MODEL VALIDATION FOR A WASTEWATER TREATMENT PLANT

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Abstract: In this paper, the different steps required for model validation as applied to a wastewater treatment plant are discussed. A mathematical model very useful to implement the automation, the methodology to determine kinetic parameters and the required information for the most important process variables are presented. Finally, how to validate this model is explained, followed by the relevant conclusions. *Copyright © 2007 IFAC*

Keywords: Modelling, Equipment, Wastewater Treatment, Parameters, Process Model.

1. INTRODUCTION

For automatic synthesis and implementation of control systems for wastewater treatment processes, mathematical models play an important role. Complex non-linear models which represent biological, physicochemical and biochemical processes are commonly used to describe wastewater treatment processes. Before modelling a wastewater treatment plant, it is necessary to estimate the rate of pollutant degradation.

The paper is organized as follows. First a mathematical model, which describes the biodegradation kinetic of wastewater treatment, is presented. Then, we explain how to determine different kinetic parameters of the model and include the required information for the most important variables. Finally, how to validate this model is explained, followed by the relevant conclusions.

The wastewater treatment plant where we carry out our study is located in Ajijic, Jalisco, Mexico. It is owned and operated by CEAS (from its name in Spanish "Comision Estatal de Agua y Saneamiento"). This plant is intended to remove organic substrates, without removing nitrogen components.

2. PROCESS DESCRIPTION

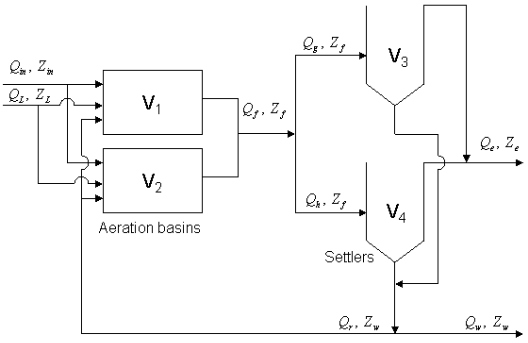

Fig. 1. Process Scheme

The Ajijic plant scheme is displayed in Fig. 1. It corresponds to a common activated sludge processes (Orhon and Arton, 1994). The main components are two aeration basins and two settlers. Due to the process configuration, it is only required to model the bioreactors; settler modelling is omitted because the sludge is recycled to the bioreactors and/or to another aerobic process; hence, sludge layers are not accumulated at the bottom of the settlers.

The organic matter biodegradation takes place inside the bioreactor. Q_{in} and Z_{in} are the influent flow rate and concentrations; Q_L and Z_L are the lixivium flow rate and concentrations; Q_f and Z_f are the bioreactor output flow rate and concentrations; Q_e and Z_e are the effluent flow rate and concentrations; Q_w and Z_w are the wastage flow rate and concentrations and Q_r is the recycled flow rate.

3. PROCESS MODELLING

The model for this process may consider 13 variables (Henze, *et al*, 1987*a*). We suppose that the process is the simplest biological wastewater treatment; it involves three components: biodegradable substrates, heterotrophic biomass and dissolved oxygen (Olsson and Newell, 1999; Bastin and Dochain, 1990).

In order to develop this model, mass balances are established for each bioreactor. The heterotrophic biomass mass balance can be expressed as:

$$\frac{dX_{BH,j}}{dt} = \frac{1}{V_j}\left(\frac{Q_r}{2}X_r - \frac{Q_f}{2}X_{BH,j}\right) + r_H \qquad (1)$$

where X_{BH} is the biomass concentration, X_r is the recycled biomass concentration, V is the volume, j is bioreactor number and r_H is the reaction rate for biomass growth. The influent and lixivium microorganism concentration are neglected. The biodegradable substrates balance is defined as:

$$\frac{d\left(S_{S,j}\right)}{dt} = \frac{1}{V_j}\left(\frac{Q_{in}}{2}S_{S,in} + \frac{Q_L}{2}S_{S,L} + \frac{Q_r}{2}S_{S,r} - \frac{Q_f}{2}S_{S,j}\right) + r_S \qquad (2)$$

