EXPERIMENTS FOR MODELLING THE BIODEGRADATION OF WASTEWATER IN SEQUENCING BATCH REACTORS

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Abstract
Three cases of wastewaters were considered: a typical municipal wastewater, the effluent of a dairy industry, both polluted with organic carbon and nitrogen, and a wastewater typical of a chemical industry, containing toxic or recalcitrant compounds (4-chlorophenol). Sequencing batch reactors (SBRs) were considered. Process experiments were performed to provide experimental data for parameter identification of the dynamical models of the SBRs. The processes were instrumented with sensors to measure O_2, NH_3, T, pH, OUR, and other off line measurements (e.g.: NO_2^- and NO_3^-, COD, phenol concentration, microbiological counts and activities) in order to study more accurately the behaviour of the biomasses. However, the general idea is to design a system with the minimal number of sensors.

1. Introduction

The aerobic treatment of wastewaters by activated sludge is a common process, but the characteristics of many industrial discharges often cause operational problems in continuous flow systems. Therefore, the discontinuous processes, as sequencing batch reactors (SBRs), can be considered because, in terms of investment and operation costs, process stability, and operation reliability, they could be better than the conventional continuous activated sludge process. The benefits of the SBRs have been shown for nutrient removal, the control of filamentous bacteria and the removal of specific organic compounds present in industrial wastewaters [1]. Despite these advantages, a SBR operated in the usual form presents several constraints when applied to toxic wastewater degradation: inhibition of the microorganisms, problems with shock loads of toxic compounds, deacclimation problems of microorganism starvation, and low efficiencies regarding the removal of toxic compounds.

In this project three cases of wastewaters were considered: a typical municipal wastewater (POLIMI), the effluent of a dairy industry (INRA and UU), both polluted with organic carbon and nitrogen, and a wastewater typical of a chemical industry, containing toxic or recalcitrant compounds (UNAM). For this case, a synthetic wastewater contaminated with a 4-chlorophenol was used.

The objective of the experiments in this part of the EOLI project was to provide data for the modelling and validation of the pollution removal present in the studied wastewaters.

2. Methodology

Carbon and nitrogen removal. The experimental plan for the modelling of the process was proposed by EOLI project members. The objective was to obtain data with respect to different Carbon/Nitrogen ratios, Oxygen/Carbon ratios and Carbon/Biomass ratios. It was recommended that at least three standard cycles were run between two variations. The sampling period of the reaction phase was fixed to obtain 10 measurements per reaction phase: 5 measurements in the anoxic phase and 5 others in the aerobic phase. The standard methods used to measure Chemical Oxygen Demand (COD), Total Kjedahl Nitrogen (TKN), Nitrate-Nitrogen (N-NO_3), Nitrite-Nitrogen (N-NO_2), Ammonia Nitrogen (N-$NH4^+$), Total and Volatile Suspended Solids (TSS) and (VSS) are described in [2].

The experiments carried out at INRA, had two specific objectives. The first one was to provide data for the modelling and for the validation of a nitrogen and carbon removal model in a SBR treating dairy wastewaters. The second one was to provide data for settling characterisation. A series of experiment were carried out in order to characterize the settleability of the sludge and define some parameters as "indicators" of functioning of the system. The sludge used in the INRA-SBR came from an urban wastewater treatment plant performing both nitrogen and carbon removal. The tank of the reactor was filled with about 100 litters of this sludge. For two months, the sludge was simply aerated and filled with a low organic loading rate (<0.7 kg COD/m^3/day). After three months of start up, a good treatment efficiency of 98% was obtained while a high sludge settleability with no suspended solids after decant was observed.

The wastewater used as influent was a semi-synthetic dairy wastewater. This feed is prepared by dilution of concentrated whey collected in a cheese dairy. The characteristics of the whey correspond to 70 g/L of COD and 2 g/L of TKN. In order to change the C/N ratio of the whey, organic nitrogen as Urea (CH_4N_2O) is added. In standard conditions, the influent volume treated after dilution is 50 L/day. Its average quality is : 5 g/L COD, 250 mg/L TKN, 10 g/L TSS and pH = 6.2.

The reactor volume varies between 150L and 200L. The SBR is equipped with a variable flow rate pump to fill the reactor and a controlled valve to withdraw the effluent and the sludge in excess. Air is used for aeration and mixing in aerobic phase. Its flow is controlled by a flow meter. During the anoxic phase, and in order to avoid a mechanical stirring system, a short aeration periods (30 seconds) every 10 minutes is used to maintain the sludge in suspension during anoxic periods. In table 1 the standard conditions of the INRA SBR are resumed.

