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Efficient Operation of Urban Wastewater Treatment Plants

Report on full-scale performance of the software sensors integrated within the supervision system Deliverable D4.2

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Responsible:
Denis Dochain
CESAME
Université catholique de Louvain
Bâtiment Euler
4-6 avenue Georges Lemaître
B-1348 Louvain-la-Neuve
Belgium
e-mail: dochain@csam.ucl.ac.be

Other Contributors:
Jérôme Harmand
Djalel Mazouni
LBE-INRA
11 avenue des étangs
11100 Narbonne
France
e-mail: harmand @ensam.inra.fr

This deliverable provides results on the implementation of the software sensors as presented in deliverable 4.2 on the full-scale plants of EOLI. It will concentrate on the application at the LBE plant in Narbonne.

Let us recall that these software sensors are based on the model EM2. Because both the carbon and nitrogen are treated, two specific phases are needed : aerobic (presence of oxygen) and anoxic (no oxygen but nitrite and nitrate). During the anoxic phase, the nitrite+nitrate from the last cycle are transformed into gaseous nitrogen. This step is realized by heterotrophic bacteria who also need soluble organic carbon to grow (Hu et al, 2003)(Jeppsson, 1996). When all the nitrite-nitrate has been removed, one can switch to aerobic mode where the ammonium nitrogen will be transformed into nitrite and nitrate while the remaining soluble carbon will be removed.

From now on, we only concentrate on what happens during the aerobic phase and the following notations are used :

X_1 : Heterotrophic microorganisms. (mg/l)

X_2 : Autotrophic microorganisms (mg/l)

S_1 : Organic carbon. (mg COD /l)

S_2 : Ammonium nitrogen. (mg N-NH4/l)

S_3 : Nitrates/Nitrites nitrogen (mg N-NO3/l+ mg N-NO2/l)

S_4: Dissolved oxygen (mg O2/l)

The reaction scheme of the aerobic phase is as follows :

$$\begin{array}{l} k_1 S_1 + k_4 S_4 \quad \xrightarrow{\mu_1} \quad X_1 \\ k_2 S_2 + k_5 S_4 \quad \xrightarrow{\mu_2} \quad X_2 + k_3 S_3 \end{array} \tag{1}$$

This synthetic scheme means that S_1 and S_2 are degraded by X_1 and X_2 respectively with the rates μ_1 and μ_2 in the presence of S_4. In other words, the pollutant S_1 serves as a basis for the growth of X_1 while S_2 is transformed into S_3 by X_2.

Considering the above reaction scheme, we can apply the mass balance principle to determine the state space model of the aerobic phase (Bastin et al 1990):

$$\dot{X}_1 = \mu_1(S_1, S_4) X_1 \tag{2}$$

$$\dot{X}_2 = \mu_2(S_1, S_4) X_2 \tag{3}$$

$$\dot{S}_1 = -k_1 \mu_1(S_1, S_4) X_1 \tag{4}$$

$$\dot{S}_2 = -k_2 \mu_2(S_1, S_4) X_2 \tag{5}$$

$$\dot{S}_3 = k_3 \mu_2(S_1, S_4) X_2 \tag{6}$$

$$\dot{S}_4 = -k_4 \mu_1(S_1, S_4) X_1 - k_5 \mu_2(S_1, S_4) X_2 + K_L a(S_4^{\max} - S_4) \tag{7}$$

with

$$\mu_1 = \mu_{1\max}\frac{S_1 - S_1^*}{K_{S1} + S_1 - S_1^*}S_4;$$
$$\mu_2 = \mu_{2\max}\frac{S_2}{K_{S2} + S_2}S_4. \qquad (8)$$

As can be seen, the specific growth rates in aerobic phase, μ_1 and μ_2, are proportional to the dissolved oxygen concentration, S_4, in the reactor instead of the classical expression $\frac{S_4}{K_O + S_4}$ proposed in (Henze *et al*., 1987). It is essentially because the available experiments were realized with a non-limiting oxygen concentration, S^* being the average of residual COD in the reactor (Mazouni *et al*., 2004).

It was shown in (Mazouni et al, 2004) that the model is very sensitive to the oxygen transfer coefficient K_La. This parameter is itself very sensitive to environmental conditions such as input air flow rate. When operating in real conditions, it is possible to classify the operating conditions into a finite number of classes depending on the input air flow rate. That way, a limited number of set of process parameters can be identified and, depending on the environmental conditions, the user can predict the future behavior of the process in using the specific model associated with the actual operating conditions. In other words, we use a multi-model approach : the process is not described by only one model but by n models, each of them being related to a given range of input air flow rates (a value of K_La).

