EOLI
WP 1 : Supervision System development
Deliverable D 1.5 : Report on the evaluation of the supervision system

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1. Introduction

This document presents the evaluation of the DSS modules integrated and implemented on the real pilot plant. The final system has been implemented at T0+31 and is completely operational from that date, *that is in advance of 4 months* with respect to the date of T0+35 initially planned in the "milestones and expected results" section of the WP8 of the EOLI technical annex.

2. The DSS modules

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 hereabove in the section "Supervision of the SBR in the case it is equipped with advanced instrumentation".
- In the presence of a sludge level sensor, an additional module was added in order to optimize the management of the sludge. In particular, a system to automatically withdraw the sludge in excess has been proposed. Details about this system are reported hereafter in the section "Automatic management of the sludge".

3. The integration of the DSS modules

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 in 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.

4. Supervision of the SBR in the case it is equipped with advanced instrumentation

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 balance which is realized is based on the following calculations.

The oxygen consumption in the reactor during the aerobic phase of a treatment cycle can be described by the following equation:

$$\text{O2\_consumption} = \text{O2\_nitr} + \text{O2\_ox\_aer} + \text{endogenous respiration} \qquad (1)$$

where O2_nitr is the oxygen requirement for the nitrification process, due to autotrophic biomass, O2_ox_aeris the oxygen requirement for the organic matter oxidation process, performed by the heterotrophic biomass and the "endogenous respiration" is due to both autotrophic and heterotrophic biomasses ("decay" autotrophs and heterotrophs).

According to the Activated Sludge Model ASM1, nitrification process and organic matter oxidation in the aerobic phase can be related to the dissolved oxygen concentration with the following relationship, that link substrates depletion to bacterial growth :

$$\frac{S_{NH}}{Y_A} + \frac{(4.57 - Y_A)}{Y_A} O_2 \propto X_{BA} \quad (2)$$

$$\frac{Ss}{Y_H} + \frac{1 - Y_H}{Y_H} O_2 \propto X_{BH} \qquad (3)$$

respectively for the autotrophs and for the heterotrophs so as the oxygen consumption in the reactor during the aerobic phase can be expressed as :

$$O_{2\ \text{consumption}} = (4.57 - Y_A) \cdot S_{NH} + (1 - Y_{BH}) \cdot Ss + \text{endogenous respiration} \qquad (4)$$

where Ss is the amount of organic matter (expressed as grams of COD) that are oxidized.

Typically for the process at LBE-INRA, we can assume that in standard conditions of operation the influent’s organic matter content is almost completely depleted, since the ratio $COD_{tot}/COD_{degradable}$ is close to 1. Therefore we can assume that the amount of organic matter oxidized (Ss) is equal to : $COD_{tot} - COD_{den}$, where COD_{den} is the amount of organic matter required to achieve complete reduction of nitrogen oxidized compounds present in the reactor at the beginning of the anoxic phase. The stoichiometry of the relationship between COD and N denitrified allows us to calculate the COD requirement as follows :

$$COD_{den} = \frac{N - NOx \cdot 2.86}{1 - Y_{HD}} \quad (5)$$

The amount of N-NOx to be reduced by means of denitrification can be estimated both by the TITAAN and/or by the on-line UV sensor : the analysis should be performed just before the beginning of a new anoxic phase. The TITAAN can estimate the amount of N-NOx with a recently developed titration modality (this modality is still not implemented on-line , but it has been widely tested at lab-scale with the titration unit MARTINA). For details on hardware sensors see EOLI WP3 3rd year report and related deliverables.

The TITAAN hardware sensor is also able to provide on-line estimations of the amount of the influent's TKN. On the basis of this data, and with the hypothesis that the amount of COD_{tot} of the influent is known, it is possible to predict the amount of nitrogen to be nitrified in the aerobic phase as :

$$S_{NH} = TKN_{tot\_inf} - TKN_{assimilation/synthesis} \qquad (6)$$

and $TKN_{assimilation/synthesis}$ can be calculated on the basis of the ratios : BOD : N : P = 100 : 5 and 1 respectively, that corresponds to the typical nutrient ratio for bacterial growth in activated sludge systems.

We can assume that the amount of inert nitrogen content of the influent for the LBE-INRA process is negligible. A software tool was developed to measure the effective oxygen consumption during the aerobic phase of the SBR cycle. For this evaluation, a reliable measure of K_La is necessary, since we use the equation that describe the oxygen consumption :

$$O_{2\,consumption} = K_L a \cdot \int (S - O_2) dt \qquad (7)$$

where S is the instantaneous value of oxygen concentration during aerobic phase in the absence of substrate (blue curve in Figure 1) and O_2 is the oxygen concentration profile in the presence of substrate to be removed (red curve in Figure 1).

