EOLI

Efficient Operation of Urban Wastewater Treatment Plants

Contract Number ICA4-CT-2002-10012

Work Package 5: Control Design and Application

Second Year Report

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Task leader:

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Participant partners:

Laboratoire de Biotechnologie de l'Environnement, INRA (4)

Universidad Nacional Autónoma de México (6)

Universidad de la República Oriental del Uruguay (7)

Ibtech SA de CV (8)

Objectives

Design and test of (sub-)optimal control strategies for Fedbatch bioreactors.

They have to be robust, reliable, easy to implement, adaptive and low-cost.

3 kinds of wastewaters:

WW1) One typical for an area including chemical industry, containing toxic or recalcitrant compounds. EOLI Model 1 (EM1)

(UNAM + IBTech)

WW2) One coming from a dairy industry, contaminated with organic carbon components as well as nitrogen. EOLI Model 2 (EM2).

(INRA + UU + SPES)

WW3) The third one a domestic wastewater which occasionally contains toxic or organic overloads. EOLI Model 2 (EM2). (POLIMI)

No optimal control law will be developed in WP5.

Specific Objectives

O1) To specify the optimisation objectives for SBRs and the relevant control variables to reach the optimisation for both cases : toxic (WW1) and agro-industrial effluents (WW2).

O2) To design and evaluate the optimal control strategies based on mathematical models of the process, and taking into account the uncertainties associated with the system.

O3) To design and evaluate suboptimal control strategies based on the optimal control laws and the hardware and software sensors available.

O4) To validate and integrate software sensors and optimal control laws in lab and field-scale process implementations.

O5) To evaluate the long-term behaviour of the plant and the improvement obtained in the process by the control strategy.

Partners

N°	Name of organisation (man month)	Short name	Man-Months	Role in project
2	Laboratoire de Biotechnologie de l'Environnement	LBE-INRA	4	Design of optimal control for WW2 Process experiments for testing optimal control for WW2
5	Società di Progettazione Elettronica e Software	SPES	2	Sensor and control system integration
6	Universidad Nacional Autónoma de México	UNAM	27	Coordination of the WP5, Design of optimal control for WW1 Process experiments for testing optimal control for WW1
7	Universidad de la República Oriental del Urugay	UU	6	Design of optimal control for WW2 Process experiments for testing optimal control for WW2
8	IBTech S.A. de C.V.	IBTech	6	Design of the pilot plant and evaluation of control for WW1

Activities

WP5.1 ***Specification of control variables and optimisation objectives***

- **WP5.1.1** Extract the collective experience of the partners to determine important and realistic optimisation objectives for SBRs, and the most reliable control variables required to reach those objectives.
- **WP5.1.2** Determine the required measurements or software sensors necessary to obtain the control objectives.
- **WP5.1.3** Create from this analysis a list of specifications for the control system.

Progress towards achieving objectives

Optimal control for WW1: Based on the EM 1 the following optimal control problem will be solved:

- **Objective:** Minimization of the reaction time
- **Control variable:** input flow
- **Measured variables:** Dissolved oxygen concentration (DO), Volume.
- **Software sensors required (WP4):** none
- **Hardware sensors required (WP3):** none
- **Expected benefits:** operation robustness; avoid the deacclimation of the biomass; higher efficiency; smaller physical dimensions of the reactor; reduction of off of operation times; reduced costs of operation and installation;

A strategy, the *Event Driven Time Optimal Control* (ED)-TOC (see the report of WP1 for the first year for a description), has been proposed by UNAM and will be tested in a lab scale and a field scale bioreactor.

- *Responsibles:* UNAM, IBTech.

Progress towards achieving objectives

Optimal control for WW2: Based on the EM 2 the following optimal control problem will be solved:

- **Objective:** Minimization of the reaction time (proposed by INRA) and minimization of enery consumption (proposed by UU).
- **Control variables:** Switching time between aerobic and anoxic phases (proposed by INRA) for a batch reactor (constant volume).

A possible control variable is the input flow. It has to be analyzed.

- **Measured variables:** Dissolved oxygen concentration (DO); pH;
- **Software sensors required (WP4):** Estimating substrate concentration
- **Hardware sensors required (WP3):** ?
- **Expected benefits:** operation robustness; higher efficiency; smaller physical dimensions of the reactor; High volume treated by day by maximizing the number of cycles

A strategy has been partly proposed and justified.

- *Responsibles:* INRA, UU, SPES.