Table 1. Standard condition for INRA-SBR

	CODt (g/L)	CODs (g/L)	NTK (g/L)	NO3 (g/L)	TSS (g/L)	VSS (g/L)
Influent	4.8 – 5	4 - 4.2	0.250	0	0	0
Effluent : Initial concentrations	0.740	0.600	0.035	0.060	12-17	10-14

Data concerning sludge settleability were collected and analyzed in order to characterize the settling phenomenon and trying to connect it to the operating conditions. In order to study the settleability, two main parameters were used. The Sludge Volume Index (SVI), which is the ratio between the decanted sludge volume after a given time and the TSS. The second parameter is the Settling Velocity (Sv) [3, 4]. These parameters are mostly related to the TSS concentration and the volumetric loading rate, the INRA SBR being equipped with a Sludge Blanket level analyser to monitor these two parameters.

Two cylindrical lab-scale reactors were used at UU: Reactor M and F (20 L) have worked continuously for over a year, with two cycles per day and five stages per cycle (Figure 1 and 2). Reactor M was fed with 2 L per cycle and Reactor F with 4 L per cycle into 15 L of working volume. In each cycle, sludge residence time was maintained at 20 day. Biomass concentration for Reactor M ranged between 2.0 and 4.0 g/L, and for Reactor F between 0.8-2,5 g/L of VSS. An air flow rate of 9 L/min was employed for both reactors.

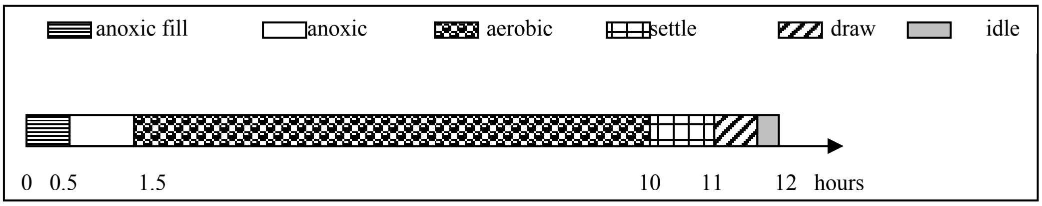

Figure 1. *Reactor M* cycle time

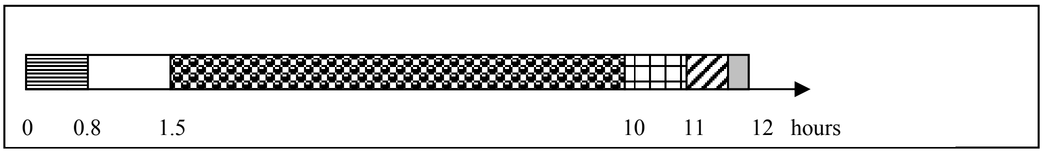

Figure 2. *Reactor F* cycle time

Reactor M was fed with a semi-synthetic dairy wastewater, by diluting ultra pasteurized whole milk, and by adding sodium nitrate solution, to simulate the wastewater generated in Rivera dairy plant. For Reactor F the effluent from a dairy industrial plant pre-treated in anaerobic pond was used in the feed. As biodegradable substrate was too low to ensure total denitrification, the SBR was fed with a mixture of 75% effluent from the anaerobic pond and 25 % synthetic raw industrial waste water (Reactor M influent). The standard characteristics of Reactor M and F influent are shown in Table 2.

Table 2. Average characteristic of SBR feed. TSS, COD, TKN, N-NH4$^+$, N-NO_3.

	Reactor M	Reactor F
COD(mg/L)	3000	1000
TKN (mg/L)	60	110
N-NH4	9	83
pH	6.2	7.5
SST (mg/L)	370	270
NO_3-N (mg/L)	80	18

An automated system was implemented to supervise and control the operation of the reactor. The system consists of a programmable logic controller (PLC) connected to a computer with a SCADA (Supervisory Control and Data Acquisition) software to provide a totally automatic operation of the reactor. It was implemented as an Intellution FIX$^®$ application. Real-time data acquisition, display and historic trending from on-line sensors (pH, DO, T and ORP) were implemented in the system. Full automatic mode operation of both reactors consists on automatic load and drainage commanded with a control–level system with electrodes, a mixer automatically activated, an aeration system composed by an automatically activated compressor and an air flowmeter, and a controlled purge pumping at a fixed flow rate.

The following parameters were measured for each cycle according to [2]: VSS and TSS, COD, TKN, N-NH4$^+$, N-NO_3 and N-NO_2. During a cycle, twelve samples of mixed liquor were extracted from the reactors. Influent, effluent and sludge were also examined. Nitrate and nitrite concentration was analyzed by High pressure liquid chromatograpy (HPLC), according to [5]. In order to study the microbiology of the reactor, a potential heterotrophic activity test was conducted. The rate of oxygen consumption for the heterotrophic organisms was measured by respirometric activity tests. The oxygen uptake rate (OUR) was determined according to [6]. Substrate concentration used in the tests was 200 ppm COD as acetate. The potential activities were expressed as mgO2/g VSS.d.

