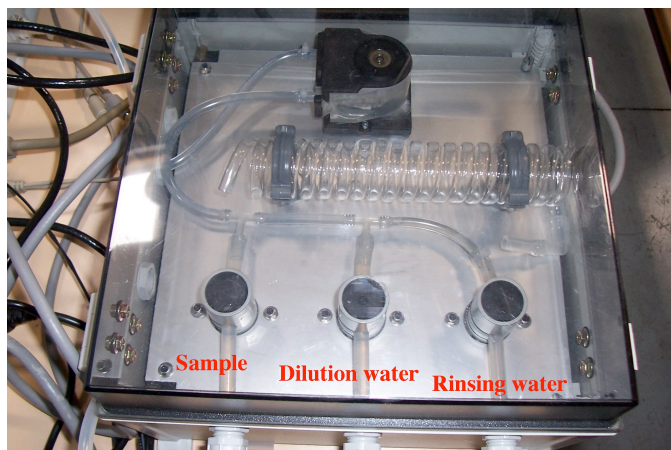


Figure 4: Rinsing and dilution module

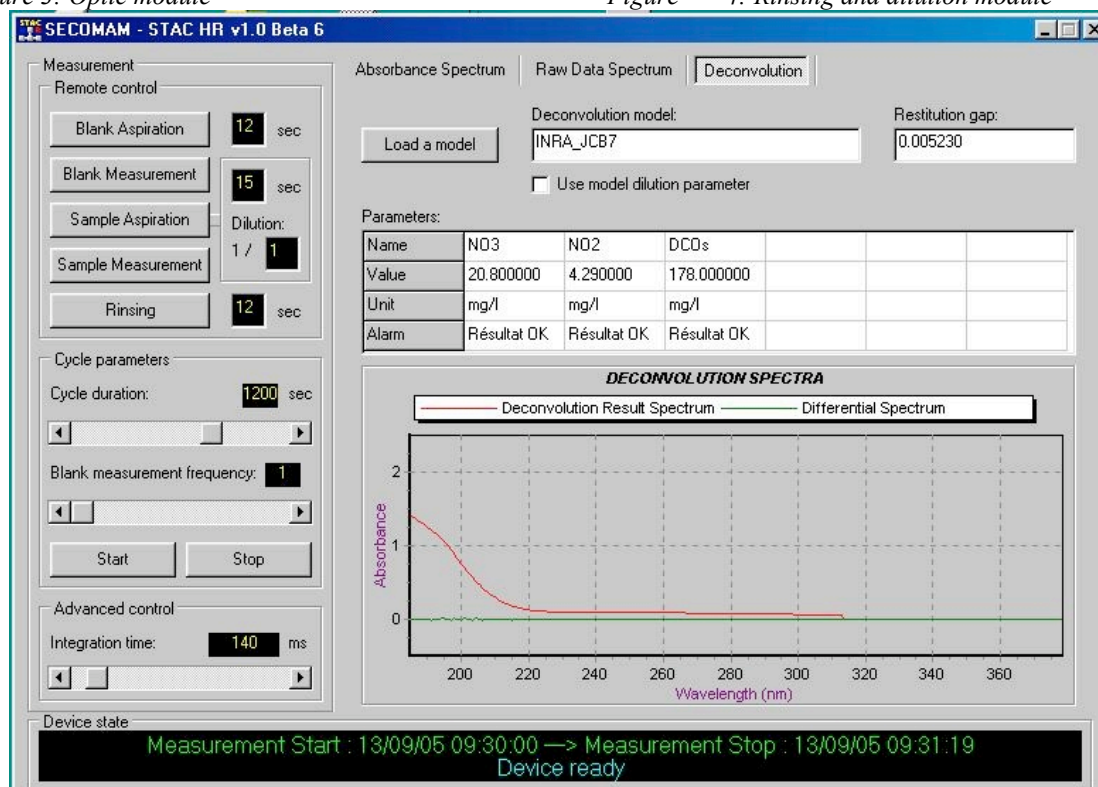


Figure 5: Screen capture of the menu of the dedicated UV-Pro software for acquisition, control and deconvolution

The electronic module contains an embedded card with Windows XP, and a dedicated version of UV-Pro software, that allows complete control of the instrument, the deconvolution of the spectra, and the recording of the spectra and of the results in text files, that can be used for the EOLI control process.

The screen capture below shows, on the left hand, the process parameters, on the top the chosen deconvolution model, and the spectrum and the results of, here, nitrate, nitrite and soluble COD. These three parameters were defined previously in the deconvolution model.

Implementation at the LBE-INRA bioreactor

The on-line spectrophotometer was implemented at the LBE-INRA SBR, in Narbonne as illustrated below. An 60 μm on-line filter and a settling column were installed in a recirculation loop allowing particle-free samples for the UV-measurement as shown in Figure 6.

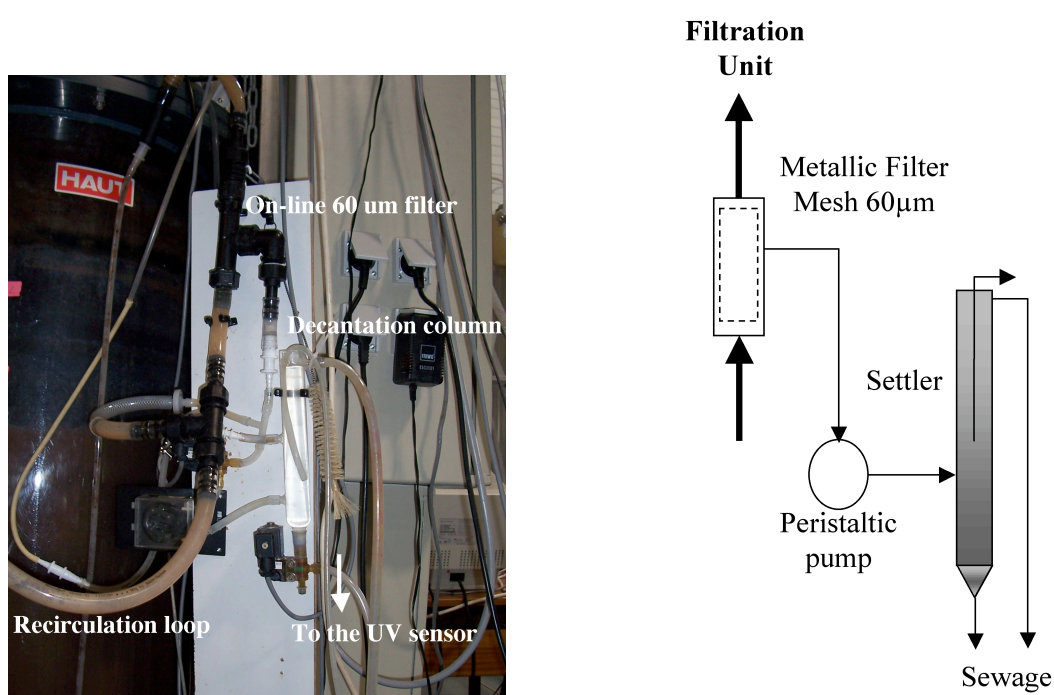


Figure 6: Filtering system implemented prior to the spectrophotometer.

On-line monitoring of COD, nitrate and nitrite in the LBE-INRA bioreactor

First attempts with the first monochromator

A monochromator, providing a light range from 190 to 240 nm was first installed. Several mixtures of nitrite and nitrate were analyzed, repeating the experimentations carried out with the off-line spectrophotometer, as described in the previous report (November 2004 to May 2005). As expected, the on-line spectrophotometer was able to clearly discriminate between nitrate and nitrite (data not shown).

A model was then built with the experimental data of nitrate, nitrite and soluble COD using two running cycles of the SRB reactor. This model was used to deconvolute spectra from next running cycles

The results shown below indicate that good correlations were obtained for nitrate and nitrite, but not for sCOD.

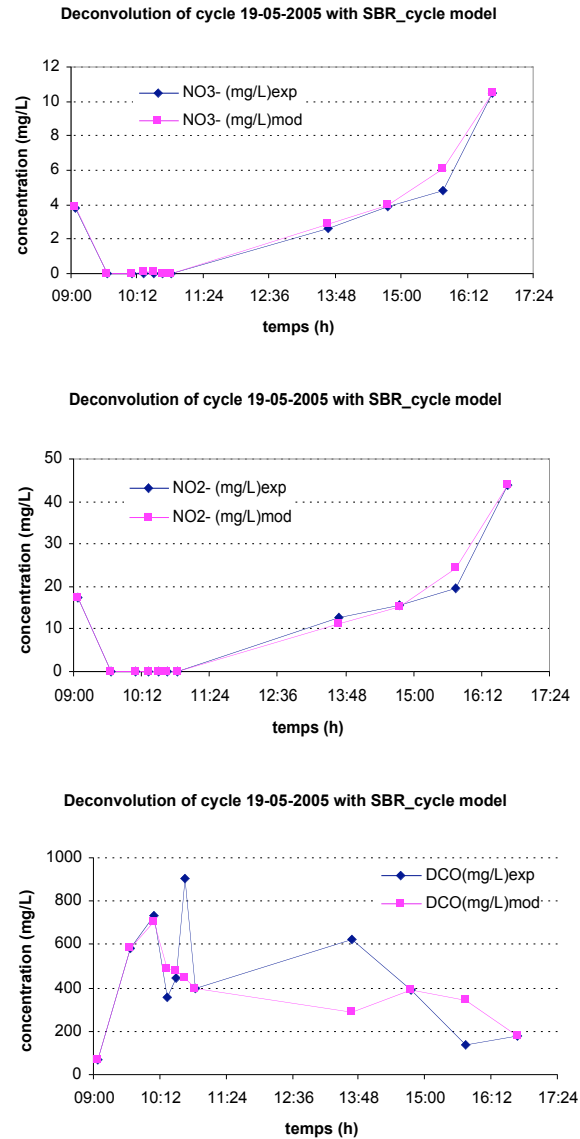


Figure 7: estimated and actual values for the monochromator during a cycle

However these results were obtained with a limited number of experimental data, and the correlations given for the next cycles were less convincing, even for nitrate and nitrite.

It was then decided to increase the number of experimental data to obtain a more robust model, and also to improve the efficiency of the spectrophotometer.

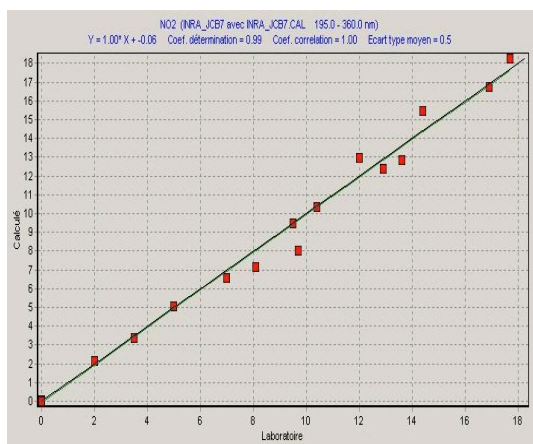


Figure 8: Calibration curve for nitrate
 $y = 0.98 \text{ exp.} + 0.44$; $r=0.99$

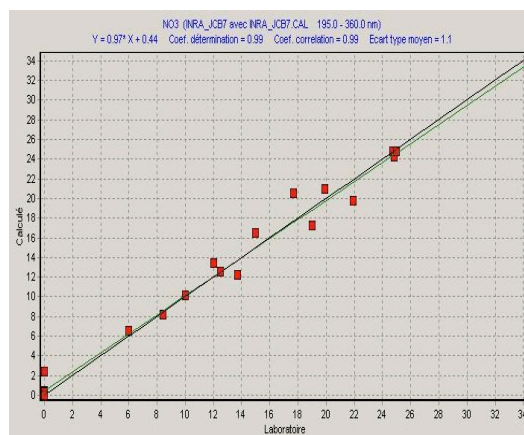


Figure 9: Calibration curve for nitrite
 $y = 1.00 \text{ exp} - 0.06$, $r=1$

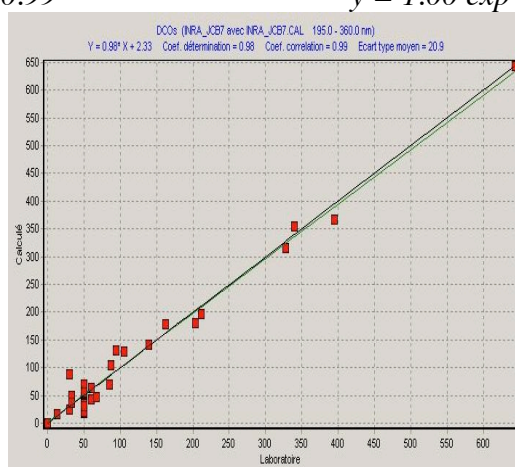


Figure 10: Calibration curve for sCOD
 $y = 0.98 \text{ exp} + 2.3$, $r = 0.99$

Method calibration and validation using a 190-360 nm monochromator

A new more sophisticated monochromator was installed and the UV-Pro software was also debugged. More experimental data were introduced in the software to obtain a more robust model. Finally deconvolution results were compared to those obtained with a Partial Least Square Regression (PLS). The three figures below show calibration results for nitrate, nitrite and sCOD. Twenty sets of experimental data were compared to the deconvolution estimations.

The experimental results obtained from 28 cycles were therefore used to validate the model. The Table below indicates that :

- for nitrate and nitrite, good correlations were obtained for the UV-Pro software, as well as for the PLS regression. A PLS mc (mild-centering) was also tested. Both PLS regressions sometimes exhibit negative values, that have never been found with the UV-Pro deconvolution.
- for soluble COD, all regressions again show good correlations with the experimental values, with again a advantage for the UV-Pro software that never provides negative values. It can also be noticed that experimental values were sometimes suspected,

especially for the low values, indicating the limits of the analytical technique for such a reactor.

The yellow, orange and red background colors refer respectively to suspected experimental values, suspected predicted values, and aberrant values.

Lab	UVPRO	PLS none	PLS mc	Lab	UVPRO	PLS none	PLS mc	Lab	UVPRO	PLS none	PLS mc
23.6	24.5	24.4	23.8	0.0	0.1	-0.1	0.4	19.0	78.0	77.3	45.7
0	0.7	2.3	2.4	0.0	0.7	0.6	0.4	34.0	172.0	65.2	77.1
15.2	15.4	15.4	15.4	11.1	11.4	11.6	11.6	14.0	62.0	60.2	57.2
25.9	27.2	27.1	27.1	10.6	11.8	11.9	11.8	12.0	24.0	34.3	42.8
26	24.6	25.9	25.4	0.0	0.2	-0.1	0.4	50.0	80.0	74.8	45.1
5	0	1.4	1.1	0.0	0.0	-0.6	-0.1	395.0	366.0	394.9	360.3
0	0	-0.1	0.3	0.0	0.0	0.2	-0.3	340.0	353.0	338.6	365.6
0	0	1.5	1.6	0.0	0.0	-0.8	-1.0	328.0	317.0	294.9	311.6
0	0	-0.7	-0.6	0.0	0.0	-0.3	-0.6	162.0	178.0	183.1	204.6
0	0	-1.9	-1.9	0.0	0.0	0.4	0.3	109.0	95.0	111.6	124.5
0	0	-1.9	-2	0.0	0.0	0.8	0.9	109.0	92.0	103.7	102.7
2	3.2	2.5	2.4	5.0	4.6	5.2	5.2	80.0	95.0	87.9	87.9
10.5	8.3	8.4	8.4	9.0	10.5	10.8	10.7	60.0	106.0	76.6	84.6
18.5	17.7	17.7	17.9	11.6	14.2	14.4	14.1	60.0	64.0	61.0	81.6
33.6	24	23.2	23.9	16.7	19.5	21.4	20.5	50.0	83.0	-11.6	48.5
34.2	30	27.7	28.8	16.8	23.7	26.6	25.3	50.0	36.0	-60.1	26.2
45	36.9	43.9	45.5	0.0	15.8	15.3	12.9	11.0	35.8	-457.8	-289.3
0	0	-2.6	-2.4	0.0	0.0	0.6	0.2	90.0	150.0	149.8	171.4
20	20.3	19.9	19.8	11.0	13.1	13.4	13.5	50.0	81.0	76.5	74.1
36	37.2	27.2	28.6	15.0	16.9	28.7	26.9	13.0	205.0	-153.0	-31.3

Nitrate

Nitrite

sCOD

From these results, it can conclude that it is possible to on-line estimate the nitrate, nitrite and sCOD content of the SBR with the measurement of UV spectra. PLS and UV-Pro regressions give acceptable correlations, especially for nitrate and nitrite. Comparing both regressions, the Table below indicates that the Root Mean Square Errors of Prediction (i.e. an average of the difference between the actual and the predicted values, lowest the value, best the result) of UV-Pro are lower that those of PLS regressions. The UV-Pro finally provided better results, and it was chosen for the online monitoring of the SBR.