Table 1 Influent concentration and air flow rate for each experimental data used for identification

Exp. No	**Air flow (l/min)**	**COD in (mg/l)**	**NTK in (mg/l)**	K_La **(h^{-1})**
27.10.03	50	4318.18	168.00	18.75
29.10.03	50	4772.25	183.68	18.75
31.10.03	50	4476.92	204.40	18.75
04.11.03	50	4836.85	319.20	18.75
06.11.03	75	4235.45	260.4	23.00
12.11.03	25	4945.61	285.60	9.60

Introducing the auxiliary variables :

$$\begin{cases} Z_1 = S_2 + \frac{k_2}{k_3}S_3 \\ Z_2 = S_4 - \frac{k_4}{k_1}S_1 + \frac{k_5}{k_3}S_2 \end{cases} \qquad (10)$$

allows us to consider the following dynamical sub-model :

$$\begin{cases} \dfrac{dZ_1}{dt} = 0 \\ \dfrac{dZ_2}{dt} = K_L a(S_4^{\max} - S_4) \end{cases} \tag{11}$$

Assuming that S_2 and S_4 are measured on-line and that $Z_1(0)= Z_{10}$ and $Z_2(0)= Z_{20}$ are known, the system (10)-(11) can be used to get an on-line estimation of S_1 and S_3 as :

$$\begin{cases} \hat{S}_1 = \dfrac{k_5 k_1}{k_2 k_4}(Z_1 - S_2) - \dfrac{k_1}{k_4}(Z_2 - S_4) \\ \hat{S}_3 = \dfrac{k_3}{k_2}(Z_1 - S_2) \end{cases} \tag{12}$$

The multi-model monitoring system for the first group was validated by comparing the observation curves with data of experiment No. 04.11.03. The comparison between the real data and the output of the monitoring system are shown in figures 4. The necessity of determining the initial values of the system (11) can be solved as follows. As explained in the introduction, at the beginning of the aerobic phase, there is no nitrite nor nitrate in the reactor. Thus $S_3(0)=0$. Since S_2 is measured, $S_2(0)=S_{20}$ is known. From equation (10), one concludes that $Z_1(0)=k_3S_{20}+k_2S_{30}$. Since S_4 is also measured one has only to assume that the initial value of the organic carbon to be removed in one cycle is known ($S_1(0)=S_{10}$) in order to compute $Z_2(0)$ using equation (10b) as $Z_2(0)=S_{40}-k_4S_{10}/k_1+k_5S_{20}/k_3$.

Usually, at the beginning of the process, the initial value of COD (or at least an average value of it) is known (measured off-line). The values of COD_in for the experiments used in this paper are shown in Table 1. It is observed that the initial value of COD at the beginning of the aerobic phase is between 3% and 4% of the value of COD_in listed in Table 1.