At UU, different influent carbon to nitrogen, carbon to biomass, carbon to oxygen ratios (C/N, C/X and C/DO) and toxic compounds addition had to be tested. Lactose was added in order to enhance C and urea to enhance N. Air flow rate was doubled or divided by two to evaluate different O_2/Carbon ratio. In order to test Toxicants Allylthiourea (ATU) and 4-chlorophenol (4CP) were used. In a previous batch test, the minimum concentration of toxicant needed to completely inhibit the bacterial activity (S_{cATU}, S_{c4CP}) was evaluated. Then, a concentration of 20% of S_{cATU}, 40% of S_{cATU} was used in a cyclic test for ATU, and 20% of S_{c4CP} was employed in order to test 4-CP. Table 3 shows the experimental cycles performed. Some replicates were also conducted. Three replicates were made for the standard conditions, 2 for C/X+50%, and one for C/N-35% in Reactor M. Four replicates of standard cycle, 1 replicate for C/X +75% and 1 for C/N+50% were performed in reactor F.

Table 3. Experimental cycles for Reactor M and Reactor F.

Different Carbon/Nitrogen ratios	[= 6 experiments] -50%,-35%, -20%, +20%, +30%, +50%
Acute toxicant	[= 3 experiments] INH 20%ATU INH 40% ATU , INH 20 % 4CP
Different O_2/Carbon ratios	[= 2 experiments] -50%, +50%
Different C/X ratios (including overload condition)	[= 4 experiments] -50%, +25%, +50%, +75%
Standard condition	[= 1 experiment]
Total	16 experiments + replicates

The experimentation of POLIMI was focused on the treatment of a typical non-toxic urban wastewater which could however occasionally contain nitrification inhibitors (e.g.: ATU or 4CP). The SBR reactor was designed to remove both organic carbon and nitrogen from the wastewater. To do this, the reaction phase of the SBR cycle was splitted into an anoxic followed by an aerobic phase, both required to achieve nitrogen removal. As many as 21 experiments were conducted to be used as a basis for model selection, calibration and validation. Moreover, such experiments gave relevant information for process management, as it was possible to follow the time course of the main chemical species during the SBR reaction phase.

POLIMI-SBR feed composition in g/L was the following: peptone (0.343), meat extract (0.236), NaCl (0.015), $CaCl_2 \cdot 2H_2O$ (0.012), $MgSO_4 \cdot 7H_2O$ (0.005), K_2HPO_4 (0.06), COD (0.6), N_{TOT} (0.075). Relevant SBR design parameters are reported in Table 4. Nitrates, nitrites, ammonium, total Nitrogen, and COD were measured by the spectrophotometric cuvette-test (Hach-Lange). TOC was determined by an IR analyzer. The overall experimental planning is hereafter resumed: standard operating conditions, at steady state [1 experiment]; overload and underload [4 experiments]; modified influent COD/N ratio [6 experiments]; increased/decreased aeration capacity [2 experiments]; presence of acute toxicants in the SBR influent [3 experiments]; 1 replicate of each of 4 different experimental conditions were also added.

Table 4. Main POLIMI-SBR design parameters

Parameter	**Value**
Filling/Reaction Ratio [%]	20
Influent COD concentration C_{in} [mgCOD/L]	600
Type of feeding	Synthetic urban sewage
Initial biomass concentration in the SBR [mgSS L^{-1}]	> 2,000
Volumetric loading rate [gCOD $L^{-1}d^{-1}$]	0.48
Biomass loading rate [gCOD $gVSS^{-1}d^{-1}$]	0.20
Influent Total TKN [mg/L]	75
Influent $N\text{-}NH_4^+$ [mg/L]	Approx. 0
Influent COD/N	8
O_2 [L min^{-1}.]	Not defined
pH	7-8 (monitored but not controlled)
T [°C]	25
SBR volume at the beginning of the cycle V(t=0) [L]	16
SBR volume at the end of the cycle V($t=t_{fin}$) [L]	20
Total cycle time [h]	6
SRT [d]	20

Toxic wastewater degradation. UNAM experiments were conducted using an optimal control strategy [7] called Event-driven time optimal control strategy (ED-TOC). A pilot reactor of 10L (7L of working volume) was used for the degradation of synthetic wastewater contained 350mg/L of 4-chlorophenol (4CP) as carbon source. The control system was implemented using a personal computer and a data acquisition card (National instruments 6025E data acquisition card and the Labview package). The temperature was controlled to 20°C inside the reactor. The input and output water flows were controlled by the computed system using two peristaltic pumps. Substrate concentration was measured using the colorimetric technique of 4-aminoantipyrine [2]. TSS, VSS and COD were determined according to the Standard Methods [2]. Dissolved organic carbon (DOC) was determined with a Shimadzu TOC-5050 analyzer. These analyses were performed to evaluate 4CP mineralization.