An automatic computation routine has been implemented on the LBE-INRA reactor, in order to provide K_La measures from two different DO probes located at different positions in the tank : the measures are performed at the end of the first daily cycle, when theoretically all substrates should have been removed.

The curve S in figure 1 can be calculated as the solution of the differential equation :

$$X' = K_L a \cdot (O_{2sat} - S) \quad (8)$$

At the end of each aerobic cycle, the software can calculate the amount of oxygen used to oxidize substrates by means of equation 7. It is important to notice that the oxygen consumption evaluated with eq. 7 allows one to avoid the evaluation of the endogenous respiration rate, assuming that this contribution is constant both in the presence and in the absence of substrates.

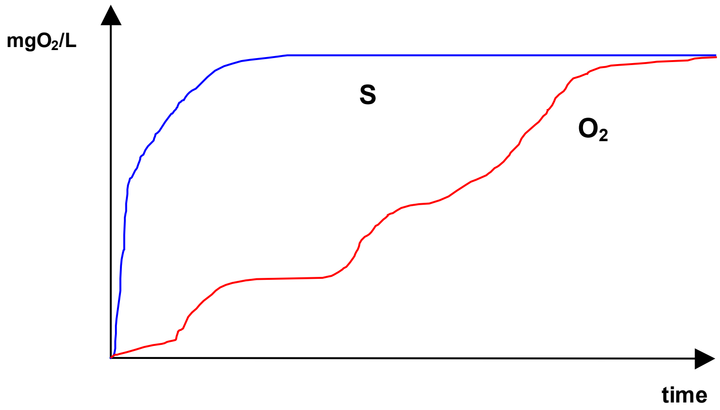

Figure 1 : *Oxygen curves in absence(blue) and in presence of substrates(red)*

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. 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.

To validate the procedure, a series of chemical analysis were performed on the influent (to know the real amount of organic matter and TKN in the feeding) and the oxygen consumed was evaluated by the oxygen mass balance described above. We used the typical ASM1 values for the parameters Y_A and Y_{BH} in the equation 4 while for Y_{HD} in equation 5 the value 0.52 gCOD/gCOD, reported for milk serum treatment (Ohron, 96), was used. The value obtained by calculation were compared to the oxygen consumption estimated by the supervision software, and the first results obtained are plotted in Figure 2.

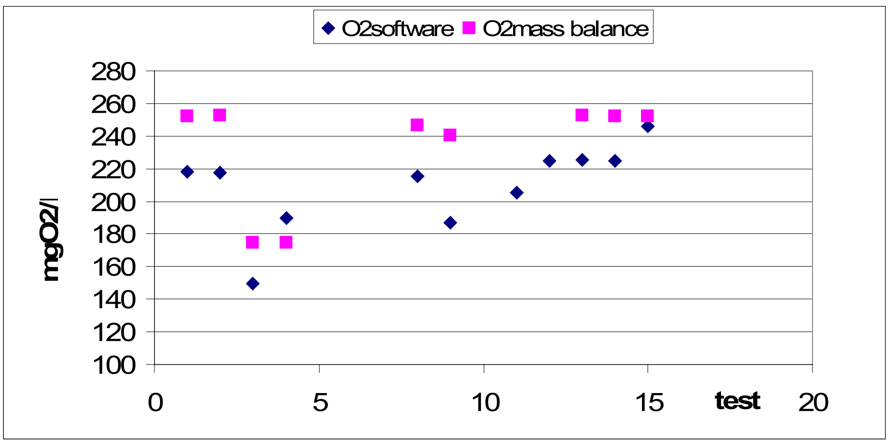

Figure 2 : *Comparison between oxygen consumption estimated by mass balance and by the supervision software*

The interface of the system is represented in the following figure :

