RESPIRATION RATE ESTIMATION FOR MODEL PREDICTIVE CONTROL OF DISSOLVED OXYGEN IN WASTEWATER TREATMENT PLANT

T. Suchodolski [*] **M.A. Brdys** [*] [**] **R. Piotrowski** [*]

[*] *Department of Automatic Control, Gdansk University of Technology, ul. G. Narutowicza 11/12, 80 952 Gdansk, Poland, email: suchy@attu.pl, r.piotrowski@ely.pg.gda.pl*

[**] *Department of Electronic, Electrical and Computer Engineering, The University of Birmingham, Birmingham B15 2TT, UK, email:m.brdys@bham.ac.uk*

Abstract: Respiration rate is very important parameter for biological processes in wastewater treatment plant (*WWTP*). The sequential algorithm for estimate the respiration rate is proposed and investigated. The Kalman filter (*KF*) is used. Simulation tests for the benchmark *WWTP* are presented.

Keywords: air, biotechnology, dynamic systems, estimation algorithms, estimation parameters, Kalman filters, modelling, waste treatment.

1. INTRODUCTION

The aeration systems at *WWTP* are very complex, nonlinear, hybrid, time-varying and multivariable where interactions between the components are strong. Aeration is important and very expensive activity. Its role is twofold. Firstly, oxygen is provided as a main component for biological processes. Secondly, it supports mixing sludge with the sewage what helps to treat the sewage.

Design of a controller utilizing airflow into the aerobic zone as a manipulated variable to achieve the prescribed dissolved oxygen (*DO*) level was a subject of the numerous papers (e.g., Olsson and Newell, 1999; Brdys and Diaz-Maiquez, 2002; Sanchez and Katebi, 2003; Piotrowski, *et. al.*, 2004; Chotkowski, *et. al.*, 2005; Piotrowski and Brdys, 2005).

The previous papers (Brdys, *et. al.*, 2002; Piotrowski and Brdys, 2005) propose a two level controller to track prescribed dissolved oxygen trajectory. The upper level control unit prescribes trajectories of desired airflows to be delivered into the aerobic biological reactor zones. The lower level controller forces the aeration system to follow these set point trajectories. A nonlinear model predictive control algorithm is applied to design this controller unit. Also, the predictive control is used to design the lower level control unit based on a linearised hybrid dynamics of the aeration process. The *DO* model is utilized for control purposes at upper level control. The discrete form of this model can be presented as follows:

$$\frac{S_o(k_u+i)-S_o(k_u+i-1)}{T_u}=K_La\left(Q_{air}(k_u+i-1)\right)\cdot \\ \cdot\left(S_{o,sat}-S_o(k_u+i-1)\right)-\frac{S_o(k_u+i-1)}{K_o+S_o(k_u+i-1)}\cdot R(k_u+i-1) \qquad (1)$$

where S_o, K_La, Q_{air}, R, $S_{o,sat}=8{,}63\,g/m^3$, $K_o=0{,}2\,g/m^3$ denote *DO* concentration, oxygen transfer function, airflow, respiration, dissolved oxygen saturation concentration and Monod's constant of *DO* limit, respectively.

In the sequel the third term in (1) is called the respiration rate and denoted as R_r.

The respiration rate is important parameter for biological processes in aerobic zones. The respiration rate is time varying, depends on the biomass concentration and describes the oxygen consumption by the microorganism. This value can be measured by a respirometers (Lukasse, 1999; Petersen, 2001).

Dedicated measurement device is very expensive and the on-line measurements of this variable is not often used. Hence, there is necessary to estimate respiration for control purposes (Lindberg, 1997). Approaches presented by Chotkowski *et al.* (2005), Piotrowski and Brdys (2005) based on the point estimation of respiration at appropriate time instant valid on the sufficient length prediction horizon as constant (utilizes fact that *DO* dynamics is much quicker than respiration dynamics).

In this paper new approaches for estimating the respiration rate is presented. The *KF* is used to estimate the respiration rate. This approach utilizes measurements of *DO* and airflow.