The ED-TOC strategy finds a variable (γ) related to the reaction rate. Such a variable can be estimated in real time by using the DO concentration and the volume of the reactor, as it was described in [7]. The influent flow rate is then controlled in such a manner that the reaction rate is close to the maximal value. This is obtained by maintaining an optimal substrate concentration in the reactor as a consequence of the controlled filling. Considering a Haldane law, the optimal substrate concentration is the S*, *i.e.* the value at which the maximal growth rate or substrate degradation rate is observed. The controller tries to maintain the substrate concentration around S* in order to avoid biomass inhibition. The strategy was tested using different influent concentrations of 4CP between 175 and 613 mg/L (which represents variations of -50, +25, +50 and +75% with respect to the standard condition of 350 mg/L). To study the robustness of the strategy under different airflow rates, two conditions were examined (± 50% with respect to the standard condition of 1.5 L/min, i.e. 0.75 and 2.25 L/min). The SBR was operated under the following strategy: pre-aeration time (15 min), filling and reaction time (variable depending on the influent concentration and set by ED-TOC), settling time (30 min) and draw time (6 min).

3. Results and discussion

Carbon and nitrogen removal. With the INRA-SBR 20 experiments with different operation conditions were performed. Some of them are shown in figure 3. In the left picture, the influence of the variation of the organic carbon concentration is shown and in the right picture the influence of the oxygen on the reaction kinetics is presented.

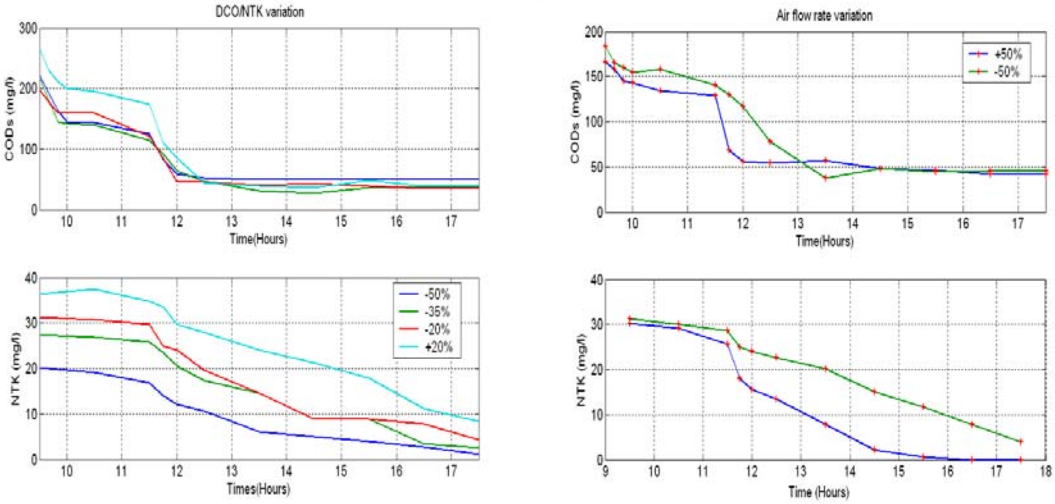

Figure 3. Comparison between cycles obtained in different conditions (C/N variations on the left and O2/TSS variations). Results obtained with the INRA-SBR reactor.

As for the settling experiments with the INRA-SBR sludge**, f**irst, 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. One can observe in figure 4 (left picture) that the initial velocity decreases when the TSS concentration increases. We observed 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.

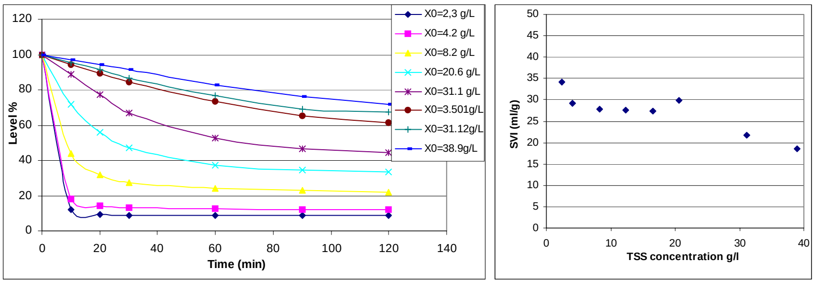

Figure 4. TSS Influence on the settleability obtained with the INRA-SBR sludge. Xo: initial biomass concentration.

Using the SVI and initial velocity, it was proposed to 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 characterize the evolution of the SVI within the mass loading rate and volume loading rate. Firstly, a long period of sludge adaptation was applied. For a long time period (greater than three months) the reactor was operated at low volume loading rate around 0.7 kg COD/m^3/day. Then the loading rate was increased up to 1.2 kg COD/m^3/day (Table 5).

The results of the experiments show that the sludge supported a high loading rate while SVI was very low compared to traditional wastewater treatment plants (usually 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. Thus, by measuring online the sludge level and offline the TSS the SVI, a new automatic sludge management was implemented. With these parameters, a bad settling can be detected. The settling phase duration or maximum TSS concentration allowed in the reactor can easily be determined. For the supervision algorithms, alarms can be activated when the SVI increases or when the settling velocity decreases.