where S_S is the biodegradable substrate concentration, $S_{S,r}$ is the recycled substrate concentration, $S_{S,L}$ is the lixivium substrate concentration and r_S is the substrate uptake rate. The oxygen mass balance is formulated as:

$$\frac{d\left(S_{O,j}\right)}{dt} = kla\left(S_{O,sat} - S_{O,j}\right) + r_O - \frac{1}{V_j}\left(\frac{Q_f}{2}S_{O,j}\right) \qquad (3)$$

where S_O is the dissolved oxygen concentration, $S_{O,sat}$ is the saturated dissolved oxygen concentration, r_O is the oxygen consumption rate and the *kla* term is the mass transfer from the aeration. The influent, recycled and lixivium oxygen concentration are neglected.

In order to end the model formulation, it is required to add the reaction rates.

The reaction rate for biomass growth can be expressed as:

$$r_H = \hat{\mu}_H\left(\frac{S_S}{K_S + S_S}\right)\left(\frac{S_O}{K_{OH} + S_O}\right)X_{BH} \qquad (4)$$

where $\hat{\mu}_H$ is the maximum heterotrophic biomass growth rate, K_S is the half-velocity coefficient for biodegradable substrate and K_{OH} is the half-velocity coefficient for dissolved oxygen concentration.

The substrate reaction rate is defined as:

$$r_S = -\frac{1}{Y_H}\left(\frac{S_S}{K_S + S_S}\right)\left(\frac{S_O}{K_{OH} + S_O}\right)\hat{\mu}_H X_{BH} \qquad (5)$$

where Y_H is the heterotrophic yield coefficient.

The oxygen consumption rate is expressed as:

$$r_O = \frac{Y_H - 1}{Y_H}\left(\frac{S_S}{K_S + S_S}\right)\left(\frac{S_O}{K_{OH} + S_O}\right)\hat{\mu}_H X_{BH} \qquad (6)$$

The heterotrophic biomass mass balance for settlers can be expressed as:

$$\frac{d\left(X_{r,k}\right)}{dt} = \frac{1}{V_k}\left(\frac{Q_f}{2}X_{BH} - \frac{Q_r + Q_w}{2}X_{r,k}\right) \qquad (7)$$

where Q_w is the waste flow rate and k is the settler number. It is assumed that effluent does not contain any biomass.

Equations (1) to (7) define the mathematical model of the process.

4. PARAMETER DETERMINATION

In order to validate the proposed process model, it is necessary to determine the kinetic coefficients: *kla*, $\hat{\mu}_m$, K_S, Y_H and K_{OH}. The methodology is as follows.

4.1 Determination of aeration constant (kla)

Taguchi and Humphrey (1966) propose a method to calculate *kla* and XQ_{O2} for batch or continuous bioreactors. This method is explained for continuous process as follows:

- First step, the continuous process inlets are closed and the blower motor is operated at maximum capacity. The mixture of biomass and influent wastewater in the bioreactor is defined as mixed liquor. The mixed liquor oxygen concentration is measured and registered until it is impossible to increase the oxygen concentration (mixed liquor is saturated). The mixed liquor oxygen concentration is shown in Fig. 2.
- Second step, the blower motor is turned off and the oxygen concentration decrease due

to oxygen consumed by biomass. In this step, the dissolved oxygen concentration must not diminish below 0.5 mg/L.

- Third step, going back to the first step. It is advised to repeat this procedure at least twice.

The oxygen concentration dynamics can be written as:

$$\frac{dS_O}{dt} = kla\left(S_{O,sat} - S_O\right) - XQ_{O2} \qquad (8)$$

where XQ_{O2} is the oxygen consumption rate by biomass.