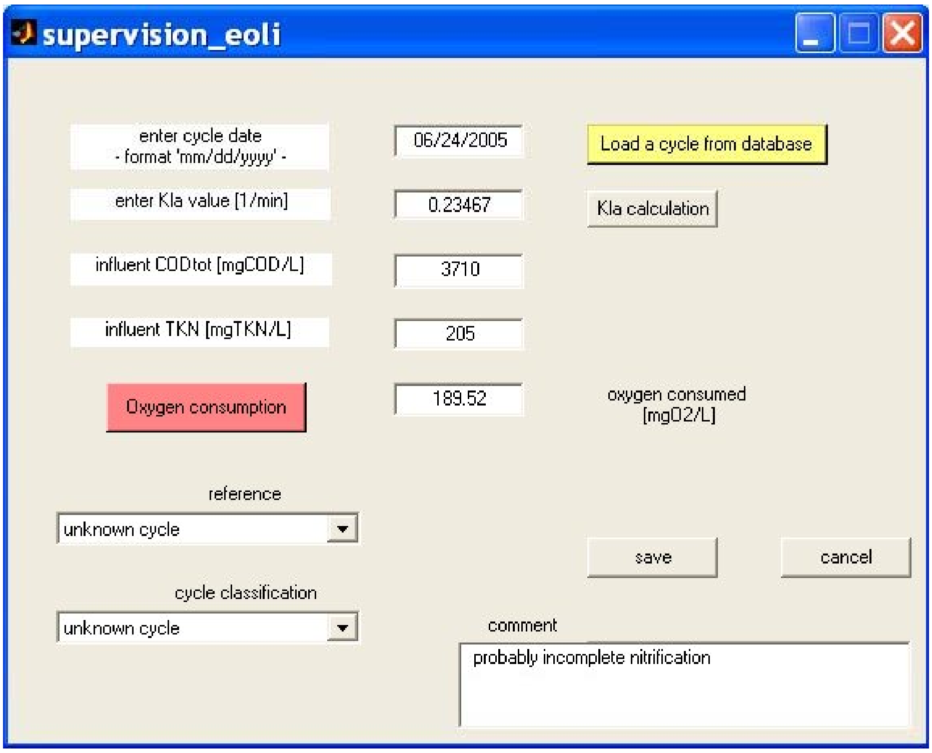

Figure 3 : *User interface of the supervision system in the case 2*

5. Automatic management of the sludge

The objectives of the developed system was twofold :

- First, it is important to early detect an eventual problem related to a poor capacity of the sludge to settle. To do so, a module able to compare the actual performances of the sludge with reference cycles where these performances were known to be good was developed. This module includes an on-line computation of four specific parameters (characteristic instants) defined as i) t0, the time it takes to the sludge to begin to settle from the instant the aeration has been switched off, ii) t1, the time during which the settlement is very rapid (this first decreasing rate is also computed), iii) t2, the time during which the decrease rate is a little bit slower and the associated rate and iv) t3, the final level. This final level is related to the SVI and thus to the actual sludge concentration. It is then possible to compute a theoretical increase of level between two successive cycle if the quantity of COD degraded during one cycle is known. This theoretical value is computed and compared to the actual level. If the increase in sludge is significantly higher than the theoretical one, the operator is adviced and a withdraw of sludge is proposed.
- Second, after a maximum sludge concentration present in the reactor has been defined, and under the condition that the settlement capacity is normal, at the end of each cycle, the system automatically computes the theoretical quantity of sludge produced and compare the theoretical total quantity of sludge present in the system. If this value exceeds the maximum allowed value, then a constant quantity of sludge is automatically removed from the system after the operator has confirmed the action.

The interface of the system is represented in the figure 4.

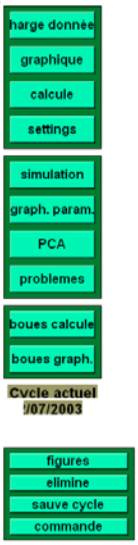

Figure 4 : *User interface of the supervision system dedicated to the management of the sludge*

Other figure available to support the decision of the operator are :

- For a given cycle, the time instants t0 to t3 and all additional parameters like the initial decrease rate, etc (cf. figure 5)…