Table 5. Experiment plan for loading rate increasing

	Step 1	Step 2	Step 3
Mass loading rate kg COD/kg TSS/d	Low 0.09	Medium 0.15	High 0.4
Volume loading rate kg COD/m3/d	Low 0.7	High 2.4	High 2
SVI mg/g	19.6±0.5	21.7±0.9	35.14±3.3

An example of one standard cycle of the UU-SBR is showed in table 6 and figure 5 (reactor M) and table 7 and figures 6 (reactor F). The reactor M operated at 2.4 gVSS/L. The maximum OUR heterotrophic potential activity for this cycle was 542 mgO2/gVSS/d. The sludge showed a negligible ammonia and nitrite oxidizers activity. Due to its high C/N ratio of the influent, Reactor M is an heterotrophic reactor. No significant autotrophic activity is detected, and organic nitrogen is employed in heterotrophic growth

Table 6.- Reactor M results for a Standard cycle

	Influent	Efluent
CODs(mg/L)	3414	40
TKN (mgN/L)	59.4	0.2
NH4(mgN/L)	6.0	0.06
NO3 (mgN/L)	93.4	< 0,5
NO2 (mgN/L)	1.5	< 0,2

Table 7.- Reactor F results for a Standard cycle

	Influent	Efluent
CODs(mg/L)	909	65
TKN (mgN/L)	98.8	nd
NH4(mgN/L)	72.5	0.23
NO3 (mgN/L)	3.3	72.4
NO2 (mgN/L)	3.6	<0,2

The reactor F operated at 1.7 gVSS/L. The maximum OUR heterotrophic potential activity for this cycle was 739 mgO2/gVSS/d. The sludge showed a moderate ammonia and nitrite oxidizers activity of 560 mgO2/gVSS/d and 179 mgO2/gVSS/d respectively. Nitrate concentration at the end of the cycle is significant for Reactor F, as nitrification activity is observed. A nitrate removal efficiency of 30% during the anoxic phase is attained, even when a better efficiency was expected. Denitrification could be inhibited due to high pH values. Adsorption-desorption of COD is observed in both reactors.

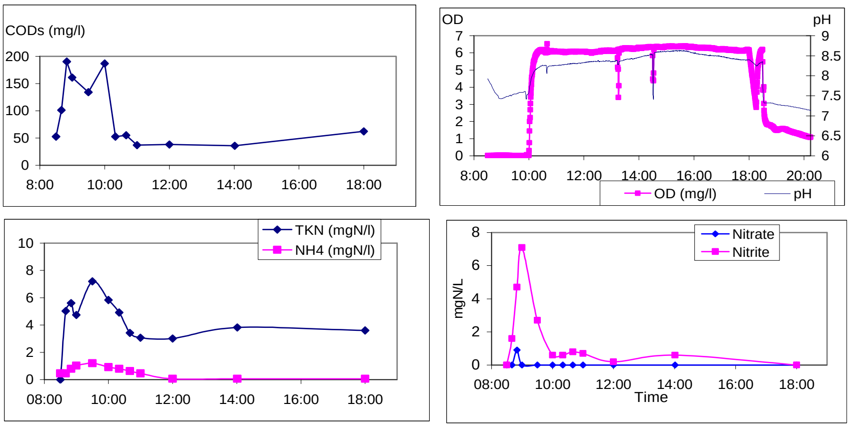

Figure 5. Reactor M cycle profiles for COD, DO, pH, TKN, NH4, N-NO3 and N-NO2

Figure 7 reports a typical profile of the main parameters during a cycle under standard loading conditions for the case of the POLIMI-SBR. During the anoxic react phase, denitrification occurs, since a rapid depletion of both nitrates and COD is clearly visible. The main aim of this process in the conversion of the oxidized nitrogen forms (NO_X = nitrites –NO_2^-– + nitrates –NO_3^-–) into gaseous nitrogen (N_2), thus reducing the nitrogen content in the wastewater. This phase is normally scheduled before the aerobic reaction phase because it requires the availability of rapidly biodegradable organic matter, which would be rapidly oxidized in the presence of oxygen. Nitrates are generally absent in the influent wastewater, while reduced ammoniacal and organic nitrogen is abundant. Therefore, NO_x are to be produced from the reduced nitrogen forms by means of the ammonification (organic nitrogen is hydrolyzed to ammoniacal nitrogen) and subsequent nitrification (ammoniacal nitrogen is oxidised to nitrites and then to nitrates). The nitrate reduction capacity of the SBR is therefore strictly related to the volume of the SBR reactor at the end of the drawing phase, which contains the amount of nitrates which will be available for the following anoxic reaction phase.