	Nitrate	Nitrite	sCOD
UV-Pro	3.27	4.02	60.60
PLS none	3.67	5.29	117.70
PLS mc	3.31	4.53	74.40

Root Mean Square Errors of Prediction

Application to the on-line monitoring of nitrate, nitrite and COD during SBR phases

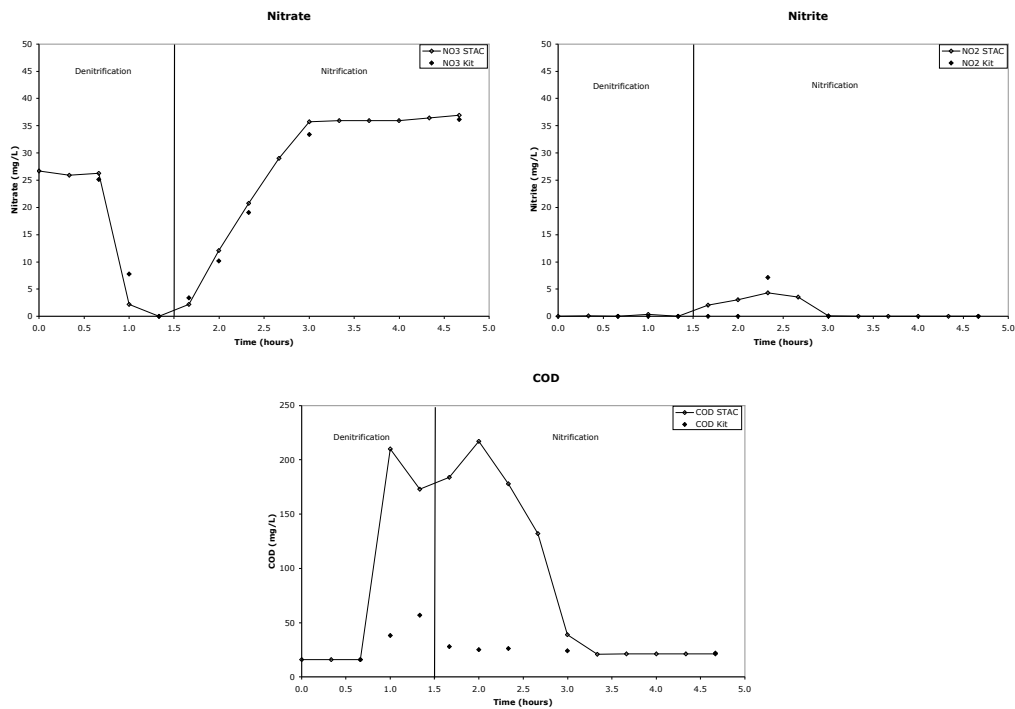


Figure 12 Monitoring of nitrate, nitrite and COD during one SBR cycle (Cycle A)

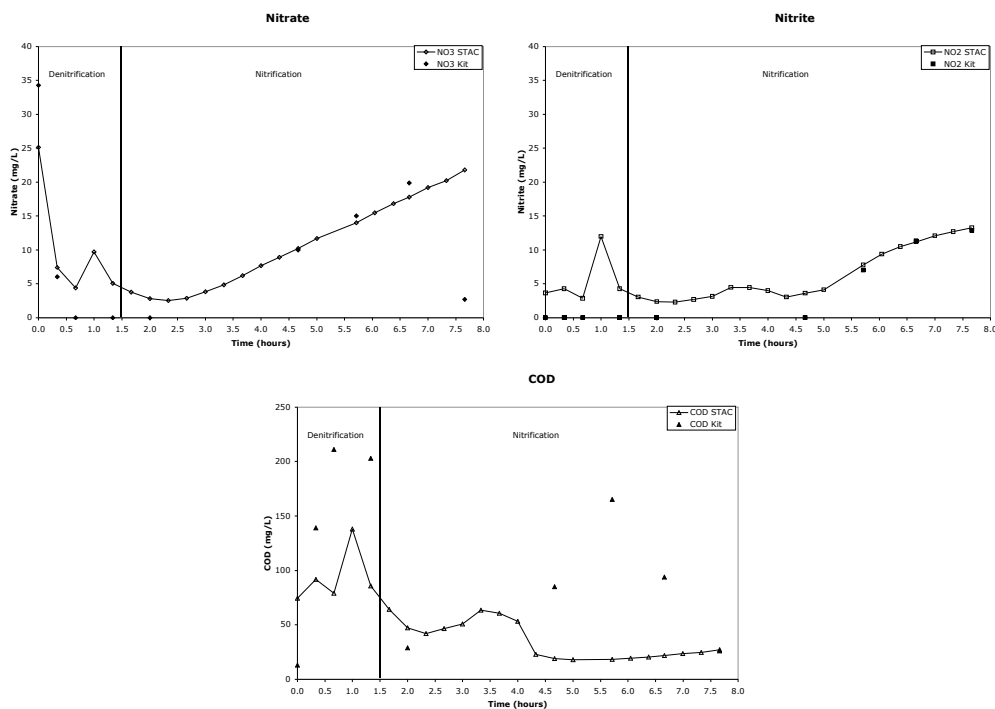


Figure 13 Monitoring of nitrate, nitrite and COD during one SBR cycle (Cycle B)

The results show that nitrate and nitrite were correctly estimated during the whole both cycles. However the estimated sCOD fit experimental values only in the first and the last hours of the cycles. During the first hours of the aeration step, some discrepancies remain.

The analytical measurements of COD, as well as their UV estimation are currently improved.

Conclusions

Based on the results obtained in the laboratory during the previous last six months, an on-line spectrophotometer was designed. The Secomam company modified an existing model (STAC) to build a sensor capable of monitoring on-line nitrate, nitrite and carbon material in a recirculation loop of the SBR reactor implemented in Narbonne. An on-line filtering unit was also designed to automatically provide particle-free fluids to the sensor.

The on-line UV spectra, obtained from numerous samples, were deconvoluted using three different regressions. Some spectra were used for calibration to monitor nitrate, nitrite and soluble COD, and the other were used for validation. The regression from UV-Pro software finally gave the best results, and it was chosen to monitor the SBR reactor. The results show that if nitrate and nitrite were correctly estimated during the whole cycles, the estimated sCOD fit experimental data only in the first and the last hours of the cycles. During the first hours of the aeration step, some discrepancies remain. The model is currently improved to better fit all the data.

Publications

Pauss A., Bekri M., Ribeiro T., Schoefs O., Moreno G. And Benitez A. (2004). On-line monitoring by UV spectrophotometric sensors. In Giornate di Studio in Memoria del Prof. Alberto ROZZI. ENEA Bologna, 25-26 November 2004.

Bekri M., Benitez A., Ribeiro T., Gutierrez S., Olivier Schoefs O., Pauss A. Off-line monitoring of NO_3^- , NO_2^- by UV-deconvolution during SBR processes. In preparation

Bouvier J.C., Bekri M., Mazouni D., Schoefs O., Harmand J., Pauss A.. On-line monitoring of NO_3^- , NO_2^- and soluble COD by UV-deconvolution during a SBR process. In preparation

Meetings, Fields, Trips and Missions

May 15 – May 30: implementation of the on-spectrophotometer in Narbonne by Meriem Bekri.

July 8: meeting for the interpretation of the first results of the on-line spectrophotometer and for the coordination between POLIMI, GRADIENT, INRA and SPESS concerning the integration of the on-line sensors in the LBE_INRA bioreactor.

3.4. POLIMI

Participating staff

Name	Background	Activities in EOLI
Prof. Roberto Canziani	Environmental engineer	WP1, WP3, WP8
Prof. Luca Bonomo	Environmental engineer	WP1, WP3, WP8
Dr. Elena Ficara	Environmental engineer	WP1, WP3, WP8
Ing. Nicola Fiocchi	Environmental engineer	WP1, WP3, WP8
Dr. Paola Butelli	Biologist	WP1

Activities

POLIMI, was concerned with WP1.2 (Experiments for the evaluation of the mass balance model developed within the framework of EOLI); WP1.5 (Evaluation of the FDI and supervision algorithms); WP3.1 (Development of an on-line combined DO-stat and pH-stat titration biosensor); WP3.3 (Pilot plant implementation); WP8.4 (Hardware and Software validation).

Activities concerned with WP1

The experimentation on the POLIMI-SBR has included the following main activities. (1) Batch activity tests on POLIMI-SBE sludge samples were performed with MARTINA to assess the activity of ammonium and nitrites oxidizers at various pH, DO, ammonium concentration and aeration patterns; main goal of these tests was to evidence factors which can favor ammonium oxidizers (AOB) over nitrite oxidizers (NOB), thus unbalancing the nitrification process. The elucidation of environmental conditions, which can lead to the main abnormal condition observed during the POLIMI-SBR operation, are of interest for early fault detection (WP1.5) and to develop appropriate control strategies and supervision algorithms. (2) Batch biosorption tests were performed to confirm that this process is irrelevant for the POLIMI SBR, as assumed in the model developed within the WP2.

Abnormal Conditions in POLIMI SBR – insights in the nitrite build-up problem

Effluent nitrite concentrations well above toxicity threshold were experienced as the main abnormal condition during the two-years operation at the lab-scale POLIMI-SBR. The main origin of nitrite build-up is the unbalanced activity of ammonia and nitrite oxidisers. In batch-fed reactors nitrite accumulation is observed more frequently than in continuously-fed systems. An experimentation was conducted to try to find out whether specific environmental or operating conditions may favor ammonia oxidising bacteria (AOB) over nitrite oxidising bacteria (NOB), creating the conditions for unbalanced nitrification and thus possibly leading to nitrite build-up. Specifically, this experimentation was focused on: (1) the evaluation of the effect of pH, dissolved oxygen concentration (DO) and free ammonia concentration on the activity of ammonium and nitrite oxidizing bacteria; (2) the identification of SBR operating conditions (aeration pattern, micronutrient support) which can prevent nitrite build-up.

Nitrification activity was measured by pH-DO-stat titration performed with the laboratory MARTINA titrator (see Deliverable 3.2). Sludge samples were drawn either from the lab-scale POLIMI SBR or from a full scale WWTP, whose sludge was also used for the SBR

inoculation, when poor nitrification occurred. Tests to assess the effect of DO, pH and NH_3 concentration on the activity of AOB and NOB were performed as follows: an initial set of environmental parameters was fixed and a first activity test was performed by adding the appropriate substrate for the bacteria group whose activity had to be assessed. Then, all parameters were kept constant but the one whose influence was under study, which was increased or decreased. The substrate was spiked again to assess the nitrification activity under the new condition. The maximum nitrification activity measured after each substrate spike was then plotted against the varied parameter. Tests to assess the effect of the aeration pattern on the endogenous decay rate were performed as follows. A batch of 8 L of sludge was sampled and kept under aeration overnight to reach endogenous conditions. Initial nitrification (AOB and NOB) activity was measured. The sludge was then split into four batches, all continuously mixed, each characterized by a different aeration patterns: *Batch A*: not aerated; *Batch B*: continuously aerated; *Batch C*: aeration was cyclically kept on for 12 h and off for the following 12 h; *Batch D*: aeration was cyclically kept on for 1 h and off for the following hour. All batches were kept under endogenous conditions at room temperature (19-22 °C). Daily, pH was measured in all batches and corrected to remain in the range from 7.5 to 8.0. Nitrification activity, VSS and nitrates concentration were measured after 4 and 7 days. The effect of the presence of micronutrients in the SBR feed was tested by monitoring NOB activity with and without micronutrient supplementation.

AOB and NOB activity against DO is plotted in Figure 1, together with the fitting Monod curve, whose best-fit parameters were estimated to be: AOB: maximum activity = 3.0 mgN/gVSS/h; half saturation constant = 0.1 mgO₂/L; NOB: maximum activity = 2.6 mgN/gVSS/h; half saturation constant = 0.4 mgO₂/L. These results confirm the higher affinity of AOB for oxygen, as it has been reported in previous experimentations. However, the DO level during the aerobic react phase of the POLIMI SBR was normally above 1 mgO₂/L, so that DO limitation does not seem to be a major factor causing nitrite build-up in this reactor. Secondly, the effect of pH on nitrification activity was studied (Figure 2). As for the NOB activity, a decreasing trend with pH can be observed. However, the 16% average reduction seems to be moderate. On the contrary, AOB activity increased with pH with both tested sludge samples. For the SBR sludge, AOB activity increased from 2.5 at pH 7.5 to 3.4 mgN/gVSS/h at pH 8.3 (+37%). An even higher increase (+57%) was observed for the sludge drawn from the full scale WWTP. It can be concluded that, by working at pH higher than 8.2 during the aerobic phase of the SBR cycle, nitrite build up can occur due to a higher activity of AOB than NOB. The third evaluation, was aimed at assessing the effect of the free ammonia concentration on NOB activity. To assess NOB activity of mixed cultures (such as activated sludge samples) in the presence of a constant ammonia concentration, an AOB selective inhibitor is needed to avoid concomitant oxidation of ammonium to nitrite. ATU is known to fully inhibit AOB and to be ineffective on NOB. Its selectivity was checked on the SBR sludge. The effect of free ammonia was evaluated by measuring the decrease in NOB activity under increasing free-ammonia concentration (FA). The latter was modified by varying the total ammoniacal nitrogen (TAN = N-NH₃ + N-NH₄⁺), or the suspension pH. The ratio between dissociated (i.e. free) ammonia and TAN can be derived by their chemical equilibrium ($\text{NH}_4^+ + \text{OH}^- \rightarrow \text{NH}_3 + \text{H}_2\text{O}$). Tests were performed on sludge samples freshly drawn from the lab-scale SBR, whose AOB activity was inhibited by addition of 15 mg/L of ATU. Tests were conducted at pH of 7.5 and 8.3 (lowest and highest pH observed in the SBR). NOB inhibition (I) was

plotted against both TAN (Figure 3) and FA (Figure 4). A similar inhibition responses was observed in the presence of different TAN concentrations but similar FA, indicating that FA more than TAN is responsible for the observed inhibition. I versus FA data were fitted with several inhibition functions and the exponential curve gave the best fitting with a R^2 of 0.972. However, when considering TAN concentrations in the SBR reactor, they never exceeded 15 mgN/L corresponding, at 22°C and at pH 8.3, to a FA of 1.25 mgN/L. At this concentration, less than 2% inhibition would be predicted by the best-fitting curve. It can thus be concluded that FA inhibition on NOB activity cannot be relevant in the SBR working conditions.

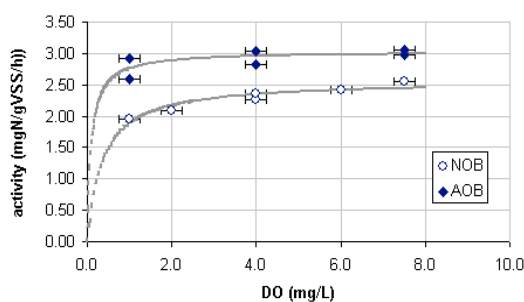


Figure 1: Effect of dissolved oxygen on the activity of NOB and AOB.