The paper is organised as follows. The respiration rate black-box models are described and validated in section 2. The random walk, filtered random walk and integrated random walk models are considered. The sequential algorithm for respiration rate and filter pole *f* estimation is presented in section 3. Two version algorithms are used: Recursive Least Squares (*RLS*) and Projection Algorithm (*PA*). The simulation results for the benchmark of *WWTP* system using activated sludge model No. 2d (*ASM2d*) of the biological reactor are presented in section 4. The simulations were performed for two typical influent scenarios: soft scenario and scenario with hard disturbances. Section 5 concludes the paper.

2. RESPIRATION RATE – BLACK-BOX MODELS

The respiration rate is not investigated in details and it is a subject of current intensive research. Therefore there is difficult how to choose appropriate model for control purposes that would describe, as precise as it is possible, present knowledge about respiration process with respect to sensible complexity and dimensions.

The respiration rate can be calculated from *ASM2d* model (Henze *et al*., 1999) but there are still eighteen nonlinear differential equations in the *ASM2d* model needed to determine $R_r(t)$, knowing the control input $Q_{air}(t)$, inflow $Q_{in}(t)$ and sophisticated information concerning parameters of the wastewater inflow into the zone. It means that the state-space model of the *DO* concentration is described by a nonlinear dynamics of very high order. Moreover, with phosphorus reactions taken into account, the *ASM2d* model involves more than sixty parameters to be calibrated. Most of these parameters cannot be identified. Hence, the control problem is also under heavy uncertainty and hence adaptive or robust control technology is needed in order to handle these. Because of *ASM2d* model complexity respiration rate is treated as an external signal.

The respiration rate may be treated as a completely unknown process with random rate. Thus respiration rate can be modelled as black-box model. The discrete models of type random walk have good properties for this problem. Previous investigations showed in (Lindberg, 1997) that models of type random walk might be used to respiration rate modelling. Three approaches for modelling the respiration rate were investigated.

The first candidate for respiration rate model was random walk model. The simulation result have showed that this model doesn't guarantee white noise, necessary for *KF*. Additionally, high values of modelling error characterized that model. Hence, that model was not sufficient for control purposes described in the paper.

The second candidate for respiration rate model was filtered random walk model. This model is given by:

$$\tilde{R}_r(t) = \frac{1}{\left(1 - f \cdot q^{-1}\right)\cdot\left(1 - q^{-1}\right)} \cdot e_{rwm}(t) \qquad (2)$$

where $e_{rwm}(t)$, f are zero mean white noise and model pole, respectively.

Parameter *f* can be taken from set [0,1]. The special case the random walk model is obtained by setting $f = 0$ and as another special case the integrated random walk model is obtained by setting $f = 1$.

Model (2) can be rewritten as:

$$\tilde{R}_r(t) = (1+f)\cdot \tilde{R}_r(t-1) - f\cdot \tilde{R}_r(t-2) + e_{rwm}(t) \qquad (3)$$

Model (3) is used for validation purposes. Variance of additive white noise became set as $var_{e_{rwm}} = 0{,}1$. Parameter f became set as $f = 0{,}97$ (Lindberg, 1997). Validation results of model are shown in Figs. 1-2 (sampling time = 5 minutes).

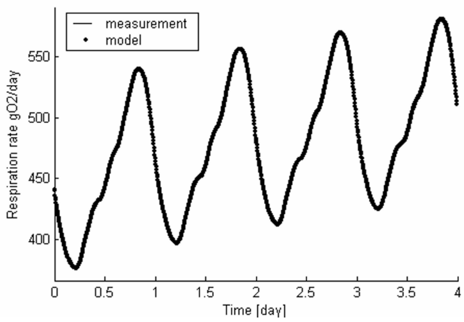

Fig. 1. Respiration rate trajectories: from measurements and from model for filtered random walk model.

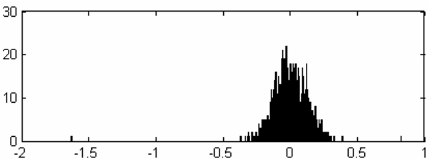

Fig. 2. Histogram of model errors for filtered walk model.

The error values are very small (average error = 0,0010, variance of error = 0,0176). Modelling errors are almost identical with white noise – average values near zero, histograms of errors are similar to