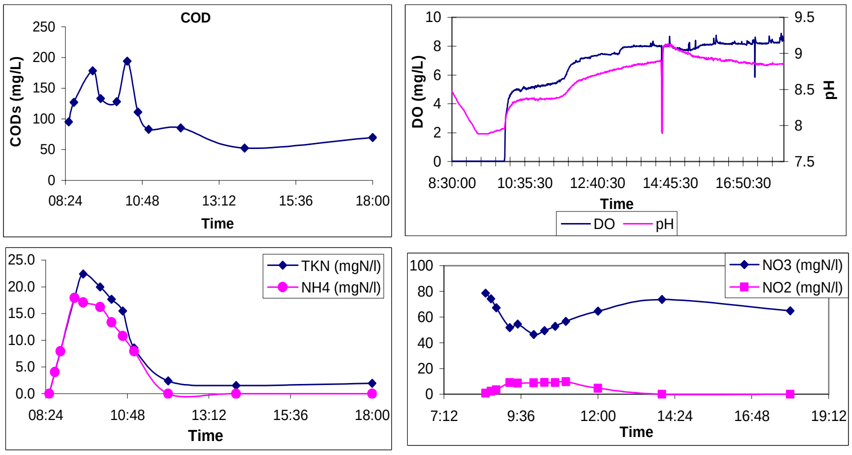

Figure 6. Reactor F cycle profiles for COD, DO, pH, TKN, NH4, N-NO3 and N-NO2

During the aerobic phase, ammonium concentration decreases while nitrites and nitrates are produced. The COD profile does not change much, since most of its biodegradable fraction is removed by denitrification. The time trend of the above described parameters shows that, during this cycle, both nitrification and denitrification were completed, indicating a satisfactory performance of the process. Also, all data indicate that the SBR is over-designed for standard loading conditions, since both denitrification and nitrification are completed well before the end of the corresponding reaction phases.

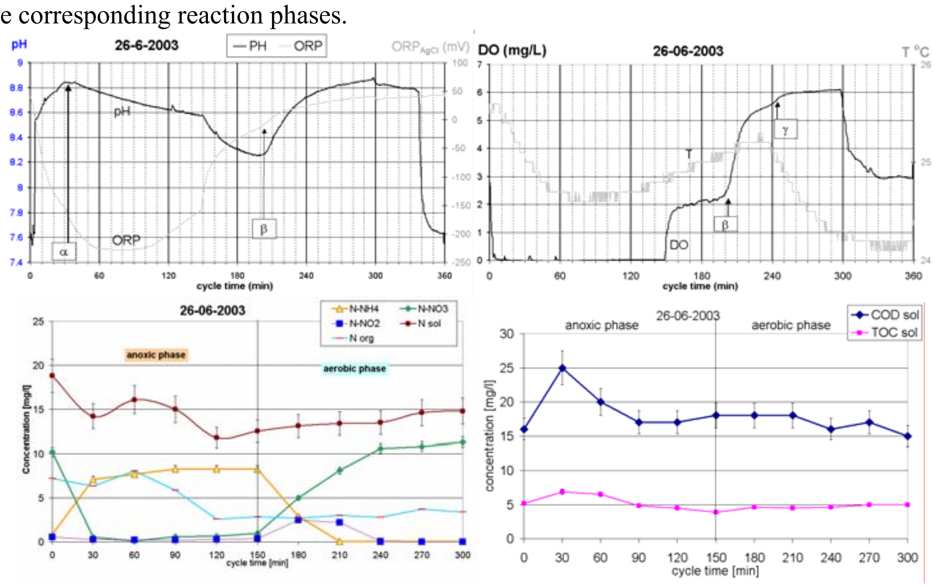

Figure 7. POLIMI-SBR, experiment under standard loading conditions

On-line signals also give very interesting information. As for the ORP signal, bending points of its trend (knees) can provide information on bacterial activity. Specifically, during the anoxic phase a “nitrate knee” is observed in the ORP profile, indicating full depletion of NO_X (α, in Figure 7). In the aerobic phase, a bending point is also observed as soon as ammonium is fully oxidized (β, in Figure 7). Since most of the biological processes exert an effect on pH, its trend also reflects the evolution of these processes. During the anoxic phase, a “nitrate-apex” (i.e. the maximum) in the pH profile indicates the end of the alkalizing denitrification phase, while, during the aerobic phase, a minimum (called the “ammonia valley”) indicates the end of the acidifying ammonium oxidation to nitrites [8]. At the same time, a "DO flex" or "break-point" [9-10] is observed due to the reduction in the bacterial oxygen consumption (β, in Figure 7); for the same reason, a similar, although less evident, notable point can be observed as soon as nitrites are fully oxidized to nitrates (γ, in Figure 7). Obviously, compared to analytical determinations, on-line data are automatically collected and have higher acquisition frequency. However, they give indirect information on the process dynamics, although a model-based relation can be established between some of them and most of the relevant process parameters. This is especially true for DO concentration which however is useless during the anoxic phase.