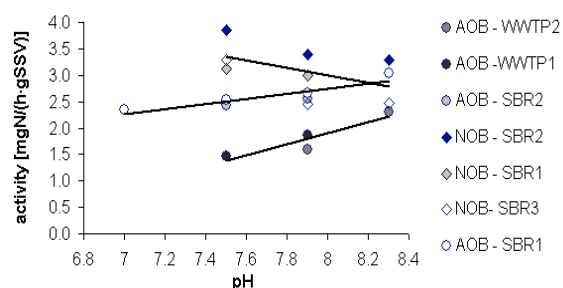


Figure 2: Effect of pH on the activity of AOB (circles) and NOB (diamonds).

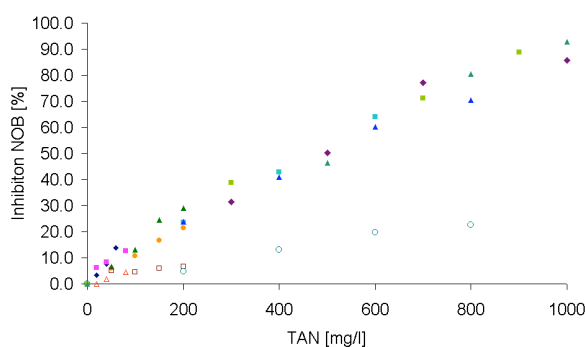


Figure 3: NOB activity inhibition by total ammonical nitrogen (TAN). Tests at pH 8.3 (full indicators) and at pH 7.5 (empty indicators).

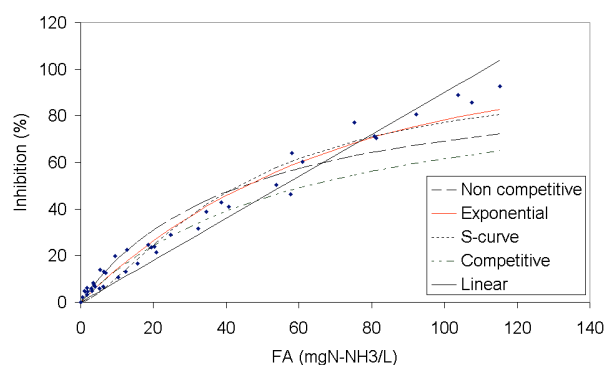


Figure 4: NOB activity inhibition by free ammonia (FA) and fitting curves.

As for the effect of the aeration pattern, Figure 5 depicts the time trend and loss in nitrification activity for both ammonium and nitrite oxidisers. AOB activity was found to decrease much faster in batches B and D in which aerobic conditions prevailed. Less than 20% of the initial activity was measured after 7 days. Batch C was only slightly more performing. On the contrary, a significantly higher nitrification activity was observed for the sludge kept under anaerobic conditions, which lost about 40% of the initial activity in 7 days. The same can be stated for NOB, although the higher data dispersion makes differences less significant. Moreover, it appears that NOB activity was higher than AOB activity for all batched but the anaerobic one, in which a similar activity was measured for both nitrifying bacteria groups. The presence of a balanced nitrifying population is indicated by a NOB/AOB activity ratio higher than 1. This is the case for all

aerobic/partially-aerobic batches, while this ratio slightly decreases with time, in the anaerobic batch. It can therefore be concluded that under aerobic/partially-aerobic conditions, on the one hand, the rate of loss in sludge nitrification capacity increases but, on the other hand, NOB are favoured over AOB, thus preventing the risk of an unbalanced nitrifiers population. On the contrary, anaerobic conditions better preserve nitrification capacity, but may reduce the nitrification over the nitrification capacity of the sludge.

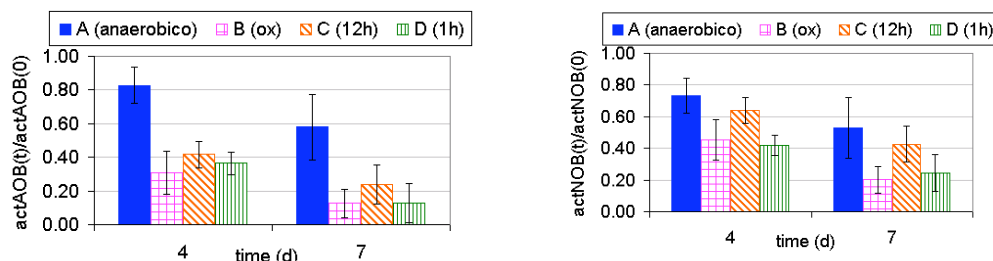


Figure 5: Loss in AOB and NOB activity for the four sludge batches. Error bars refer to one standard deviation calculated on 3 repetitions.

Finally, the limitation of NOB growth by micronutrients availability in the SBR feed was also studied. A micronutrient solution was therefore supplemented for approximately 1 month and then suspended for three weeks, supplemented again for another month and suspended for one more month. During this period NOB activity was monitored. NOB activity grew as long as micronutrients were supplemented, while it decreased during non-supplemented periods, resulting to be significantly lower than AOB activity. Nutrient limitation seems to be a key-factor for nitrites build-up in lab-scale SBR fed on synthetic sewage, while it would be presumably much less relevant for full-scale plants fed on real sewage.

In conclusion, the following conditions were found as being favorable to AOB over NOB, thus possibly leading to nitrite build-up: (1) very low oxygen concentration (less than 1 mg/L) during the aerobic react phase; (2) high pH values (above 8.3) during the aerobic react phase; (3) free ammonia concentration above 10-20 mgN/L; (4) prolonged endogenous periods under anaerobic conditions, which may take place during the anoxic mixed-react phase under low loading conditions; (5) addition of micronutrients to the SBR feed appeared to be essential to support a balanced nitrifying population.

Batch experiments for the study of the biosorption phenomenon

Batch tests were performed on sludge samples drawn from the SBR to which various amounts of COD were initially spiked. The same experimental procedure as the one proposed by LBE was followed. Two organic sources were tested: the synthetic wastewater used to feed the POLIMI-SBR and a suspension of dry milk serum, similar to the feed of the LBR-SBR. The evolution of the soluble COD concentration was then followed in time. In order to discriminate the relative contribution of denitrification and adsorption to the overall COD removal, the following redox conditions were tested: strict anaerobic (AN), anoxic (AX) and anaerobic followed by anoxic (AN+AX). Various food to biomass ratios were tested ($F/M = 0.05-0.19 \text{ gCOD/gVSS}$).

As for the adsorption of the synthetic wastewater, Figure 6 (dark bars) summarizes the percentage of the remaining COD for anaerobic adsorption tests. It can be clearly observed that after 30 min of contact the COD biosorption levels around the 15-20% of the initial

amount. As for anoxic tests, the assessment of COD and nitrogen evolutions allowed to evaluate (1) the denitrification rate ($r_D=10-24 \text{ mgN}_{\text{eq}} \text{ g}^{-1}\text{VSS h}^{-1}$), which resulted to be in the upper literature range; (2) the carbon to nitrogen ratio ($\text{COD/N} = 9-11$) which is quite high suggesting that the COD uptake is due to both denitrification and biosorption. As for the adsorption of the dry milk serum, Figure 6 (light bars) summarizes the percentage of the remaining COD for anaerobic adsorption tests. The fraction of “biosorbed” organic substrate leveled out after 30 min of contact. Averagely, a fraction of 15-20% of the initial organic carbon was absorbed. The biosorption behaviour of the sludge resulted to be very similar to the one observed with the synthetic WW as carbon source. The sludge behaviour under anoxic conditions was found to be very different from the one observed in the presence of the synthetic WW. No significant difference was found among the COD trends in the three batches, suggesting that no denitrification took place. This hypothesis is supported by the negligible nitrate decrease in both batches 12 and 13. Apparently, the sludge grown on the synthetic feed could not efficiently use the milk serum as carbon source for denitrification, without proper acclimation.

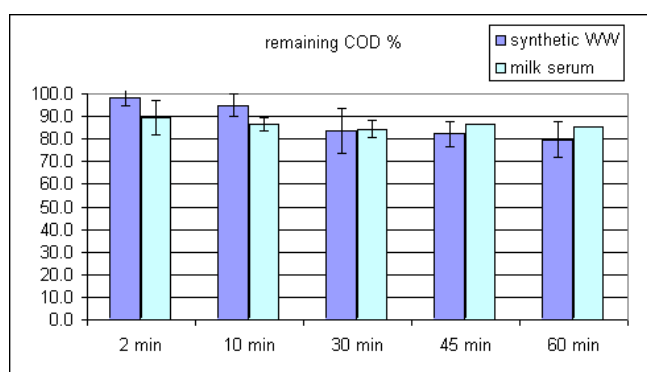


Figure 6: comparison between the biosorption behavior of the sludge with two different organic carbon sources under anaerobic conditions.

Experimental results suggest the following conclusions: (1) the biosorption behaviour of the POLIMI-SBR sludge resulted to be similar in all tests and limited to a fraction ranging from 15 to 20% of the initial amount of COD added; (2) no correlation between biosorption and initial F/M was observed; (3) biosorption resulted to be substantially concluded within the first 10 min of contact; (4) the extent of biosorption was similar with both the organic carbon sources tested.

Activities concerned with WP3

During the third year and within the objectives of WP3, some activities were performed at POLIMI, Milano and some others at ENEA, Bologna.

Activities performed at POLIMI, Milano were the following. (1) DO-stat titration tests were compared to classical closed respirometry to assess operational differences and constraints for practical applications; in particular, comparison between DO-stat titration and closed respirometry allowed the assessment of OUR and Y_H in long term experiments. (2) Further pH-stat titration tests were performed in order to achieve operational information to implement operational MODE 5 of the automatic titrator (TITAN) to assess nitrates concentration.

Activities performed at ENEA, Bologna were the following. (1) Field tests were performed with the prototype of the on-line pH/DO-stat automatic titrator (TITAAN) for debugging; this activity was performed in strict cooperation with SPES. (2) More pH/DO-stat tests were performed; these data enable to perform tests to simulate some of the modes of operation of the TITAAN during its development.

DO-stat titration tests were compared to classical closed respirometry

The aim of this experimentation was to compare respirograms of sludge samples oxygenated with air (b_{air}) to those of samples oxygenated with hydrogen peroxide ($b_{\text{H}_2\text{O}_2}$). For this purpose 27 long term parallel respirometric tests were performed to verify whether the two oxygen source could be considered equivalent.

Typical respirograms related to b_{air} and $b_{\text{H}_2\text{O}_2}$ obtained during respirometric tests with the synthetic influent and in the presence of ATU are reported in Figure 7 (left graph). The following observations can be made: (1) the shape of the respirogram is similar; (2) the initial and final endogenous OUR are similar for both respirometric techniques; (3) maximum OUR, measured right after substrate addition, were the same; (4) exogenous OUR measured afterwards are different and higher for $b_{\text{H}_2\text{O}_2}$. The exogenous cumulative oxygen curve (Figure 7 – right graph) was also calculated as the area under the respirogram subtracted by the endogenous oxygen consumption estimated from the OUR measured at the end of the test. These amounts are referred to the volume of influent dosed ($\text{mgO}_2/\text{mL}_{\text{influent}}$) and confirmed a higher oxygen demand for $b_{\text{H}_2\text{O}_2}$. The difference between the two respirometric techniques was limited during the firsts two hours after substrate addition, while it increased with time between 1 and 5 hours after substrate addition. The following hypotheses can be made to explain the above described experimental results: (1) H_2O_2 makes the hydrolysis of the particulate substrates faster, thus increasing the OUR related to the oxidation of the slowly biodegradable fraction of the synthetic influent. (2) H_2O_2 favors the degradation of the organic debris from death biomass, thus increasing the availability of biodegradable organic substrate; (3) H_2O_2 affect the biomass metabolism decreasing the Y_H value. The latter hypothesis was validated by performing respirometric tests on two easily biodegradable substrate (glucose and acetate). Results are reported in Table 4 and suggest that a lower biomass growth takes place in the presence of hydrogen peroxide as oxygen source.

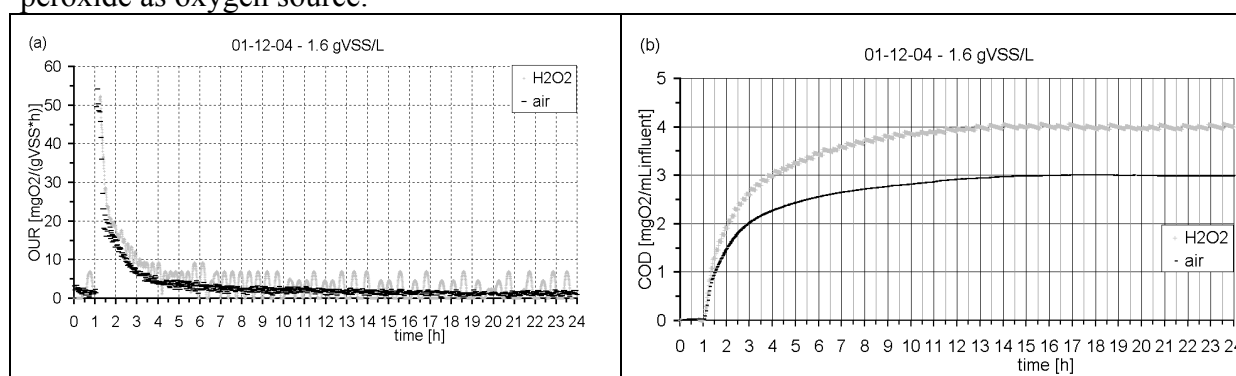


Figure 7: Typical respirograms and exogenous cumulative oxygen consumption curve obtained during two respirometric tests with the synthetic influent and in the presence of ATU.

Table 4: Y_H values (mean±standard deviation) obtained for the two respirometric techniques in the presence of acetate and glucose.

Oxygen source	Organic substrate	
	Acetate	Glucose
air	0.70±0.11	0.86±0.01
H ₂ O ₂	0.61±0.07	0.79±0.02

Finally, the calculation of the f_{rbCOD} of the synthetic influent based on the cumulated oxygen uptake was performed by assigning to Y_H , the average value obtained for acetate (Table 4) and therefore higher for $b_{\text{H}_2\text{O}_2}$. Under this assumption, f_{rbCOD} resulted to be 0.45 for b_{air} and 0.42 for $b_{\text{H}_2\text{O}_2}$, resulting in a discrepancy of 5 % between the two respirometric techniques.

In conclusion, results indicate that respirometric tests with H₂O₂ cannot be used to estimate the heterotrophic yield, since the latter would be underestimated. However, if the main aim of the respirometric test is the assessment of the biodegradable fraction of a wastewater, the latter cannot be calculated by assuming average literature values for Y_H , but the latter should be experimentally calculated, e.g. in respirometric experiments with acetate.