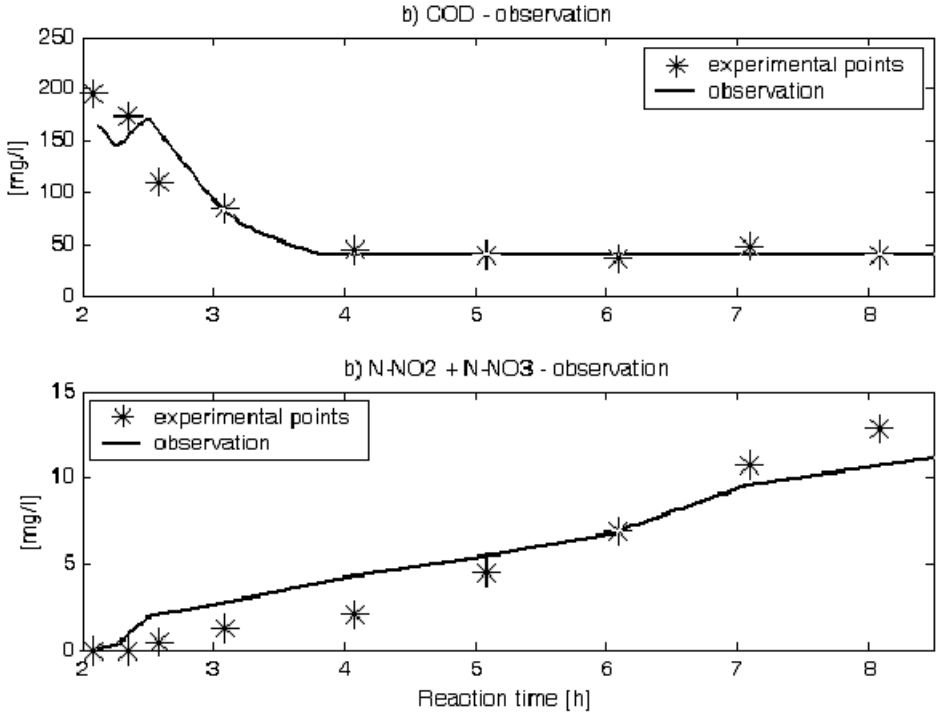

Figure 2. Software sensor implementation on data of November 4, 2003

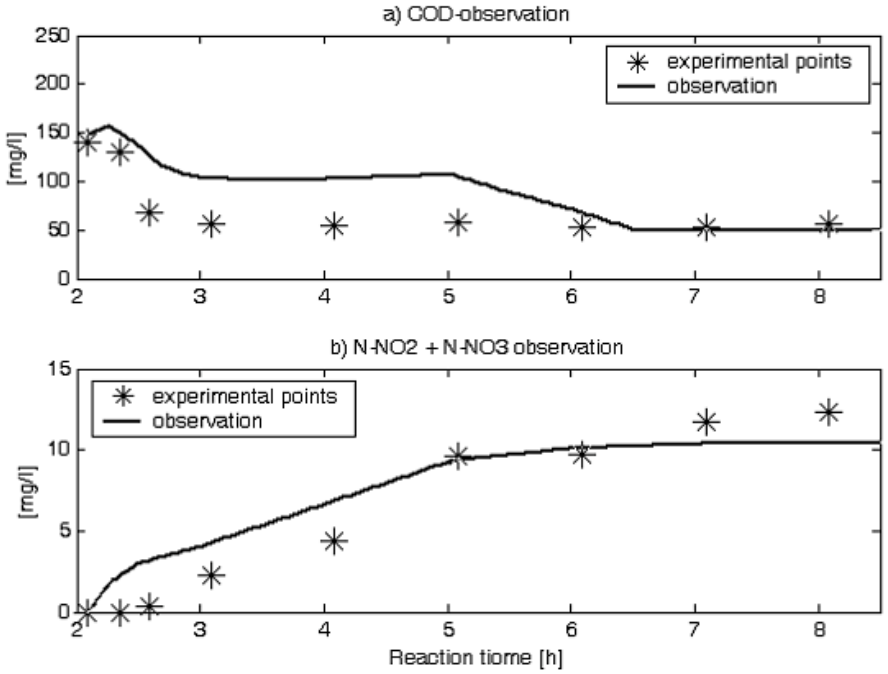

Figure 3. Software sensor implementation on data of November 6, 2003

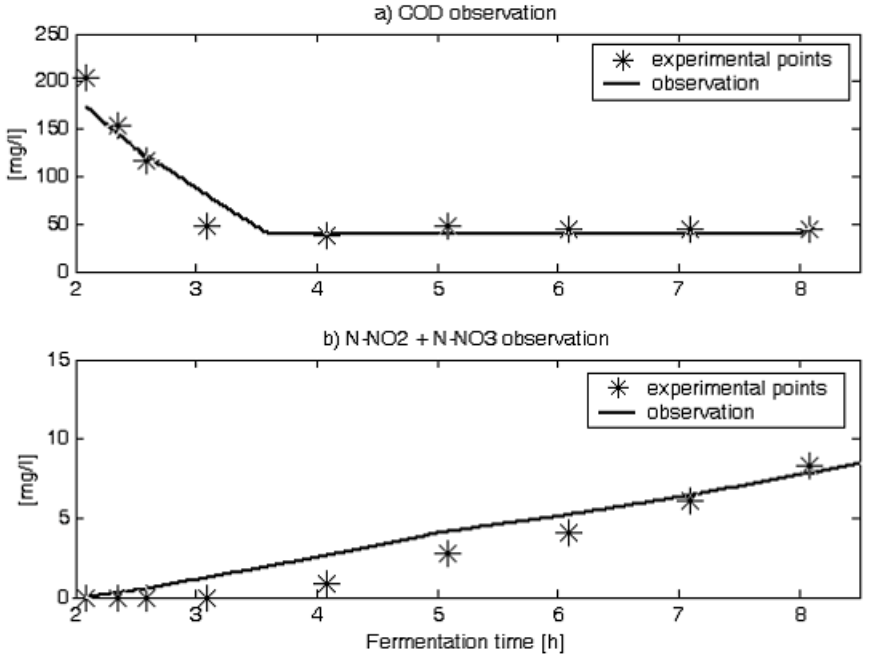

Figure 3. Software sensor implementation on data of November 12, 2003

As can be seen in Figure 2a, observations fits well with off-line measured points until 4h30. After that time, a saturation of the COD observed value is included in the observation algorithm to overcome the difference between the data and the monitoring system. That differance relies on the fact that COD measurement includes a part of non-biodegradable COD (usually self generated by biomass decay (Orhoni et al., 2003)). This residual COD is a constant value and is around 40 mg/l

In Figures 3 and 4, the observation concerning the others two groups are validated with the experimental points.

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