Activities

WP5 Task & Objectives	Progress towards achieving objectives (Outputs)
Task 5.1 Specification of control variables and optimisation objectives. **WP5.1.1** Extract the collective experience of the partners to determine important and realistic optimisation objectives for SBRs, and the most reliable control variables required to reach those objectives. **WP5.1.2** Determine the required measurements or software sensors necessary to obtain the control objectives. **WP5.1.3** Create from this analysis a list of specifications for the control system.	**UNAM (10L and 1000L):** Optimization objective is defined as treating the whole batch in the minimum possible time, for an SBR degrading waste water with organic toxic substrates. Measured variables are the Dissolved Oxygen Concentration and the Volume, the controlled variable is the biomass growth rate and the manipulated variable is the input inflow. **LBE-INRA (200L):** Optimization objective is the minimization of the total cycle time of a sequencing batch reactor (SBR) with carbon and nitrogen removal (agroindustrial effluents). This control method has to be easy to implement, reliable and robust. Measured variables are the Dissolved Oxygen Concentration and the pH. The manipulated variable is the switching time between cycle phases.

WP5 Task & Objectives	Progress towards achieving objectives (Outputs)
Task 5.2 Design of optimal and adaptive suboptimal control laws. **WP5.2.1** Based on process model and on control variables available, and by using the optimal control theory determine the optimal control law for the SBR. This has to be made robust against process uncertainties. **WP5.2.2** Since not all variables are measurable, an adaptive suboptimal control law based on the optimal control and the software sensors has to be determined	**UNAM:** A control law called Event Driven Time Optimal Control strategy (ED-TOC) was proposed and implemented. The ED-TOC strategy finds a variable, called gamma, related to the reaction rate. Such variable can be estimated in real time by using the dissolved oxygen in the reactor and its volume. The influent flow rate is controlled in such a manner that the biomass growth rate stays near to the maximal value. It is controlled maintaining the toxic concentration oscillating in a gap during the SBR filling. Every time it tries to leave this gap, an event is issued and the EDTOC then switches the influent flow on/off, to prevent it. This procedure will work regardless of the influent toxic concentration value and despite changes in most of the SBR parameters. Only the mass transfer coefficient and the dissolved oxygen concentration at saturation are needed to estimate gamma and they do not even need to be known precisely.

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Task 5.2 Design of optimal and adaptive suboptimal control laws. **WP5.2.1** Based on process model and on control variables available, and by using the optimal control theory determine the optimal control law for the SBR. This has to be made robust against process uncertainties. **WP5.2.2** Since not all variables are measurable, an adaptive suboptimal control law based on the optimal control and the software sensors has to be determined	**LBE-INRA:** The time minimization was processed in two steps: • A first control strategy to reduce the phases duration by eliminating the time-out of biological reactions were finished. • A second control strategy to minimize the biological reaction time. This last strategy requires the estimation of two substrate concentrations by means of software sensors. Both of the two strategies can work together for minimal time optimisation.

WP5 Task & Objectives	Progress towards achieving objectives (Outputs)
Task 5.3 Control law validation **WP5.3.1** Validation of the control law with extensive simulations and confrontations with off-line data. **WP5.3.2** Evaluation and validation of the performance of the adaptive suboptimal control law via tests performed in lab-scale and field-scale conditions.	**UNAM:** 3 different approaches to validation are taken. First simulation using both MATLAB and LABVIEW. Results are satisfactory. Second experimental tests. Results are also satisfactory. And third, theoretical proof of almost-optimality, convergence and robustness. **LBE-INRA:** The first strategy was applied and validated on the LBE SBR.

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WP5 Task & Objectives	Progress towards achieving objectives (Outputs)
Task 5.4 Process improvement evaluation **WP5.4.1** Long-term running of a lab SBR to test the correctness of the adaptive optimal control strategy and to compare the improvement in process performance compared to state-of-the-art control strategies. **WP5.4.2** Integration with the supervision system.	**UNAM:** Single experimental batch tests have been made to evaluate process improvement. Improvements of EDTOC over FTC has been experimentally tested. Long term tests are yet to be performed. **LBE-INRA:** The first strategy produced an improvement in the number of cycles per day that can be realized, compared to the standard operating mode.

List of deliverables

Deliverable No.	Deliverable title	Delivery date
D1.1	Report on the validation of the software sensors and the optimal control law in the pilot plant	T0+27
D1.2	Report on evaluation of the process improvement with the application of the optimal control law: shock loads and the long-term stability of system	T0+34
D5.1	Control laws based on software sensors for optimising the performance of SBRs.	T0+27
D5.2	Report on full-scale performance of the optimal control law and the software sensors in terms of process and economic variables.	T0+30

Future Work

UNAM:

- Software modifications to the control software for the field-scale SBR are going to be prepared in order to allow integration with the supervision system.
- After starting-up the field-scale SBR, evaluation and validation of the performance of the adaptative suboptimal control law will be made, in accordance with WP1.
- Long-term running of the lab SBR to test the correctness of EDTOC strategy is going to be performed in accordance with WP1

LBE-INRA:

- The optimal control strategy will be tested and evaluated.