Further evaluation of the feasibility to use of pH-stat titration to assess nitrate concentration

A pH-stat titrimetric procedure has been developed and applied to monitor the denitrification process (Mode 5). A sludge sample is withdrawn at the end of the phase of aerobic or anoxic reaction and loaded into the titrator beaker. Under pH-stat conditions, acetate is added in excess as external carbon source to trigger denitrification. Having this process an alkalinising effect, the acid titrant is dosed to the sludge until no more oxidised nitrogen is available and the titration rate decreases significantly. A first titrant volume is determined ($V_{\text{HCl,sludge}}$). At this point, a known amount of nitrates ($\text{NO}_{3\text{spike}}$) is added and a second titration curve is collected, whose acid volume ($V_{\text{HCl,spike}}$) is used as reference for the calculation of the mass of nitrate denitrified per amount of acid added (N/H):

$$N / H \left[\frac{\text{mgN} - \text{NO}_3^-}{\text{mmol}_{\text{HCl}}} \right] = \frac{\text{NO}_{3\text{spike}}^- [\text{mgN} - \text{NO}_3^-]}{V_{\text{HCl,spike}} [\text{mmol}_{\text{HCl}}]}$$

Being the latter ratio substrate and sludge dependent, it can be used to infer the amount of nitrate which were denitrified in the first titration step and which were thus present in the sludge when sampled:

$$N_{\text{sludge}} \left[\frac{\text{mgN} - \text{NO}_3^-}{L} \right] = N / H \left[\frac{\text{mgN} - \text{NO}_3^-}{\text{mmol}_{\text{HCl}}} \right] \cdot \frac{V_{\text{HCl,sludge}} [\text{mmol}_{\text{HCl}}]}{V_{\text{sludge}} [L]}$$

This estimation method was compared with analytical determinations on 42 tests. Results are shown in Figure 8 where errors are calculated as:

$$err_{NO_3}(\%) = \frac{N_{sludge}^{NO_3} - N_{analytical}}{N_{analytical}} \cdot 100;$$

By focusing now on the whole set of 42 data of $err_{NO_3}(\%)$, the test of Kolmogorov was applied to the whole set of $err_{NO_3}(\%)$ values which indicated that data could be considered to be normally distributed (with a significance level of 5%) their mean value being 2.8% and their standard deviation being 14.3%. It can therefore be concluded that estimates of nitrates concentration by the titrimetric procedure would differ from the spectrophotometric ones of less than $2.8 \pm 14.3\%$ in not less than the 68% of the cases. This difference is indeed acceptable when dealing with the monitoring of treatment efficiencies. Moreover, denitrification rates were calculated by using the titration rate of each calibration step ($r_t^{NO_3}$) and its related conversion factor:

$$r_{den}^{NO_3} \left[\frac{mgN}{gVSS \cdot h} \right] = \frac{r_t^{NO_3} [mmol_{HCl} / h] \cdot N / H^{NO_3} [mgN - NO_3^- / mmol_{HCl}]}{VSS [gVSS / L] \cdot V_{sludge} [L]}$$

Denitrification rate in the presence of nitrate was found to vary between 7.3 and 23 $mgN \ gVSS^{-1} \ h^{-1}$, its average value in the experimental period being $14.1 \pm 3.3 \ mgN \ gVSS^{-1} \ h^{-1}$. The effect of the test pH on denitrification rates was analysed by grouping data in pH classes and by applying a one-way analysis of variance which suggested that pH variations within the experimented range are not relevant (p-value of 0.98).

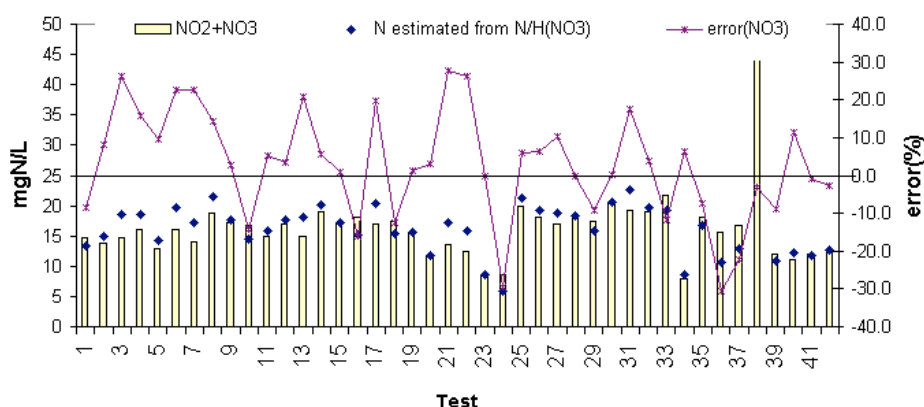


Figure 8: On the left y-axis: Sludge oxidised nitrogen content estimated according to the pH-stat titrimetric procedure and analytical determinations. On the right y-axis: Percentage errors.

In conclusion, this experimentation allowed confirming that the proposed pH-stat titrimetric procedure is sufficiently precise and accurate to assess nitrate concentrations in SBR sludge samples for process monitoring purposes; moreover, the proposed procedure also allows assessment and monitoring of maximum denitrification rates without any nitrate analytical determination.

Development of the on-line pH/DO-stat titrator and its implementation at ENEA SBR pilot plant

The prototype of the on-line titration unit TITAAN, built by SPES on the basis of POLIMI specifications during 2004, has been placed at the Bologna SBR pilot plant during

November '04. First, the hydraulic connections between the instrument and the plant were installed; then, data-transfer lines were laid down among TITAAN and the PLC managing the SBR. A debugging procedure was then followed in cooperation among ENEA, POLIMI and SPES. Several problems had to be fixed including both instrument hardware and software. Details related to this debugging activity are reported in the SPES report. Then, the instrument was calibrated and preliminary tests could be performed on-line in Mode 1 and 3 (see Deliverable 3.2). Nitrification activities measured on the ENEA-SBR sludge in the winter season are reported in **Figure 9** (Mode 3). A slow increase in nitrification rate can be observed as a result of the increased SBR temperature from December to March. In *Table 5*, nitrification activity data assessed by TITAAN according to Mode 1 are reported and show a case of nitrification inhibition, possibly due to the recycling of the sludge dewatering supernatant to the plant inlet. Although not many reliable data could be collected during this first field test, the experimentation at the ENEA SBR was precious for instrument debugging before sending it to LBE for the final integration step.

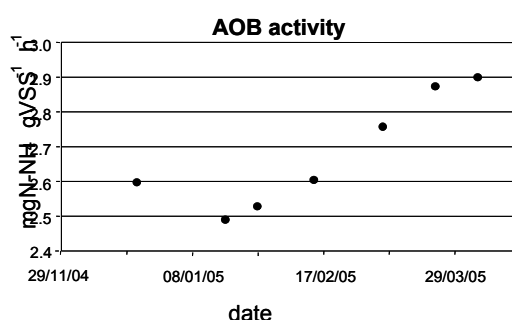


Figure 9: AOB activity as measured by TITAAN according to Mode 3 on ENEA-SBR sludge samples.

Table 5: AOB activity [mgN/(gVSS*h)] measured by the TITAAN prototype on real sewage (average from pH-stat and DO-stat test)

Date and time of test		AOB activity normalized at 20°C
19 / 04 / 05	10 : 45 : 35	3.05
19 / 04 / 05	12 : 09 : 37	2.81
20 / 04 / 05	11 : 30 : 13	2.28
21 / 04 / 05	10 : 44 : 11	1.80
22 / 04 / 05	11 : 57 : 16	2.19

Activities concerned with WP8

On 6th July 2005, the TITAAN instrument arrived at the LBE laboratory where it has been integrated in the overall supervision system. The instrument was operated in Mode 1, the most complex and challenging procedure, within the 5 Modes of operation proposed and tested with the MARTINA instrument.

Meetings, field trips and missions

Project Meetings:

- o Montevideo – Uruguay (9-11/05/2005)
- o Mexico City – Mexico (17-19/10/2005).

Missions for conferences:

- o Ecomondo: Norme, tecnologie e controlli ambientali, Rimini –Italy, 3/6 Nov.04.

- o IWA Specialized Conference in Nutrient Management in Wastewater Treatment Processes and Recycling Streams. Krakow, 19-21 Sept. 2005

Technical Meetings:

- o with SPES and/or ENEA (2/12/2004 in Fabriano I, 25/1/2005 in Milan 2005; 23/2/2005 and 21/06/2005 in Bologna).
- o with LBE and SPES (Narbonne 11-13/07/2005)
- o with SPES and/or ENEA (2/12/2004 in Fabriano I, 25/1/2005 in Milan 2005; 23/2/2005 and 21/06/2005 in Bologna).
- o with LBE and SPES (Narbonne 11-13/07/2005)

Publications

- Canziani R., Ficara E., Fiocchi N., Luccarini L., Mariani S., Pirani M., Ratini P. (2004). 'Monitoraggio on-line dei processi a fanghi attivi mediante sensore a titolazione pH/DO-stat'. Atti dei seminari Ecomondo: Norme, tecnologie e controlli ambientali, Rimini 3/6 Nov., Vol. 2, pp. 123-133.
- Fiocchi N., Ficara E., Canziani R. (2004) On-line monitoring by set-point titration. Giornate di Studio in Memoria del Prof. Alberto Rozzi "Ricerca ed innovazione nella depurazione delle acque reflue", Milano - Bologna, 25 - 26 Novembre 2004, pp. 148-159.
- Ficara E., Fiocchi N., Canziani R., Luccarini L., Ciappelloni F., Ratini P., Pirani M. and Mariani S. (2005). SBRs on-line monitoring by set-point titration. ICA 05, The 2nd IWA Conference on Instrumentation, Control and Automation for Water and Wastewater Treatment and transport systems, 29 May – 2 June 2005 Busan, Korea, paper R-16-s, accepted for publication on Wat. Sci. Tech.
- Ciappelloni F., Luccarini L., Fiocchi N., Ficara E., Canziani R., Ratini P., Pirani M. and Mariani S. (2005). On-line monitoring of nitrification efficiency by set-point titration. Proc. IWA Specialized Conference in Nutrient Management in Wastewater Treatment Processes and Recycling Streams. Krakow, 19-21 Sept. 2005. pp. 823-832.

Annexes

- **ANNEX WP1 POLIMI project activities**
- **ANNEX WP3 POLIMI project activities**

3.5. SPES

Participating staff

Name	Background	Activities in EOLI
Ing Paolo Ratini	Electronic Engineer	WP3 and WP8
Ing Davide Mancini	Electronic Engineer	WP3 and WP8
Ing Fernando Negozi	Electronic Engineer	WP3 and WP8
Ing Franco Bodreghini	Electronic Engineer	WP3 and WP8
Ing. Mirko Bartolucci	Hardware Designer	WP3 and WP8
Ing. Massimiliano Pirani	Software Designer	WP3 and WP8
Dr. Simone Mariani	Chemist Technician	WP3

Activities

During the third year of the project the activities were carried out within the WP3 and WP8: in the WP3 the effort was focused on the test and validation of the on-line version of the titration biosensor; as far as the WP8 concerned, the sensors' network configuration was defined, validated and reported in the Deliverable D8.2, while the design and implementation of the system architecture was over and detailed in the Deliverable D8.3, and the validation of the integrated system was implemented at the two pilot plants, the one located at INRA facilities and the other one in Bologna, and the Deliverable D8.4 was provided to present the final results of the work.

Validation of the on-Line version of the titration biosensor (WP 3)

The activity of SPES during the third year of the project was focused on the validation of the on-line version of the titration biosensor, the TITAAN, and its integration into the EOLI digital platform.

The major issue of this activity is the field test of the instrument both at the ENEA pilot plant in strict co-operation with POLIMI and at the INRA pilot plant.

The TITAAN was shipped to Bologna and located at the ENEA pilot plant in the second half of October 2004. Since November 2004 till June 2005 the biosensor was under test and debug. Three technicians from SPES were continuously in Bologna during this period to accomplish this activity.

A summary report of the effort spent and of the activity implemented is presented below:

Hydraulic and mechanical components field test.

Problems and faults reported:

1. solenoid valves clogging;
2. inefficient feeding hydraulic circuits for the withdrawal of the sample.

Actions implemented:

1. redesign of the hardware component for the solenoid valve motion control; washing cycles procedure for the vessels and the hydraulic circuits were defined and implemented.
2. redesign of the feeding circuits.

Electronic components field test.

Problems and faults reported:

1. noise disturbance for the level sensors signal acquisition
2. unreliable management of the level control using different inflow speed for the two feeding circuit (sludge and wastewater).

Actions implemented:

1. redesigned the cables wiring and replaced the connectors; designed and realized new electrodes with different shape.
2. designed a FW routine to implement the auto-calibration of the level sensing.

Firmware features and functionalities field test:

- withdraw the sample to be analyzed;
- execute the titration experiment;
- discharge the sample;
- elaborate data collected during the experiment;
- provide elaborated data available for monitoring and control systems.

Major issues addressed and investigated were the reliability and repeatability for:

1. the probes' calibration and signal acquisition;
2. the management of the dosing lines;
3. the automatic withdrawal and discharge of the sample;
4. the automatic management of the washing cycles;
5. the automatic management and execution of the titration experiment;
6. on-line automatic data collection and elaboration.

A PC software package was designed and developed to record, debug and evaluate the performances of the several functionalities of the on-line titrator during the field test.

Actually this software is the main tool used for the validation of the results produced by the titrator analyzer. It has been developed within Matlab environment for two main purposes: to speed up design and test of the analysis algorithms , and to make it become the first release of the software which will permit the user-friendly analysis and storage of the experimental data.

In fact experiment data are stored on a removable flash disk, and the user can watch and order the results on a PC using the usual widely known file browsing tools.

In the current debugging version, two kind of files are created during an experiment: a .log file and a .dat one. In the .dat file are stored all the probes acquisitions and actuators actions plus an header part with the settings of the current experiment. In the .log file are written the results of elaboration and debugging information.

The validation of the routines running on the Main board of Titaan, implemented to elaborate the on-line data, is made comparing the output in the .log file with the output created by the PC software version of the same routines implemented in Matlab.

In Figure 1 it is shown a screenshot of the Matlab tool with the experiment data track loaded from the .dat file.

In Figure 2, the elaboration has been already run, and it is shown the screenshot with the results for the Mode 1 analysis algorithm. The results produced are written in a .log file which can be used for reading the results themselves and debug information of the last elaboration.

The use of this kind of .log file is conceived to be a temporary one. In the final release the results will be provided in a dedicated .out file which will be used for historical database storage. The file .log is necessary only in this debug phase and it will probably no longer be in use in the final version.

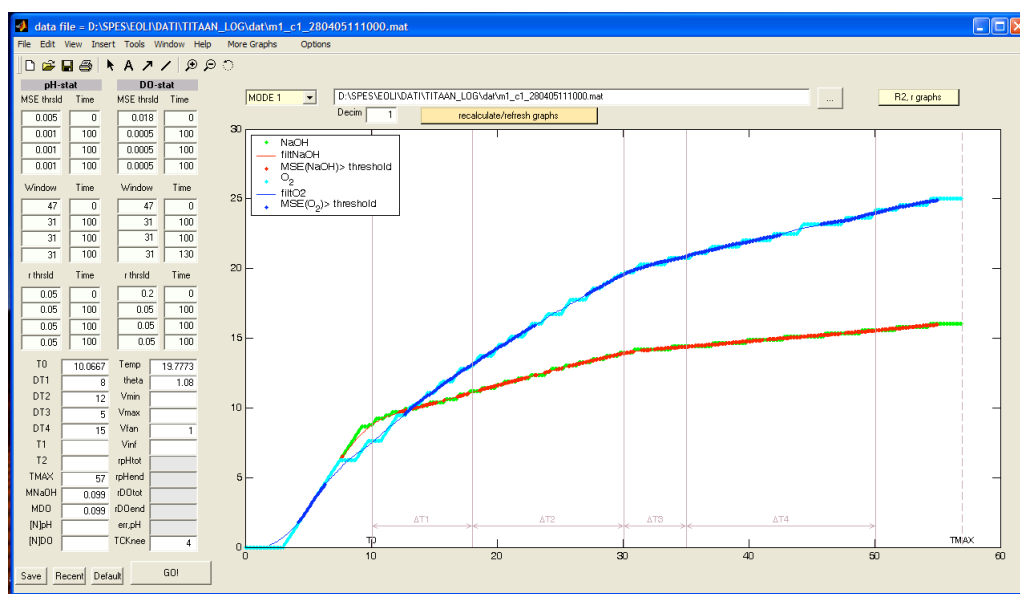


Figure 1

Note that the algorithm running on Titaan is exactly the same implemented in the Matlab environment. Indeed a very strict translation into Linux C language have been made as both programming environments are forced to use the same LAPACK math libraries.