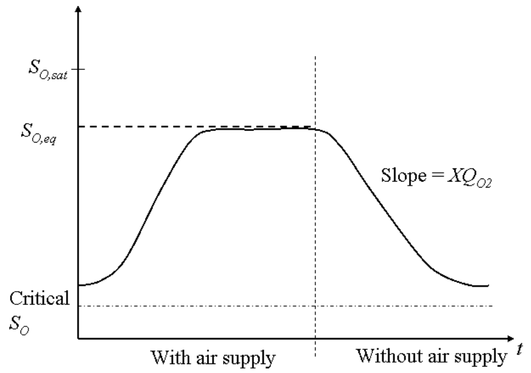

Fig. 2 Dissolved Oxygen Time Evolution

For saturation concentration, the dissolved oxygen fulfills the following relation:

$$\frac{dS_O}{dt} = 0 \Rightarrow 0 = kla\left(S_{O,sat} - S_{O,eq}\right) - XQ_{O2} \qquad (9)$$

where $S_{O,eq}$ is the equilibrium dissolved oxygen concentration of mixed liquor.

For the second step, the dissolved oxygen concentration evolution is described as:

$$\frac{dS_O}{dt} = -XQ_{O2} \qquad (10)$$

For the first step (oxygen transfer), the oxygen concentration dynamic is expressed as:

$$\frac{dS_O}{dt} = kla\left(S_{O,sat} - S_O\right) - XQ_{O2} \qquad (11)$$

Subtracting equation (9) from (11), we obtain:

$$\frac{dS_O}{dt} = kla\left(S_{eq} - S_O\right) \qquad (12)$$

To determine *kla*, equation (12) is integrated, with respect to time, to obtain:

$$\ln\frac{(S_{O,eq} - S_O)}{\left(S_{O,eq} - S_{O,0}\right)} = -kla * t \qquad (13)$$

where $S_{O,0}$ is the oxygen concentration of the aeration restart (going from the second step to the first one).

Experimental Procedure at The Treatment Plant. To carry out the tests to determine *kla*, the following equipments are required: a dissolved oxygen sensor and transmitter, and a digital register.

We proceeded as follows:

1. The influent, lixivium and recycle inlets, at the bioreactor, are closed and the blower motor is turned on. The oxygen concentration is increased up to saturation ($S_{O,eq}$).
2. When the mixed liquor is saturated, the blower motor is turned off. Oxygen concentration decreased; then, we select a value above the critical dissolved oxygen concentration.
3. When the selected oxygen concentration is 3.2 mg/L, the blower motor is turned on and we repeat the process.

Finally, we obtain a graph as shown in Fig. 2. The dissolved oxygen concentration information is used to calculate XQ_{O2} and *kla*.

Experimental XQ_{O2} and kla Calculations. For the second step, the dissolved oxygen concentration is traced to obtain the graph of Fig. 3. Employing lineal regression, the oxygen consumption slope is calculated as:

$$y = -0.06345x + 6.0245 \qquad (14)$$

where XQ_{O2} is determined as the slope of (14). The obtained experimental value is equal to 0.06345 mg/L-min.

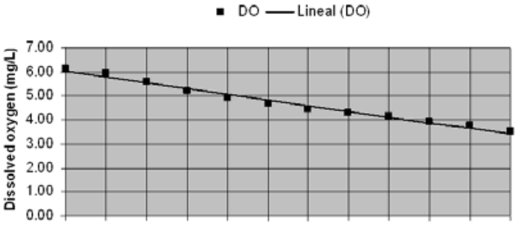

Fig. 3 Dissolved Oxygen Time Evolution

For the first step, an exponential curve is obtained as shown in Fig. 4. It is observed that the maximum oxygen concentration is 6.10 mg/L and $S_{O,0}$ is equal to 3.2 mg/L.

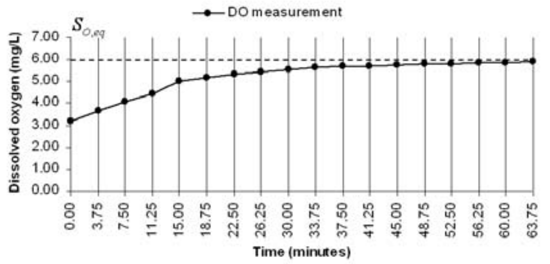

Fig. 4 DO Measurement

To calculate *kla*, the DO measurements are substituted in equation (13) in order to trace the graph shown in Fig. 5. Using lineal regression, the following equation is deduced:

$$y = -0.04111x - 0.22165 \qquad (15)$$

where *kla* is determined as the slope of (15). The obtained experimental value is equal to 0.04111/ min or 59.2 /day.