Failures related to the biological processes are mainly related to nitrification and denitrification processes, rather than organic carbon removal. Nitrification is carried out by slowly growing bacteria, very sensitive to a variety of chemicals. Therefore, nitrification failures are often experienced at full scale applications continuous as well as fed-batch systems. Denitrification failures are normally caused by insufficient carbon availability, which causes excessive nitrate concentrations in the effluent. Nitrites build-up may also be an issue, since they are intermediate products of the oxidation of ammonia to nitrates or the reduction of nitrates to N_2. In Figure 8, nitrification inhibition is shown, caused by addition of allylthiourea to the standard SBR influent. It can be observed that the entire aerobic phase is necessary for completion of ammonia oxidation, and the pH profile does not shows the ammonia valley, indicating an abnormal behavior. A case of insufficient COD availability can be observed also observed in Figure 8, where both nitrates and nitrites are still present at the end of the anoxic reaction phase while no clear nitrate apex is observed in the pH signal.

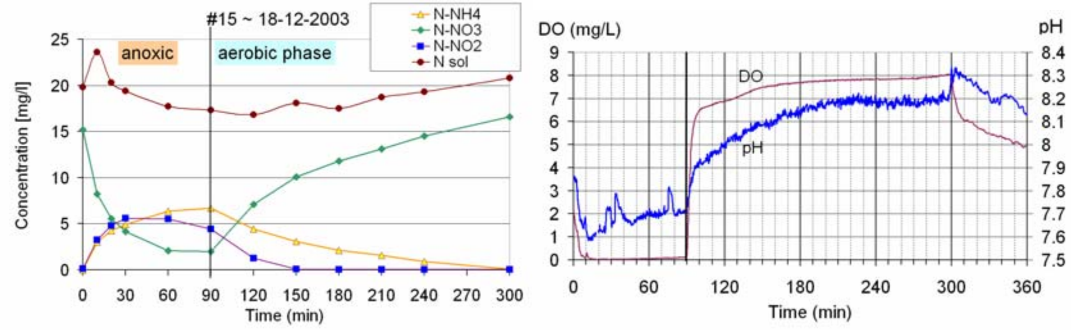

Figure 8. POLIMI-SBR, experiment in the presence of a nitrification inhibitor

Toxic wastewater degradation. Figure 9 presents the behavior of the substrate concentration, measured as 4CP and DOC during a cycle operated under the ED-TOC strategy with the standard condition (350 mg4CP/L). It is possible to distinguish how the control operates following the substrate and the DO evolution curve. Once the influent begins to be fed to the reactor, the reaction starts. The DO decreases (first 0.2 h, figure 9) as the metabolic activity of the biomass increases to degrade the 4CP. Simultaneously, the estimator calculates γ and follows its value. When a maximal point of γ is detected (before a minimum in the DO concentration), the feeding pump is turned off. At this point, the concentration of substrate is lower than expected (it has decreased from 48 to 22 mg4CP/L, at 0.4 h in Figure 9). Thus, the feeding pump is switched on, and a new charge of substrate is fed to the reactor. This procedure is repeated until the maximal volume has been reached and then, the degradation proceeds in a batch manner, ending the reaction when the DO concentration increases to a constant value. It is possible to observe in Figure 9 how the internal concentration of 4CP in the reactor is maintained around 30 mg/L, which corresponds to a concentration close to S* and thus, around μ^* (or γ^*).

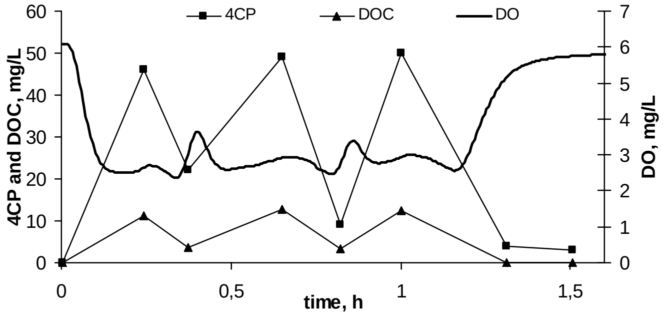

Figure 9. Evolution of the substrate concentration, measured as 4CP and DOC during a cycle operated under the ED-TOC strategy

In order to study the robustness of the control strategy against the variation of the influent substrate concentration, four conditions were tested, i.e., 175, 438, 525 and 613 mg 4CP/L. Figure 10 presents the behavior of the 4CP and dissolved oxygen concentrations. It was observed that, as expected, an increase of the 4CP concentration in the influent generates an increase of the degradation time. However, for all cases the removal efficiency of the toxic was superior to 95% as COD, and 99% as 4CP, indicating that a shock load of 613 mg/L had no influence on the performance of the reactor. Note that the maximal concentration in the reactor was around 50 mg/L irrespectively of the concentration in the feed. The reactor was really never exposed to a shock load, since S inside the reactor oscillates around the value S*.