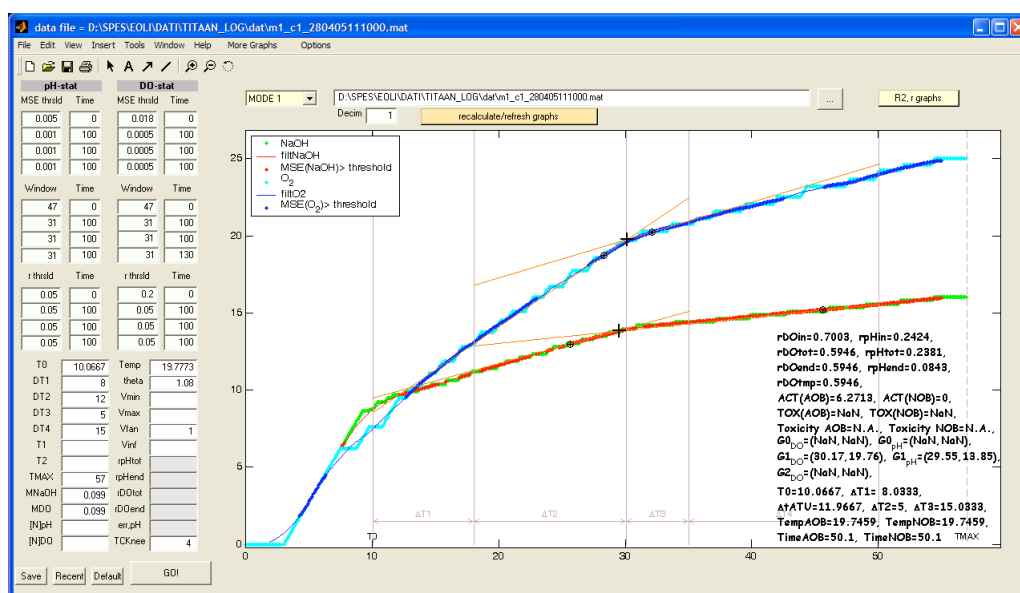


Figure 2

In Figure 3 are presented some snapshot taken during the field test activity at the ENEA pilot plant.



Figure 3

On July, at the beginning, the TITAAN was removed from the ENEA pilot plant and shipped to Narbonne to be located at the INRA pilot plant. Six persons from SPES were in Narbonne for two weeks in July, since the 4th till the 20th, to provide support for the installation, the set up, the startup of the biosensor and its integration into the EOLI digital platform.

A set of hardware and software tools were developed and set up to provide tele-assistance for the maintenance and the update of the biosensor.

At now, two technicians working at the SPES' facilities are full time employed both in providing tele-assistance for the tuning and maintenance of the biosensor and in the co-operation with the work for the experimental activity carried on in Narbonne at the INRA labs.

Below in Figure 4 are presented some snapshoot taken during the shipping and the activity at Narbonne.



Figure 4: the shipping of the TITTAN and its location in Narbonne

Validation for the integrated system (WP8)

The activity within the WP8 during the third year was focused on the validation of the integrated EOLI digital platform (WP8.4).

The first release of the of the hardware and software platform was delivered and reported in the Deliverable D8.3. Two sensor network configuration were assessed and validated: they are presented and detailed in the deliverable D8.2.

The final release of the hardware and software platform was implemented and installed at the two pilot plants of the project. The final implementation of the EOLI system is reported in the Deliverable D8.4.

Within the project, there are several wastewater treatment plants that are being fitted with the EOLI system, adapted to their individual needs. These are the project's integrated systems. Integration means the setting up and basic testing of the EOLI modules on a SBR plant site, within the framework - the middleware - that allows them to communicate with each other and with the SBR process itself. The integration activity involved two real physical plants with the aim of validating the reliability and customisability of the system: the pilot scale plant at ENEA (Italy), and the pilot scale plant at INRA (France). These plants have very different characteristics, and thus it was a strong test for the EOLI approach to be able to integrate them all using the same framework.

Starting from the beginning of November 2004, at the ENEA pilot plant a complete field test of the digital platform and its hardware and software components was performed. In this phase of the project, as far as the hardware sensor integration concerned, the biosensor titration TITAAN – developed in WP3 - was run and tested in parallel at the ENEA pilot plant: the TITAAN is managed by the main board of the EOLI digital platform in the same way of a slave board, connected by a RF link or a serial link, that's why the TITAAN is provided with the same kind of links as it is a slave board (see deliverable D8.2 for details). So its integration is attended by simply enrolling the variables needed for the management of the measurements produced into the EOLI local software, and this implies automatically the update of the database tables.

For the whole period of the field test at the ENEA pilot plant, three technicians from SPES spent three weeks a month in Bologna (250 KM away from SPES facilities) - since November 2004 till June 2005. In Figure 5 are presented some snapshots taken during the activity in Bologna.



Figure 5: details of the electric cabinet set up and of the control room at the pilot plant in Bologna

When the field test was over, in July the platform was installed at the INRA pilot plant for the integration of the other hardware sensor – the UV sensor – and of the Matlab Modules (control and supervision) and for the validation of the whole EOLI supervision system.

The UV sensor is managed by a devoted PC: the EOLI system interact with this alien PC using a software module as media. As a consequence the integration of this hardware

sensor is reduced to the enrolment of the related both software module and variables, to manage the measurements produced, into the SPESGateway - the EOLI local Software (for more details see deliverable D8.4) –actions that automatically imply the update of the database tables.

At the same time, the TITAAN was shipped to Narbonne and installed at the INRA pilot plant too.

In July, since the 4th till the 20th, six technicians from SPES were in Narbonne to provide support for the shipping, the installation and set up and for the start up of the EOLI system at the INRA pilot plant.

Screenshots presenting this phase of the activity are in Figure 6

At now the full integrated system is running at the pilot plant in Narbonne.

The whole integrated system produced at the end of the project is characterised by the high level of modularity pursued for the integration that makes it possible to configure, to enrol, to enable or to disable all the several components: so the system can be applied at plant of different size, under different sensors network configurations. The experience from the installation, running and maintenance at two different pilot plants, the ENEA and the INRA ones, confirm this result. The full customisability, that was a key requirement for the development of the system, is a consequence of this high and reliable modularity.





Figure 6: details of the electric cabinet and of the control workstation at the pilot plant in Narbonne

The EOLI project is based on the idea that a web WWTP is connected to a Remote Server Machine – located at a remote control centre - in order to upload measured data and alarms and download control actions. This Remote Server is essentially a supervisor system which implements a distributed control architecture.

The EOLI remote control centre was set up.

The lab and pilot scale plants enrolled in the EOLI system are: two lab plants at UU, two pilot plants, one at INRA and the other one at ENEA, and one full scale plant at IbTech in Mexico. The data from these plants are available at the remote server. At the *login page* <http://82.190.245.149/eoli>, a public login, *user name* **demo**, *password* **demo**, is available to experience the general features and functionalities of the EOLI systems as far as the remote monitoring and control of the plants.

In order to test and to demonstrate the potentialities and capability of the EOLI system as far as the data management and integration, three plants, than the two pilots, located out of Europe, the IbTech full scale plant in Mexico and the two lab plants at UU have been logged to the EOLI remote server.

SPES provided assistance and know how to realize the software packages for the data transfer from these plants to the remote server.

Meetings, field trips and missions

During the third year, SPES personnel attended to: the mid term meeting in Montevideo (May 2005, Massimiliano Pirani); five technical meetings at ENEA (in November 2004,

January 2005, May 2005, July and September 2005, Paolo Ratini, Massimiliano Pirani and Simone Mariani), in Bologna, for coordinating the experimental activity on the pilot-scale SBR; two technical meeting in Milano, the first one in January 2005 with INRA and POLIMI (Simone Mariani, Massimiliano Pirani and Paolo Ratini) and the second one in October 2005 with POLIMI (Simone Mariani and Paolo Ratini); one technical meeting in Narbonne with INRA, POLIMI and UTC/Gradient (in July 2005, Simone Mariani, Massimiliano Pirani and Paolo Ratini). Three technicians (Simone Mariani, Massimiliano Pirani and Davide Mancini) were in Bologna three weeks a month since November 2004 till June 2005 during the field test activity at the ENEA pilot plant. Six technicians (Simone Mariani, Massimiliano Pirani, Paolo Ratini, Andrea Quintabà, Francesco Esposti and Mirco Lancioni) were in Narbonne in July 2005 since the 4th till the 20th to provide support for the installation at the INRA pilot plant.

3.6 UNAM

Participating staff

Name	Background	Activities in EOLI
Prof. Germán Buitrón	Chemical process scientist	WP1, WP3
Prof. Jaime Moreno	Process control scientist	WP2, WP5
Prof. Cristina Verde	Control scientist	WP6, WP7
Prof. Alejandro Vargas	Control Scientist	WP3
Dr. Wilverth Villatoro	Biotechnological scientist	WP1
M.Sc. Manuel Betancur	Process control scientist	WP2, WP5
M. Sc. Iván Moreno	Biotechnological scientist	WP1
Ing. Antonio Linares	Biotechnological scientist	WP1
M. Sc. Gloria Moreno	Biotechnological scientist	WP1, WP3
M. Sc. Dieter Wimberger	Computer scientist	WP6, WP7, WP8
Ing. Juventino Cuéllar	Control Scientist	WP6
M. Sc. Elia Velázquez	Bioprocess Scientist	WP1
M. Sc. Jaime Pérez	Bioprocess Scientist	WP1
Ing. Leonardo Jiménez	Bioprocess scientist	WP1, WP3
Ing. Alma Corrales	Bioprocess scientist	WP1
Ing. Norman García	Control scientist	WP8
M. Sc. Jesús Mina	Control Scientist	WP6, WP7, WP8
Ing. Alexander Schaum	Control Scientist	WP5

Activities

In the third year of the project, the activities of the UNAM were carried out within several Work Packages: Process Experiments (WP1), Hardware Sensors (WP3), Control Design (WP5), Fault Detection and Isolation (WP6), Supervision System (WP7), and Integration (WP8).

Activities Concerning WP1

In this period, the Event Driven Time Optimal Control developed in the UNAM was tested. The ED-TOC strategy was evaluated against the introduction of shock loads. The long-term stability of system under the standard conditions was also evaluated for the degradation of 4CP.

In order to evaluate the process improvement with the application of the optimal control law two sets of experiments were tested: The evaluation of the optimal control strategy against the shock loads and in during the long-term operation of system. The evaluation of the evolution of the microorganisms community in the acclimation and the long-term stability of the system was carried out using molecular biology techniques. The toxicity of the treated wastewater using the ED-TOC strategy was also determined.

Experiments Conducted

1. Degradation of Shock loads of 4CP by the ED-TOC strategy
 - a. Comparison of FTC and ED-TOC strategies
2. Degradation of a mixture of municipal wastewater and shock loads of phenol by the ED-TOC strategy
3. Long term stability

- a. Bacterial community analysis and identification
 - i. Changes in the bacterial community during the acclimation
 - ii. Evolution of the bacterial community during the long-term stability of the system using the ED-TOC strategy
 - iii. Toxicity of the treated wastewater using the ED-TOC strategy
4. Start up and ED-TOC strategy operation in the field scale plant

With the application of the ED-TOC strategy it was possible to degrade shock loads of 4CP concentrations and a mixture of municipal wastewater and phenol without any problem. A better performance of the reactor operated with the ED-TOC strategy was observed when it was compared to the response obtained with the reactor operated under the conventional strategy. It was shown that not only higher concentrations of toxic could be treated with the ED-TOC strategy, but also a reduction in degradation time (around 52%) and in the supplied air volume was obtained.

A good performance of the reactor operated with the ED-TOC strategy was obtained since the degradation and mineralization of the mixture with high load of the 4CP and phenol cases was efficiently completed. The ED-TOC strategy was able to manage increments of toxic concentrations in the influent up to 7000mg/L of phenolic compounds in the wastewater without any inhibition problem.

In theory the strategy could degrade any influent concentration of toxic wastewater without problems. The use of the ED-TOC strategy can minimize the volume of the reactors because it is not necessary to dilute high concentrated toxic wastewater as in the usual operation mode in order to avoid inhibition. The strategy can be applied for industrial wastewater containing high phenols concentrations or other inhibitory compound.

The reactor operated by ED-TOC strategy showed that is robust and stable in large periods of operation (100 days), with efficiencies of plus than 99% for the 4CP degradation, and 97% as COD degradation. The DGGE analysis showed that there are changes in the microbial population during the acclimation and during the stability in a long operation period by ED-TOC. The analyses of toxicity demonstrate that the bioreactor operated by ED-TOC eliminates the toxicity in the wastewater.

Activities Concerning WP3

The partner 6 (UNAM) has participated in the WP3 of the EOLI project, regarding the use of spectrophotometric techniques to determine on-line measurements of concentrations during biodegradation of toxic (aromatic) substances.

Spectrophotometers operating in the ultraviolet and visible (UV/Vis) range are capable of reliably scanning the absorbance spectrum of a sample for a whole range of wavelengths. This multiwavelength data can be used to further enhance the concentration measurements, e.g. via partial least squares (PLS) regression or spectral deconvolution (SD), which is based on expressing the measured absorbance spectrum as a linear combination of a few base spectra.

In the course of the possible development of such a hardware sensor, the group has examined two possible concentration measurement techniques using data from a spectrophotometer to estimate the concentration of 4-chlorophenol (4CP) during its

biodegradation in a sequencing batch reactor (SBR) operating under a fixed-time strategy (see WP1 UNAM), as well as the parallel estimation of a metabolite that may appear during the reaction. This metabolite, which apparently corresponds to the compound 5-chloro-2-hydroxy-muconic acid appears when oxygen concentration within the reactor is limiting and the biomass is stressed. It is important to detect it because its apparition signals problems during biodegradation, since another (slower) metabolic pathway is being taken by the microorganisms.

Two experiments were performed. A first one was simply to test the technique under no oxygen limiting conditions, i.e. no metabolite formation, in which case only one base spectrum is needed for the SD technique. For the second experiment, no calibration to get the base spectra was made. The base spectrum for 4CP was that from the previous experiment, while the one for the metabolite was the one for which absorbance at 380 nm was maximal, minus the one of the effluent, considering the range from 310 to 480 nm. This implies that the concentration estimation for the metabolite has 1 as a maximum in whatever units this results.

As it can be seen from the results presented, for the first experiment both methodologies MWL and SD seem to give acceptable results, comparable with those obtained for the standard technique. Both techniques are suitable for the construction of a hardware sensor, such as the one that has already been built by the other WP3 partner and this may be future work in a close collaboration.

Activities Concerning WP5

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 (ED-TOC), which demonstrated being able to solve the desired optimizing criteria (minimum treating time), for the given restrictions, both under Standard conditions and under Shock load conditions, in lab-scale experiments.

During the reported period the assessment of the practical advantages of the ED_TOC (fed-batch operation mode), over the traditional Fixed Time Control (FTC) (batch operation mode), was done.

Following the WP interaction policy, various additional tasks were performed:

- The redesign of the control software and instrumentation for both, a lab-scale and a field-scale, Sequencing Batch Reactors (SBR) was done following the WP8 integration criteria, in order to allow for convenient data integration.
- The software and the I/O hardware for the field-scale SBR were tested. The I/O device is independent from the control computer, able to serve simultaneously various clients. The link is based on an open Modbus protocol. This allows WP6 and/or WP7 results to be integrated to the WP5 control modules already working.
- The guidelines for commissioning the field-scale SBR were given to IBTech.
- The possibility of using a WP3 hardware spectrophotometer sensor for the substrate concentration was studied. On-line integration seems not possible at this time.

At UNAM, the biodegradation of a toxic compound by naturally occurring microorganisms is investigated. 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 (ED-TOC). The comparison showed the advantages of the ED-TOC. A lab-scale reactor was used to obtain the first results. A second SBR, field scaled, is already built and is being commissioned. The very first essays were successfully done just before closing this report.

Activities Concerning WP6

The third year the WP6-FDI team at the UNAM concentrated its efforts in the tuning of the FDI algorithms considering abnormal condition in sensors, actuators and the parameter deviations K_i and K_s in the model EM1. The details of the algorithms and their tuning are reported in the deliverable D6.1 Diagnosis algorithms for robustly detecting and isolating of a number of sensor, actuator or/and process faults for discontinuous SBR. Then, the FDI team at UNAM achieved the second milestone of WP6 A set of validated FDI routines which guaranties the protection of the biomass in the SBR process third milestones of WP6.

An improvement of the DPCA has been proposed by the UNAM team to detect fault when the variables do not satisfy the stationary condition and it has been applied specifically to the actuator fault selected in WP6.1 (servo-valve). Results were presented at 2nd International Conference of Electrical and Electronic Eng, Sept 2005.