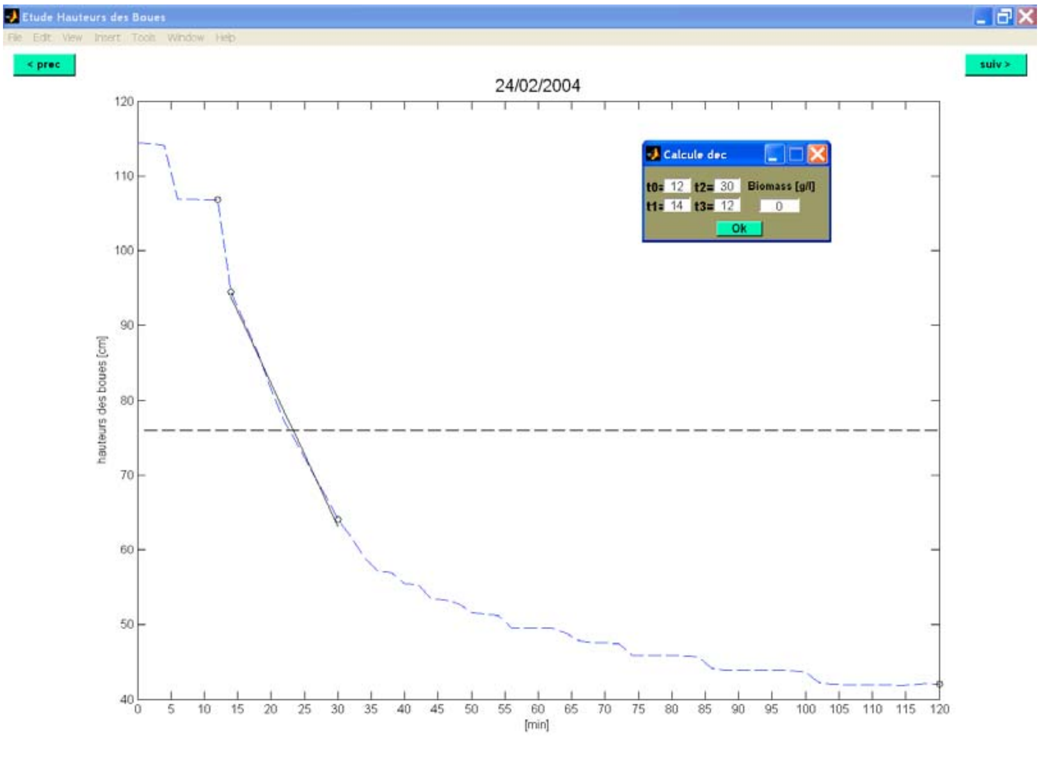

Figure 5 : *User interface of the supervision system dedicated to the management of the sludge*

- For a given set of cycles, the comparison of the initial decrease rates can be plotted (cf. figure 6).

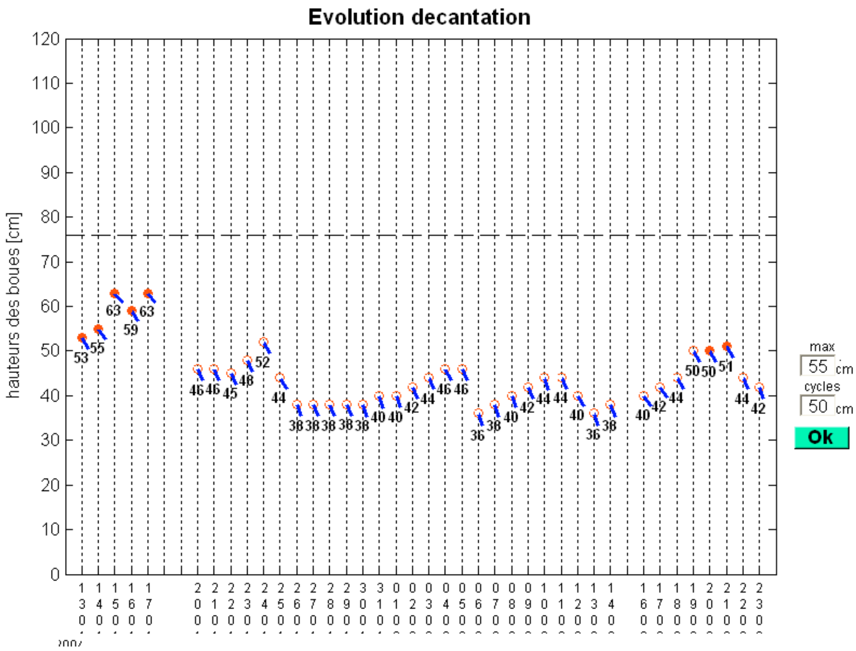

Figure 6 : *User interface of the supervision system dedicated to the management of the sludge*

On the previous figure, the final height of the sludge is represented together with a small bar representing the initial decreasing rate. A number of parameters such as the maximum admissible level and the admissible level differences between two successive cycles allow the user to parameterize this figure : the points for which the actual final sludge level exceeds the maximum one are colored in red while the other points are empty (in the figure, it corresponds to the cycles for which the final actual level exceeds 50 cm).

On the pilot plant, the system is activated though the use of an interface developed with the Guide User Interface of Matlab. This interface allows any module to be run independently of any other. It is the responsibility of the user to verify that any new functionality of the system does not interfere with the actions of any other running module (for instance the control module) and the plant.