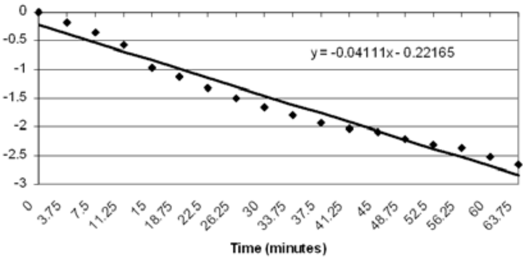

Fig. 5 *kla* Coefficient

4.2 Determination of Kinetic Coefficients

The kinetic coefficients for the removal of carbonaceous material by heterotrophics bacteria are given by the default values recommend for the IAWPRC ASM1 model (Henze et al., 1987*a*). Typical values are shown in Table 1.

Table 1 Activated-sludge kinetic coefficients for heterotrophic bacteria at 20ºC

Coeff.	Unit	Range	Value
$\hat{\mu}_m$	g VSS/g VSS*d	3.0 - 13.2	6.0
K_S	g bCOD/m^3	5.0 - 40.0	20.0
Y_H	g VSS/g bCOD	0.30 - 0.50	0.40
K_{OH}	mg/L	0.10	0.10
θ values			
$\hat{\mu}_m$	Unitless	1.03 - 1.08	1.07
K_S	Unitless	1.00	1.00

Temperature affects the metabolic activities of the microbial population as well as the gas-transfer rates and the settling characteristics of the biological solids. The effect of temperature on the reaction rate of a biological treatment process is expressed as:

$$k_T = k_{20}\theta^{(T-20)} \qquad (16)$$

where k_T is the kinetic coefficient at temperature *T*, k_{20} is kinetic coefficient value at 20ºC, θ is the temperature activity coefficient and *T* is the bioreactor temperature. Only maximum specific growth rate ($\hat{\mu}_m$) and the half-velocity coefficient (K_S) will be calculate, below.

The Ajijic plant operation bioreactor temperature is equal to 26ºC. Using the values of Table 1 and equation (16), we can calculate $\hat{\mu}_m$, taking K_{20} equal to 6.00 and θ equal to 1.07; then $\hat{\mu}_m$ = 9.00 g VSS/g VSS*d. To calculate K_S, K_{20} is taking equal to 20.00 and θ equal to 1.00; then K_S = 20.0 g bCOD/m^3.

5. REQUIRED INFORMATION

It is necessary to characterize the plant influent and effluent in order to validate the proposed model. The following measurements are required.

Dissolved Oxygen. This measurement has to be performed continuously.

Flow. The influent, lixivium, recycled and effluent flow are continuously measured.

Chemical Oxygen Demand (COD). The COD measurements are necessary for the influent, lixivium, recycled and effluent; two hours samples for a day will be taken. Fig 6 portrays a typical COD hourly time evolution.

Volatile Solids Suspended (VSS). The VSS measurements are necessary to perform for the influent, bioreactor and effluent; two hours samples for a day will be taken.

To this end, we are performing these measurements.

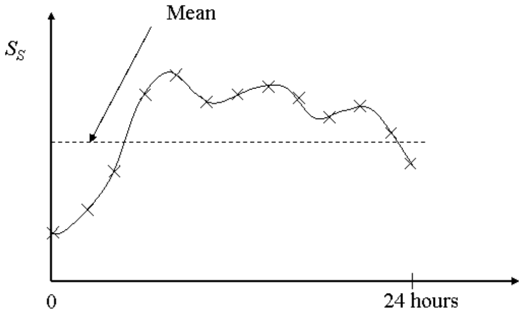

Fig. 6 Typical COD Hourly Variations

7. CONCLUSIONS

This paper has discussed the main steps for modelling and the parameter determination of an activated sludge wastewater treatment plant. It will help to implement the automation of this plant.

Acknowledgement – The authors thank the support of the Mexican State of Jalisco through COECYTJAL (Jalisco State Council for Scientific and Technological Researchs) and CEAS (Jalisco State Council for Water Treatment). They also thank the support of CNRS, France and CONACYT, Mexico and through the French Mexican research Initiative on Automatic Control (LAFMAA).

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