The limitation of the model reported by WP2 for the POLIMI reactor were pointed out and the FDI team at UNAM concluded that it cannot be used to emulate the nitrification capacity of the SBR process. An intent was proposed to solve the detection task using a quality cause effect model, without success (see annual report 2005). Moreover, the nitrites build up issue was analyzed and recommendations for the monitoring of the process are given after the analysis made in POLIMI. These suggestions are part of the deliverable D4.1; however any specific FDI algorithm has been designed.

To increase the number of faults that can be detected in a SBR process, the FDI team at the UNAM exploits the sequential property of the batch process. A formal discrete event system model for the traditional SBR process is proposed and augmented it with new states to enable three mains tasks: (1) the online identification of the oxygen transfer parameter KLa ; (2) the observation of the respiration rate $r(t)$ during the reaction phase; and (3) a test for verifying substrate presence at the end of the reaction, This result were presented by the doctoral student D Wimberger at the IFAC World Congress this Summer in Prague.

Another proposition was made by the FDI team at the UNAM to solve the process abnormal condition of the model EM1 using signal based approach. Particular features were extracted of the respiration rate estimation which allows the identification of deviations of the parameters K_i and K_s in model EM1 from the normal values given in WP2-D2.3. The training algorithm is described in D6.1 and the corresponding software package (MATLAB and Java) is available on request. Simulation results of this contribution are encouraging.

Activities Concerning WP7

A set of routines to protect the hardware (2) and the biomass of the reactor (4) has been implemented and integrated to the supervision system with the control for the field-scale pilot plant at the UNAM. The details and description of the routines are given in the D1.6.

Activities Concerning WP8

The main activity was the selection and integration of a modular and low cost industrial hardware with the existing visualization and control software (NI LabView) for the reactor constructed in the UNAM by IBTech. As target hardware we have selected a Beckhoff BK 9000 with the minimum required I/O modules. Three solutions for the integration of the hardware solution with the existing control and visualization software (NI Labview) were considered. The final decision is to work with the NI Lookout OPC Modbus Ethernet Driver due to its lower cost. With this activity we have to achieve the Milestone WP8.1 A set of electronic boards to equip the plant.

Additionally we have evaluated the integrability of other components through the open communication protocol and the standard bus technology.

Future activities

Both laboratory and field-scale plants are going to be operated in order to finish the data acquisition for the long term stability. At UNAM the mixing capacity of the field scale plant is going to be determined.

Meetings, field trips and missions

Meetings with IBTECH and UNAM WP1, WP2 and WP6 participants were held when necessary, specially to give advice and guidelines for the construction and the commissioning of the field scale pilot reactor (EOLI-UNAM-02) by IBTECH.

The final project meeting is planned to be held in Mexico City, 17-19 Oct 2005.

Alexander Schaum, master degree student from the Institut für Systemdynamik und Regelungstechnik of the University of Stuttgart, stayed 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"

M. Sc. Technician Gloria MORENO made an stay at the Universite de Technologie de Compiègne (UTC) in Compiègne, France, from July to December 2004.

Master of Sciences student Leonardo JIMÉNEZ made an stay at Politecnico di Milano (POLIMI), Milano, Italy, from September to December 2004.

G. Buitrón, I. Moreno-Andrade, J. Moreno, C Verde and D Wimberger. Workshop dedicated to the memory of Prof. Alberto Rozzi. Research and Innovation in Wastewater Treatment. Milano-Bologna 25-26 November 2004.

Doctoral student D Wimberger, stayed a couple of days at the Laboratory of Milan to discuss with the bioprocess experts a possible cause effect model to describe the nitrate build up at the POLIMI SBR process.

Publications

1. Betancur MJ, Moreno JA, Moreno-Andrade I, Buitrón G. (2005 accepted). Practical optimal control of fed-batch bioreactors for the wastewater treatment. *International Journal of Robust and Nonlinear Control*, Special Issue on "Control of (Bio)Chemical Reacting Systems".
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3. Betancur M.J., Moreno-Andrade I., Moreno J.A., Dochain D., Buitrón G. (2005). Modeling for the optimal biodegradation of toxic wastewater in a discontinuous reactor. Proc. 4th IWA Activated Sludge Population Dynamics Specialist Conference. Microbial Population Dynamics in Biological Wastewater Treatment (ASPD4), 17-20/07/2005. Queensland, Australia.
4. Buitrón G., Moreno J.A., Moreno-Andrade I., Betancur M.J., Vargas A. (2005). Control óptimo de biorreactores aerobios para el tratamiento biológico de aguas residuales industriales inhibitorias. Taller Nacional preparatorio al IV foro mundial del agua. 5-7/09/2005, Jiutepec, Morelos.
5. Buitrón G., Moreno-Andrade I., Betancur M.J., Moreno J.A. (2005). Biodegradation of toxic wastewaters in an optimally controlled discontinuous reactor. 78th annual technical exhibition and Conference of the Water Environmental Federation (WEFTEC.05). 29/10-02/11/2005 Washington, DC., USA.
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7. J. Mina y C. Verde (2005). Fault Detection using Dynamic Principal Component Analysis by Average Estimation. 2nd International Conference on Electrical and Electronics Engineering and XI CIEA., México DF: Sept page 374-377.
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9. Moreno-Andrade I., Betancur M.J., Moreno J.A., Buitrón G. (2005). Inhibitory wastewaters degradation using a discontinuous bioreactor. Water and Wastewater Management Congress (Achemamerica 2005), 12-15/04/2005. México D.F.
10. Moreno-Andrade I., Pérez J., Betancur M.J., Moreno J.A., Vargas A., Buitrón G. (2005). Degradation of a mixture of municipal wastewater and phenol in an aerobic optimally controlled SBR. 3rd IWA Leading-edge conference & exhibition on water and wastewater treatment technologies, 6-8/06/2005. Sapporo, Japón.
11. Moreno-Andrade I., Pérez J., Betancur M.J., Moreno J.A., Buitrón G. (2005). Biodegradation of high 4-chlorophenol concentrations in a discontinuous reactor fed with an optimally controlled influent flow rate. Proceedings of the IWA Chemical Industry conference, June, 14-16, 2005. Tsukuba and Kashima, Japan.
12. Moreno-Andrade I., Corrales A., Martínez D., Buitrón G. (2005). Phenolic compounds degradation in a discontinuous moving bed bioreactor. Proceedings of the IWA Chemical Industry conference, July, 14-16, 2005. Tsukuba and Kashima, Japan.
13. Moreno-Andrade I., Buitrón G. (2005). The activity of the microorganisms acclimated to 4-chlorophenol vary when they are exposed to starvation. Proc. 4th IWA Activated Sludge Population Dynamics Specialist Conference. Microbial Population Dynamics in Biological Wastewater Treatment (ASPD4), 17-20/07/2005. Queensland, Australia.
14. Moreno-Andrade I., Buitrón G. (2005). Variación de la actividad de los microorganismos degradadores de compuestos fenólicos debida al ayuno. XI Congreso Nacional de Biotecnología y Bioingeniería. 17-22/09/2003, Mérida, Yucatán.
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18. Moreno JA, Betancur MJ, Buitrón G, Moreno-Andrade I. (2005 submitted). Event-Driven Time-Optimal Control for a Class of Discontinuous Bioreactors. *Biotech Bioeng*.
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20. Vargas, A. and Buitrón, G. (2005). On-line concentration measurements in wastewater using nonlinear deconvolution and partial least squares of spectrophotometric data, 2nd IWA Conference on Instrumentation, Control and Automation, Busan, South Korea, May-June, 2005.
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3.7 UU

Participating staff

Name	Background	Activities
Rafael Canetti	Electrical engineer	WP2, WP5, WP8 and WP1
Soledad Gutiérrez	Chemical engineer	WP1, WP2 and WP5
Claudia Etchebehere	Microbiologist	WP1
Javier Menes	Microbiologist	WP1
Adrián Ferrari	Chemical engineer	WP1 and WP5
Alejandra Benítez	Chemical engineer	WP1 and WP3
Dayana Travers	Microbiologist	WP1
Nicolás Pérez	Electrical engineer	WP3

Activities

The third year UU is concerned with WP1.3 (Evaluation of the optimal control strategy), WP2.1 (Model Selection) WP2.3 (Parameter Identification and model validation) WP2.4 (Model Evaluation), WP5.3 (Control law validation) WP8.1 (Hardware and Software specification for the integrated system) and WP3.

Activities concerned with WP1

During the third year of experimentation the main objectives for UU were to perform experiments to evaluate the process improvement with the application of the control strategy for Reactor M, evaluate the loading capacity of Reactor M and improve N removal for Reactor F. Batch experiences related with adsorption, heterotrophic and denitrification kinetics were carried out. Microbiological analysis was focused in trying to understand microbiology of denitrification.

During the third year of the EOLI Project, Reactor M and Reactor F operated continuously in a automatic mode, except during January and February, due to a failure in the air supply. Manual operation was implemented during this period.

In order to follow the SBR performance, biomass concentration (volatile suspended solids – VSS), ammonium nitrate and nitrite concentrations; effluent soluble COD, and effluent suspended solids were periodically analyzed.

Operation of the SBR lab-scale Reactor M

Organic load of Reactor M was progressively augmented by increasing the influent volume from 2 to 4 l/cycle, to evaluate the reactor loading capacity, during 08/11/04 to 20/12/04. As it was exposed in the last annual report, aerobic phase duration was excessive. It was reduced since 14/04/05 to 20/08/05 from 9.5 to 6 hours. Reactor M was reinoculated with a real scale dairy plant SBR sludge, on May 23, in an attempt to improve settling capacity. After reaching steady state, a Control law (CL) was implemented in August 2005. Standard and Shock load cycles were performed before and after CL implementation.

Experiments for evaluation of reactor performance under increasing organic load

Reactor M operation was characterized by a poor settling capacity of the sludge. In order to evaluate if increasing feeding could enhance sludge age and concentration by improving settling properties, an experimental plan was proposed. During these experiences, the cycle phase duration was the same as described in last annual report (Anoxic fill 30 min, Anoxic 30 min, Aerobic phase 9.5 hours). Influent concentration had a typical value of 3 gCOD/l,

and a C/N ratio of 30. Feeding volume varied from 2 to 4 l/cycle, by increasing feeding in 0.5 l every week. The resulting loading conditions are shown in table 1.-

Date	Feed Rate (L/cycle)	Resulted HRT (days)
Up to 08/11/04 (standard)	2	3.75
08/11/04 - 15/11/2004	3	2.50
15/11/2004 – 22/11/04	3.5	2.14
24/11/2004 – 20/12/2004	4	1.88
Since 20/12/2005	2	3.75

Table 1.- Organic load experimental plan for Reactor M

COD, BOD, and total and ammonia nitrogen were monitored in the influent, effluent and reactor content. In order to evaluate settling properties, Sludge volume index IVL and settling velocity v_s of the sludge were measured. Also, Volatile suspended solids in the reactor and effluent were evaluated. .

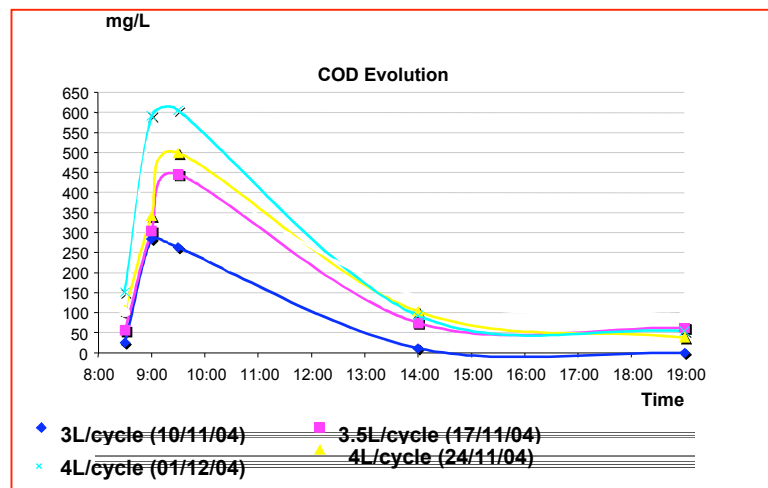


Figure 1.- Organic matter profile for Reactor M at different organic load

Organic matter profile is shown in figure 1. Effluent quality at the end of the cycle was acceptable, but both COD and TKN removal efficiency were slightly reduced.

SVI and v_s improved considerably as loading rate increased, even when the final values have to be still improved (Figure 2.-). OD concentration in the reactor and effective aeration time were appreciably reduced (time in which OD concentration was above 2 mg/l decreased from 9 hours to a mean value of 3 hours). As long aeration periods are suspected to be detrimental for settling, this could be the key point for settling improvement.

Settling velocity was reduced appreciably on 26/Nov, 3/Dec and 10/Dec. Recycle pump was ON during these days, and sludge seems to be affected by physical stress. Even when this effect is reversible, the section area of the recycle was augmented to avoid this. A compressor failure occurs in January, and reactor performance and settling was degraded again. As OD consumption was excessive for air supply capacity, we decide to reduce the aeration time and the air flow rate in 50% and keeping the organic load in 2l/cycle.

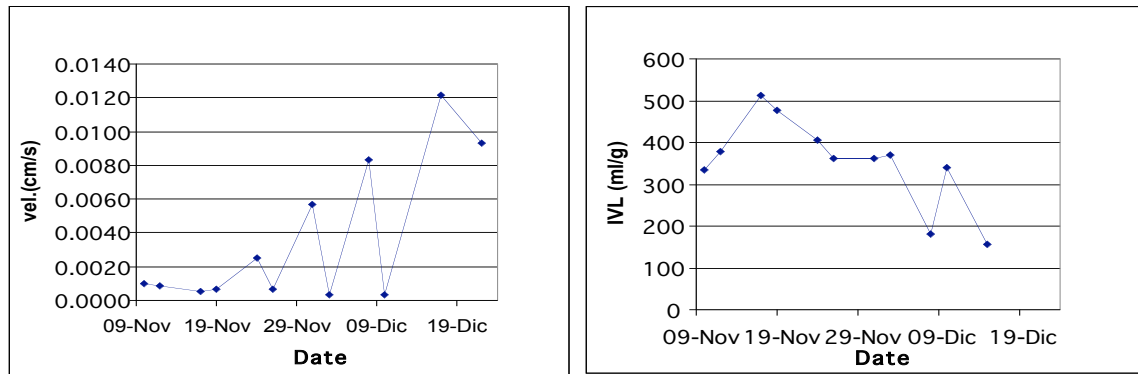


Figure 2.- Settling velocity and IVL of Reactor M during organic load increase.

Reinoculation and steady state

Based on the hypothesis that for laboratory-generated synthetic sludge the absence of competitors could be the cause of filamentous bulking, Reactor M was reinoculated (May 23). The sludge came from a SBR treating anaerobically pre-treated dairy wastewater. Settling properties of this sludge were good.

Steady state was reached after 3 weeks, since ORP, OD, and pH profiles, bacterial activity and removal efficiency were kept constant after this period. Reactor was then ready to evaluate standard condition in order to compare the performance before the implementation of the CL.

Experiments for the evaluation of the CL

The conventional strategy under evaluation has been conducted before the implementation of CL, during two months, after re-inoculation and reaching its steady state. Five standard conditions and three shock loads were evaluated by on line and off line measurements.

The described CL generated by Narbonne was evaluated during three weeks by on line measurements. During the first week, the standard condition was evaluated by off line and on line measurements. During the second and third week, a shock load condition followed by a standard one was conducted (off line and on line measurements).

For standard conditions, reactor was fed as usual with synthetic crude dairy wastewater, with 2l/cycle of 3 g COD/l influent. 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.