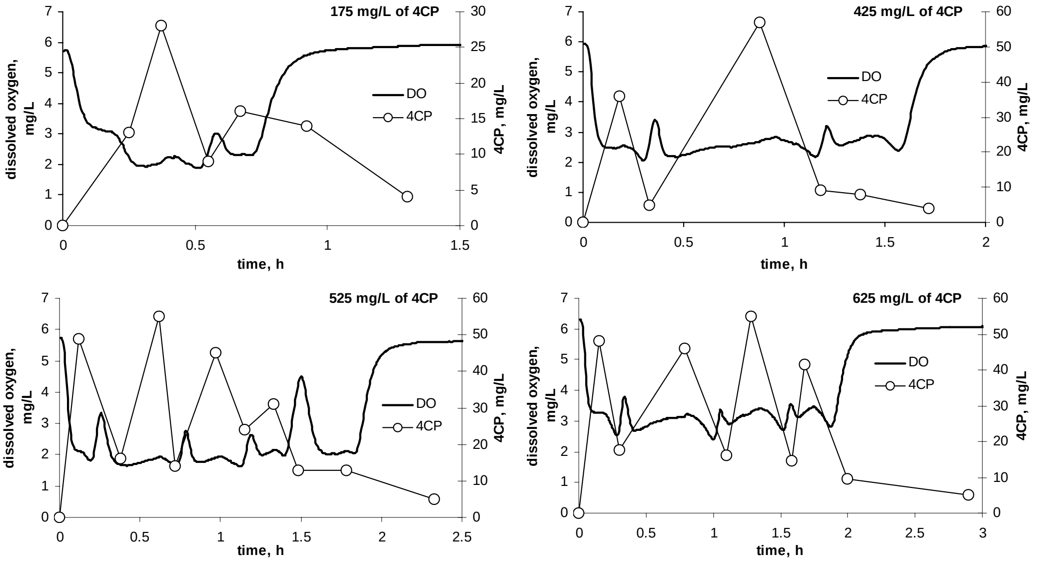

Figure 10. Degradation kinetics for different 4CP initial concentration and dissolved oxygen evolution

As the ED-TOC strategy depends on the DO concentration to control the feed rate, it is important to study how much the variation parameters related to it could affect the performance of the reactor. Two experiments were conducted by varying the oxygen flow rate with respect to the standard value of 1.5 L/min. In all the cases, the Kla was determined for the different value of the oxygen flow rate tested (11.5, 13 and 18.5 h^{-1} for the flow rates of 0.75, 1.5 and 2.25 L/min, respectively). Figure 11 presents the evolution of the dissolved oxygen during the variation of ±50% of the airflow in respect to standard conditions. For all the cases initial concentration of 4CP was 350 mg/L. When a –50% condition was applied, DO in the tank was always superior to 2 mg/L. Thus, it can be considered that no limitations for this element were present.

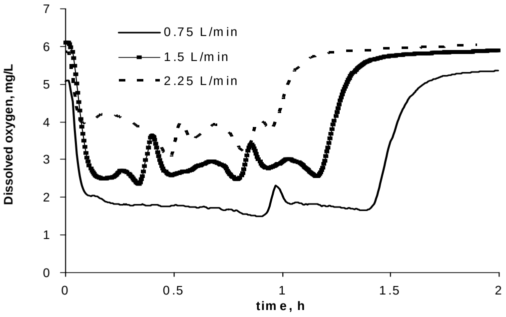

Figure 11. Evolution of the dissolved oxygen concentration as a function of time

5. Conclusions

A set of data was obtained in order to calibrate and validate a model for SBR systems fed with crude and pre-treated dairy wastewater in anoxic and aerobic phases. Results showed that experiments were coherent with the mechanistic knowledge of the basic biological processes taking place in the SBR

Data concerning the INRA-SBR sludge settling will be used to develop a supervision algorithm to monitor the settling phase and to avoid a bad settleability in the SBR. In UU-SBR different pathways of N removal took place. In Reactor M heterotrophic consumption for growth was the main mechanism for N removal, while in Reactor F Nitrogen was removed mostly by autotrophic nitrification and denitrification. Adsorption of COD during feeding is also observed.

POLIMI-SBR indicate that basic information on the biological behavior can be obtained from on-line signals (DO, pH and ORP), although they are more qualitative then quantitative. However, a simple monitoring does not allow plant operators to prevent unwanted events to happen (e.g. nitrification inhibition), but only to realize that they are happening. The need for on-line systems allowing plant operators to have early-warning information on the quality of the influent to be treated, allowing for effective plant operation, would greatly improve process efficiency.

The biodegradation of a toxic wastewater containing 4CP as model of an inhibitory compound was obtained in the UNAM-SBR. A good performance of the reactor operated with the ED-TOC strategy was obtained since the degradation of the 4CP was efficiently completed. During the operation of the reactor with the optimal strategy, average removal efficiencies were 99%, as chemical oxygen demand, and 100% as 4CP. The ED-TOC strategy was also able to manage increments of toxic concentrations in the influent up to 613 mg 4CP/L. There was not a significant influence on the performance when the air inflow rate was varied ±50% with respect to the standard condition, but care must be taken when aeration is low, since harmful by-products may be formed.

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