1. Conventional strategy. Typical strategy employed for SBR operation during six months before control law implementation is described in Table 2 :

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

2. *Control law strategy* SBR operation under the CL, was characterized by the following work scheme (Table 3):

Stage	Duration	
	Standard	Shock Load
Anoxic Fill		~ 10 min.
1 st Anoxic	~ 20 min.	~ 5 min.
1 st Aerobic	2 hours	2 hours 35 min.
2 nd Anoxic	70 min.	2 hours 40 min.
2 nd Aerobic	70 min.	1 hour 50 min.
Settle		2 hours
Draw		~ 10 min.
Idle	~ 5 hours	2.5 hours

Table 3.- CL cycle phase duration

3. *Conventional strategy results* Reactor performance and effluent quality for standard conditions presented average substrate removal efficiencies $\geq 90\%$ (COD, TKN and Total - N) and an acceptable effluent quality. Effluent sludge content remained high due to sludge bulking, frequently observed in Reactor M.

4. *Control law strategy results* SBR reactor presented average substrate removal efficiencies $\geq \sim 84\%$ (COD, TKN and Total - N) and acceptable effluent quality, 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, the cumulative air consumption is appreciably reduced. Total cycle time duration for standard operation under CL (7 hours) is lower than conventional cycle (9 hours). Shock load cycle time under CL is similar to the conventional cycle duration.

Individual cycle data analysis (under CL)

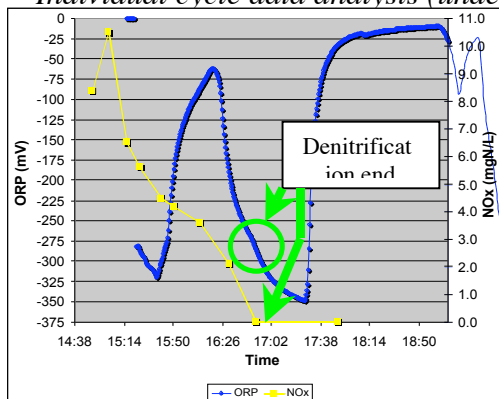


Figure 3.- ORP and NO_x profiles for standard CL cycle (4)

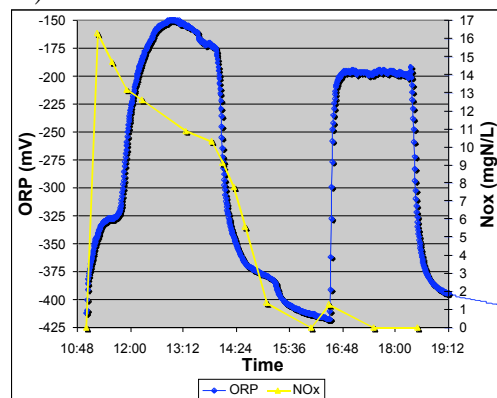


Figure 4.- ORP and NO_x profiles for shock load CL cycle.

4.1. Standard cycle. ORP and NO_x (N-NO₂ + N-NO₃) concentration profiles of one standard cycle under CL are shown in Figure 3.

4.2. Shock load cycle ORP and NO_x ($\text{N-NO}_2 + \text{N-NO}_3$) concentration profiles of one shock load cycle under CL are shown in Figure 4.

Discussion Even when final effluent quality is acceptable for both standard and shock load cycles under CL application, the second anoxic phase duration in the reactor was excessive (around 30 minutes in standard cycle and 1 hours and 20 min extra time during shock load). This observation could be explained by some of the following effects: a) High N-NH_4^+ assimilation on biomass, and low nitrification extent in the reactor, neglected for the CL, b) presence of N-NO_x removal during aerobic stage (assimilative reduction, denitrification at not sufficiently inhibitory DO levels). Regarding aerobic phase, parameters (OD, ORP..) variation is detected within the first 60 minutes. Extra aeration time seems to be not necessary.

The CL proposed by Narbonne assumed that fill should be very fast. As our set for filling time was not negligible, an undesirable anoxic phase was established before aeration. An evaluation of the CL minimizing feeding anoxic phase will be evaluated during the next six month period.

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 strategy Standard cycle before and after 2 consecutive shock load cycles are compared. COD, total nitrogen and nitrite and nitrate evolution were compared and shown in the following Figure 5. No signs of instability could be found: COD removal was even higher and nitrite consumption was faster after the shock load. After shock load condition, OD and ORP profiles a slow evolution could be detected, and profiles stabilized within 3 days.

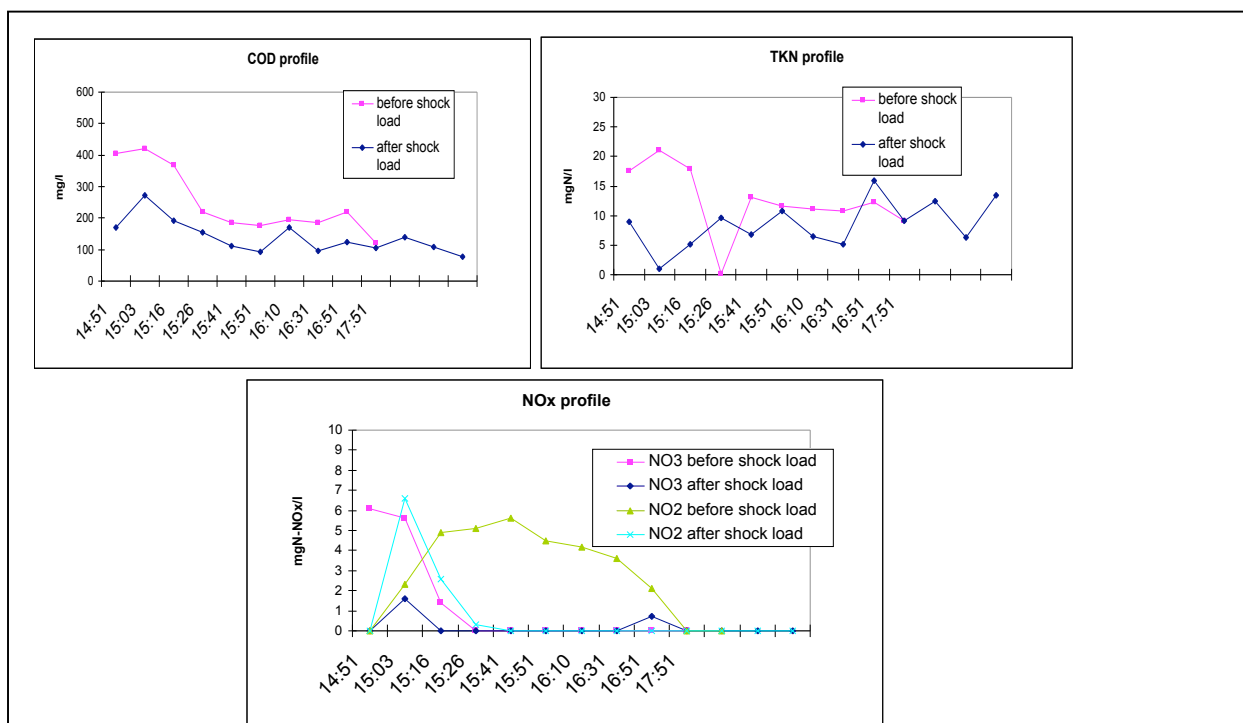


Figure 5 - COD, TKN and NOx profiles of standard cycle before and after a shock load.

Conclusion

The application of the CL reduced the total cycle time from nine to seven hours for standard condition, and total air consumption is reduced in 50%, with comparable effluent quality. However, second anoxic and aerobic phase duration seems to be excessive. Nitrogen assimilation for biomass growth is the main mechanism of N reduction for this wastewater with a particularly high C/N ratio. A CL based in a model which specially consider this process could be necessary to optimize the cycle phase for this effluent. Reactor performance after a shock load didn't show signs of instability as normal effluent quality and profiles were obtained.

The CL proposed by Narbonne assumed that fill should be very fast. As our set for filling time was not negligible, an undesirable anoxic phase was established before aeration. An evaluation of the CL minimizing feeding anoxic phase will be evaluated during the next six month period.

Deliverable 1.2 concerning these results contents more details.

Operation of the SBR lab-scale Reactor F

Cycle phase duration has been changed as follows:

I) 23/02/05-27/02/05:

Aeration phase was shorted. A second anoxic phase with substrate addition was implemented in Reactor F, to enhance nitrate removal. The cycle time is the following:

Anoxic fill: 30 minutes

1st Anoxic: 2 hours

1st. Aerobic: 3 hours 10 minutes

2nd. Anoxic: 2 hours

During 2nd. anoxic phase an instantaneous addition of substrate needed for denitrification (0,5 L of raw dairy effluent) was set at the end of aerobic phase.

II) 27/02/05-25/05/05:

2nd anoxic phase was shorted to 55 minutes

A 2nd aerobic phase of 55 minutes was added

III) 25/05/05-21/07/05:

1st Aerobic phase was extended to 4hours and 30 minutes

no 2nd aerobic nor anoxic phases were set.

IV) 22/07/05- :

1st Aerobic phase was extended to 5hours and 30 minutes,

2nd anoxic phase of 1 hour

2nd aerobic phase of 1 hour

Cycle performance before and after a 2nd anoxic phase implementation

Reactor F sludge had no adequate denitrifying efficiency in the reactor, and nitrate concentration in the effluent remained high as described in last report. The pH measured in the SBR was generally over 8,5 (between 7,9-9,5) and during aerobic phase it generally increased, even when no changes in the rest of parameters were detected. To reduce aeration cost and prevent pH inhibitory effect, the aeration stage was shorted. To eliminate all Nitrite in the effluent an anoxic phase with addition of biodegradable substrate was set at the end of aerobic phase. For these new conditions (I), COD and TKN removal were

similar as previous (standard) cycles, measured pH was lower, varying between 7,5-8,5, and “Nitrate knee” in ORP profile indicates that denitrification was complete in the first anoxic phase. This result suggests that denitrifying biomass was exposed to an inhibitory effect of pH in the previous operating conditions. For the second anoxic phase, Nitrate value at this point was under detection limits.

Experiments in adsorption and respirometry

Adsorption This series of experiments was conducted in order to include adsorption in the model. The adsorption EOLI protocol was followed and a 1 litre volume stirred, closed vessel was employed. N₂ was fluxed to ensure anaerobic conditions. A concentration of 1gVSS/l of Reactor M sludge and 2gCOD/L of diluted milk as substrate were employed. Samples were periodically extracted and centrifuged to determine soluble COD. The experience was repeated on 4 different days of reactor operation. Results are shown in table, in which the time needed to adsorb 50% of the total adsorbed COD is presented to compare how fast is the sorption.

Experience n°	% sorption	time (min), 50%
1	16	9
2	22	5
3	20	29
4	55	5

Table 4.-.- Sorption test results for Reactor M sludge.

For the 3 first experiences, the amount of adsorbed COD was quite low (less than expected). The last one was taken from the reactor after an operation fail, and the sludge had suffer an overload some days before, and could be considered abnormal. A mean sorption percentage of 19% can be then stated.

Adsorption could vary significantly depending on sludge condition, and it is a fast but not an instantaneous phenomena .

Respirometric tests An experimental protocol was adapted for the evaluation of heterotrophic growth kinetic parameters estimation and variability evaluation. Sludge from Reactor M and diluted milk were employed, and the oxygen uptake rate data and soluble substrate consumption were collected. The results showed good reproducibility, however an oxygen input during measurement has to be characterised before data processing.

Microbiological analysis

In the first and second year the Microbiology Department research was focus in detect, quantify and identify the nitrifying organisms (ammonia oxidation and nitrite oxidation) During the work performed from October 2004 to October 2005 the work was focus in trying to understand the microbiology of the Denitrification.

The following activities were performed:

- 1- **Denitrifying activity tests along reactor operation.** The Denitrifying activity was optimized and used to evaluate Reactor F along operation. The results showed that denitrifying community presented the same variation that the Heterotrophic Activity determined from the Oxygen Rate Technique.
- 2- **Monitoring the microbial composition of the sludge samples by T-RFLP.** This technique was applied to study the ammonia oxidation organisms (studying the amoA

gene), for the denitrifiers (studying the *nirS* gene) and for the Total Bacterial community (Studying the 16SrRNA gene).

- 3- **Characterization of the Denitrifying population by *nirS* library.** This was performed to characterized the denitrifying community in one sample. For that, a *nirS* library was performed and the *nirS* sequence of the clones were analyzed. The results showed a prevalence of organisms belonging from the *Thauera-Azoarcus* Cluster between the beta Proteobacteria and *Paracoccus* between the alfa Proteobacteria. The results were correlated with the T-RFLP results indicating that several of this organisms were present along the reactor operation.
- 4- **Isolation and Characterization of the Denitrifiers.** From both reactors the predominant denitrifying organisms were isolated and characterized by biochemical tests and genetic tests. The results are under study.
- 5- **Other activities.** The Microbiology of the Reactors were also followed by Nitrifying activities (AOB, NOB and Heterotrophic) for both reactors during more than two years of operation. The results showed that Reactor F presented an Activity for Nitrifying organisms that were unstable during time. The nitrite oxidation activity was maintained in low values. The heterotrophic activity was high and also presented variations. For Reactor M only heterotrophic activity was detected indicating that no nitrification occurred in the reactor. FISH analysis was also performed to detect ammonia oxidizers and nitrite oxidizers during reactor operation. The FISH results confirm the results obtained by activity Tests. In order to determine the number of cells per gSSV, a correlation between cells and gSSV was obtained for pure cultures. With this numbers it will be possible to estimate the proportions in gSSV for the different organisms.

Activities related to WP8.

The activities at Universidad de la República during the third year were related to two tasks: a) Modification of the control system in order to provide a lab-scale test facility to test a control law developed in the frame of EOLI project. b) Provide data from on-line operating records, to the EOLI database developed by SPES.

Modification of the control system

Both reactors (UU1: Reactor M, and UU2: Reactor F) operate controlled by the same control system. Its general structure is shown in fig. 1.

Reactors fluids are manipulated by valves, pumps, agitator which are driven by electrical drivers. Some sensors sense its state (levels, leaks, DO, pH, etc.).

A PLC is programmed to control the reactors by controlling those drivers. It receives signals from level and leaks sensors, and operating orders from a SCADA system to which it sends status data. The PLC performs the actual real time control of the reactors in a robust way, e.g.: not depending of power failures, SCADA failures, etc.

The SCADA system resides in a PC. It performs the operator interface through screens, sends operating instructions to the PLC, reads the data from the on-line instruments and keeps a historical recording of the reactor operation.

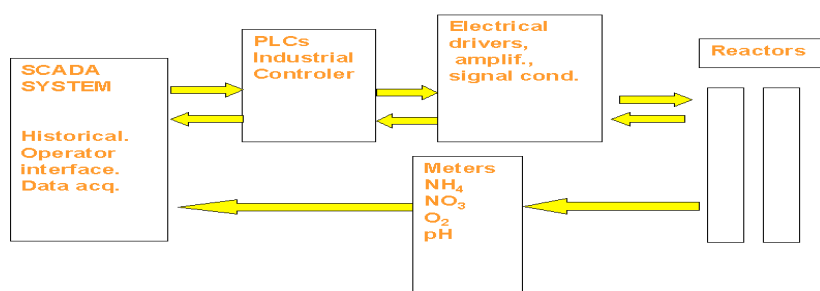


Fig. 1.- – Control system structure

The reactor operation of this system was based on a fixed schedule of SBR stages whose duration could be programmed. This schedule is shown in fig. 2.

FILL	ANOXIC	AEREATE	PURGE	SETTLE	DRAW
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Fig. 2 – SBR operation stages

As the control law to be tested is based on different sequences of anoxic and aerobic stages, the control system had to be modified. The PLC and the SCADA programs, as well as their communication routines were modified in order to perform schedules of the type shown in fig. 3. This modification includes real time control routines of the PLC, new operator – machine screen interface in order to program reactor's operation (see fig. 4), and recipe files in order to keep typical operation modes.

FILL	ANOXIC	AEREATE	ANOX	AER.	ANOX	AER	PURGE	SETTLE	DRAW
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Fig. 3 – SBR operation stages



Fig. 4 – Operation parameters screen interface.

On – line records for EOLI database.

SPES developed a common database for operating data of EOLI reactors. In order to provide data from lab reactors to this database, a format was agreed for UNAM and UU records: data in text file, tab separated, one column per

variable.

The variables sent are:

Measured variable	units	Description
Date and Time	dd/mm/yyyy hh:mm:ss	Date and time
R1 pH		pH
R1 NH4	ppm	NH4 concentration
R1 O2	mgO2/l	O2 concentration

As an example some lines of a data file are shown:

Date and Time	R1 pH	R1 NH4	R1 O2	R1 NO3	R1 Temp	R1 Pre	R1 BDRE	R1 MAGI	R1 VAER	R1 VLLE
29/08/2005 00:00:00	7.55	-414	0.01	?-???	22.5	735.333	0	0	0	0
29/08/2005 00:00:30	7.55	-414	0.003	?-???	22.5	732.667	0	0	0	0

To generate the data files, on – line operating records are exported from the SCADA historical database to csv files which are later converted to agreed format.

Activities related to WP3.

A Ultra sound technique was employed to measure settling velocity and sludge concentration. Results are detailed in Annex.

Meetings, field trips and missions

Project meetings

Montevideo- Uruguay 9-11/05/2005

Adrián Ferrari, Alejandra Benítez, Claudia Etchebehere, Javier Menes, Soledad Gutiérrez and Rafael Canetti participated at:

Mexico city- Mexico 17-19/10/2005. Soledad Gutiérrez and Rafael Canetti

Missions for conferences:

2nd Mercosur Congress on Chemical Engineering, 4th Mercosur Congress on Process Systems Engineering, 14-18 August, Río de Janeiro, Brasil

VIII Latinamerican Workshop and Symposium on Anaerobic Digestion, IWA conference, 3-5 October, Punta del Este, Uruguay.

Publications

Gutiérrez S., Ferrari A., Benítez A., Hermida, S., Canetti, R. M. (2005) *Carbon and nitrogen removal from dairy wastewater in a laboratory sequential batch reactor system*, 2nd Mercosur Congress on Chemical Engineering, 4th Mercosur Congress on Process Systems Engineering, 14-18 August, Río de Janeiro, Brasil

Benítez, A., Ferrari, A., Lema, P., Irigoyen, Gutiérrez., S. Travers, D. Etchebehere, C.(2005)

Effect of the flocculant periodical addition on the performance of a sequential batch reactor treating dairy wastewater, 2nd Mercosur Congress on Chemical Engineering, 4th Mercosur Congress on Process Systems Engineering, 14-18 August, Río de Janeiro, Brasil

Benítez A., Ferrari A., Gutierrez S., Canetti R., Cabezas A., Travers D., Menes J., Etchebehere C. (2005) *Sequencing batch reactor as a post-treatment of anaerobically treated dairy effluent*, VIII Latinamerican Workshop and Symposium on Anaerobic Digestion, IWA conference, 3-5 October, Punta del Este, Uruguay.

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- Travers, D., Tiedje, J., Etchebehere, C. (2005) Estudio de la diversidad de bacterias desnitrificantes en sistemas de tratamiento de efluentes industriales utilizando el gen de la nitrito reductasa. Workshop Internacional de Microbiología Ambiental, Campinas, Brasil, September 19 to 20, 2005.
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- Cabezas, C. (2005) "Microbiología de los procesos biológicos de Nitrificación-Desnitrificación en la descontaminación de desechos". MSc Thesis, Facultad de Química, Universidad de la República, Uruguay, September 29, 2005.

Planning of activities for the following year

Activities concerned with WP1

Future work (if the Project will continue)

UU. The evaluation of the long term stability of the system will be continued for Reactor M. A control law based in a model which takes into account the N consumption for biomass growing will be tested for Reactor M. A control law will be implemented for Reactor F. Batch tests related to adsorption coupled with COD consumption for sludge M/F and dairy wastewater will be carried out More studies in the microbiology of denitrifiers will be performed along time to try to quantify them and to follow the stability of denitrifiers in the reactors, specially in reactor F, some changes will be performed in the operation to increase the denitrification step. The genetic characterization of the isolates will be performed and a correlation with the T-RFLP results will be study.

- ANNEX WP1, WP3 and WP8 UU 3rd year activities

3.8 IBTech

Participating staff

Name	Category	Activities in EOLI
Mr JorgeLopez	Senior Engineer	WP8
Mr Adalberto Noyola	Senior Engineer	WP8
Mr Juan Morgan	Senior Engineer	WP8
Ms Ana Perez	Process Engineer	WP8
Mr Rafael Ortega	Civil Engineer	WP8
Mr Jorge Salazar	Electrical Engineer	WP8
Mr Guillermo Guerrero	Instrumentation/piping Engineer	WP8
Mr Enrique Osnaya	technical	WP8

Objectives

To construct the pilot-scale SBR plant that will operate under field conditions for experimentation and data collection according to the following:

General objectives

- Validation of the experimental work performed by Universidad Nacional Autónoma de México (UNAM, partner 6) and, if proved economically feasible, by other members of the EOLI project, such as Politecnico di Milano (POLIMI, partner 2), Laboratoire de Biotechnologie de l'Environnement (INRA, partner 4) and Universidad de la República Oriental del Uruguay (partner 7).
- Implementation of the Fault Diagnosis and Isolation (FDI) supervision system, according to the work performed by Universidad Nacional Autónoma de México (UNAM, partner 6).
- If proven economically feasible, implementation of the hardware and software sensors that may be developed or used by Politecnico di Milano (partner 2), and Gradient (partner 5).
- Integration of the supervision and data acquisition system that is being developed by SPES (partner 4).

Specific objectives

The specific objective of IBTech's collaboration in the EOLI project for this period was the following:

- To finish the construction of the pilot plant according to the design basis of the field scale SBR reactor and auxiliary facilities, to the basic engineering project (process engineering) and to the detailed engineering project developed on the first year of the project.
- Operation of the wastewater treatment plant

Activities

The activities of IBTech during this third year were conducted under close collaboration with the UNAM team, since the main objective was to construct the pilot plant according the engineering design basis based on UNAM specifications.

Regarding WP1, from November 2004 to October 2005 various meetings were held between IBTech and the UNAM team in order to discuss technical aspects referring to the construction of the pilot plant, particularly those aspects which were relevant to the controlling system.

IBTech provided technical assistance to UNAM team in the procurement of equipment. In fact IBTech was in charge of all equipment procurement activities, including equipment inspection at manufacturer's site before delivery.

Apart from that, various meetings were carried out at UNAM's offices in Mexico with the UNAM team (WP1, WP6) in order to:

- a) Coordinate equipment delivery at the construction site.
- b) Check pilot plant construction progress.
- c) To define the adequate equipment supplier.
- d) To coordinate supplier access to restrained UNAM facilities
- e) To transport the pilot plant to the final location where it will be used for the experiments
- f) To start up the pilot plant
- g) Operation of the pilot plant

The pilot plant is finished and ready to be used for the experiments that were conducted by UNAM team.

The plant was already checked concerning hydraulic, electrical, mechanical and control systems.

Difficulties

The main difficulties encountered during this period were the following:

- a) Supplier's response for time requirements was very slow.
- b) Some equipment had to be replaced due to factory flaws

Results

The results of this period corresponds mainly to finish the construction of the field-scale SBR reactor and to start up the pilot plant and to help in its operation.

FIELD SCALE REACTOR BASIS SUMMARY.

Design basis summary

SBR reactor design

- | | |
|--------------------------------------|--------------------------------------|
| ➤ Reactor volume: | 1.0 m ³ |
| ➤ Volumetric exchange rate (maximum) | 60% |
| ➤ Maximum volume exchanged: | 0.6 m ³ |
| ➤ Maximum volumetric loading rate: | 12 kg/m ³ in 50 hours. |
| ➤ Fill time: | 15 to 20 minutes |
| ➤ Settling time: | To be determined at field conditions |
| ➤ Decanting time: | 15 to 20 minutes |
| ➤ Idle time: | To be determined at field conditions |

Flexibility

- The Pilot Plant will not operate if power supply fails.
- The Pilot Plant will not operate if air supply fails.
- The process air will be supplied by two-air blowers and a diffuser system, consisting of 3-disc diffuser with flexible EPDM membrane.
- The climatology and geography data correspond to Mexico City, due to the fact that the FSPP will be tested first in the UNAM's wastewater treatment plant. So, these conditions should be changed as needed according to some others future site conditions.

On Line Measurements

The online measurements that has been specified for the field scale reactor are:

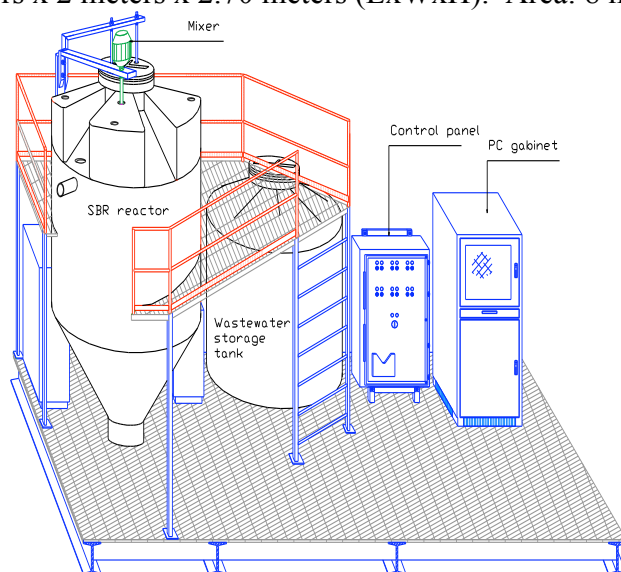
- Dissolved Oxygen Concentration.
- Temperature.
- pH
- Wastewater Feed flow.
- Air flow for the oxic phase.
- ORP (if needed in future tests).
- Water level in SBR reactor.
- Time variable would also determine operation of the reactor according to the mode of operation selected by the operator and specified by the control system.

Control platform and SCADA

- National Instruments LabView 7.0.
- Human Machine Interface developed by UNAM Team.
- SCADA as integral part of LabView. Interface developed by UNAM Team.

Description of the field- scale pilot plant already constructed

The field-scale pilot plant is based on an aerobic process known as activated sludge in the Sequencing Batch Reactor modality, controlled by the system developed by Engineering Institute of UNAM. All tankage and equipment were mounted on a carbon steel skid and the design will be intended to allow easy transportation of the skid. The skid dimensions are 4.0 meters x 2 meters x 2.70 meters (LxWxH). Area: 8 m².





The influent will be fed from a 1.0 m^3 wastewater storage tank (ST-01) to the SBR reactor, which will be an 1.0 m^3 HDPE tank with conical bottom.

In this process the air is supplied to the reactor by a centrifugal blower and fine diffuser system located at reactor bottom.

This air system is also responsible of reactor mixing, and varying the airflow provides the operational flexibility needed depending on the operation mode desired.

The inlet flow rate of the reactor may be controlled by a peristaltic pump (FP-02) with adjustable drive velocity that will be used in the strategy, or by means of a larger flow capacity centrifugal pump for common operating strategy. This reactor is also equipped with a mechanical mixer with adjustable speed in case anoxic-anaerobic steps are needed for future experiments.

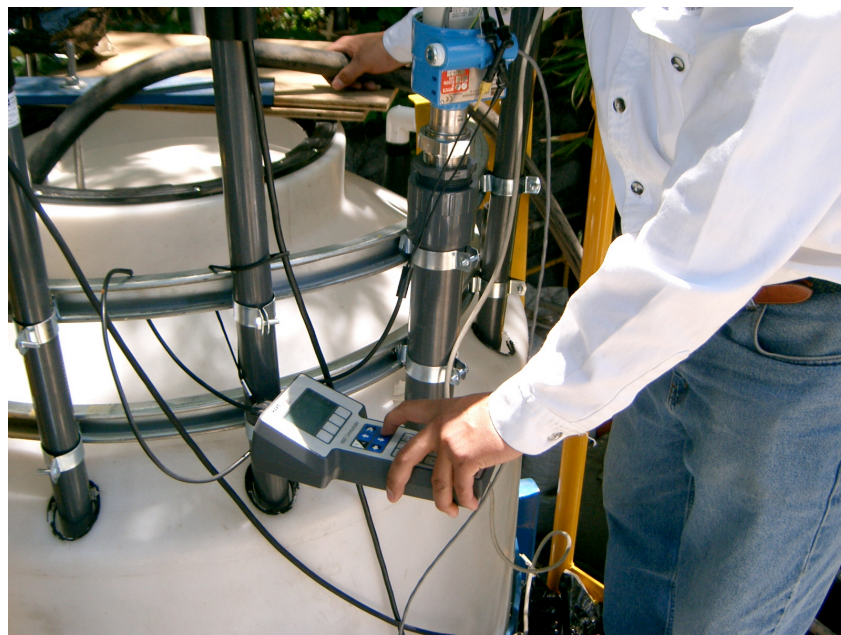
The process will be a batch process with the following conditions:

- Star-up and inoculation (acclimation experiments)
- Regular operation

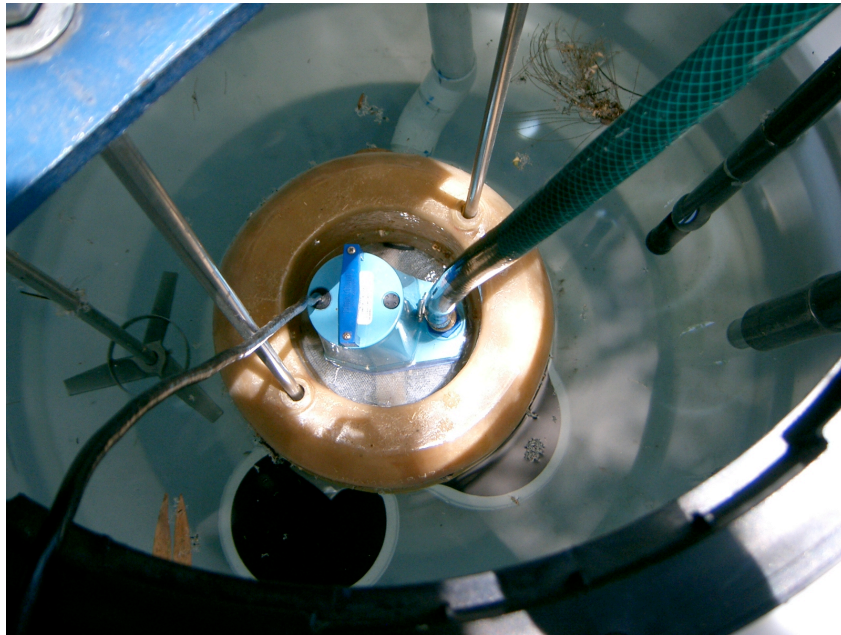
The operation of the pilot plant may be continuous, but the operation process is typically carried out in batch condition.



Transportation of the pilot plant to the new location where it will be used for the experiments. For that was necessary the use of a crane.



Instruments calibration.



Inside of the reactor. It is possible to see the floating pump, the diffusers, the mixer and level sensors.



Control system.

Contract number : ICA4-CT-2002-10012**Year : 2005****Data sheet for annual report****1. Dissemination activities**Totals (cumulative)

Number of communications in conferences (published)	27
Number of communications in other media (internet, video, ...)	0
Number of publications in refereed journals (published)	0
Number of articles/books (published)	0
Number of other publications	8

2. Training

Number of PhDs	6
Number of MScs	17
Number of visiting scientists	1
Number of exchanges of scientists (stays longer than 3 months)	4

3. Achieved results

Number of patent applications	1
Number of patents granted	0
Number of companies created	0
Number of new prototypes/products developed	1
Number of new tests/methods developed	0
Number of new norms/standards developed	0
Number of new softwares/codes developed	4
Number of production processes	0

4. Industrial aspects

Industrial contacts	yes	☒	no	☐
Financial contribution by industry	yes	☐	no	☒
Industrial partners : - Large	yes	☐	no	☒
- SME ¹	yes	☒	no	☐

5. Comments

New prototype of the off-line hardware sensor and related software were developed by POLIMI together with SPES. An on-line hardware sensor and the related software were developed by the SECOMAM company on request of GRADIENT.

¹ Less than 500 employees.