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FUZZY CONTROL OF DISSOLVED OXYGEN AND
ON-LINE OUR ESTIMATION IN A SBR PILOT PLANT

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Abstract
This work is focused on controlling the Dissolved Oxygen and obtaining an on-line software sensor for estimating the OUR parameter in a SBR pilot plant fed with real wastewater. This work presents two different implementations of Dissolved Oxygen control and software sensor. On the one hand, an ON/OFF control allows the OUR estimation by applying the respirometry method, on the other hand, fuzzy control allows the OUR estimation using the mass transfer oxygen model. The results of using both methods are shown and compared.

Keywords
Sequencing Batch Reactor (SBR); Fuzzy Control; Oxygen Uptake Rate (OUR); software sensor

INTRODUCTION
Sequencing Batch Reactors (SBR) works by operational cycles divided in stages. Basic stages for a SBR are: feeding, anoxic reaction, aerobic reaction, sedimentation and extraction. This contribution is focused on the operation conditions during aerobic stages, when it is necessary to provide external air flow and control the Dissolved Oxygen (DO) concentration inside the reactor.

The aim of this work is, first, to improve DO control in a SBR plant, and second, to obtain a software sensor in order to calculate OUR estimations in aerobic stages. The method used for OUR calculation depends on the way of controlling DO in the reactor. DO concentration inside the reactor, influences in the growth of the micro organisms and in the floe formation in the sludge combined with the influence of mixing action. By this, it is necessary to maintain a balance between the energy saving during the aeration and the biological needs for the reactions that happen in the reactor. So, it is necessary maintain the DO concentration in a set point value with a feedback controller (Olsson and Newell, 1999). On an ON/OFF DO control, is possible to apply the method of respirometry for obtaining OUR estimations (Spanjers et al., 1998; Johansen et al., 1997). Also, OUR estimations can be obtained using the DO mass transference model inside the reactor if DO control allows keeping DO concentration constant in a set point. So, a good DO control allows a better OUR estimation.

As the process is non-linear and time variant, a good DO control can be achieved by applying fuzzy logic. Fuzzy control is used in Wastewater Treatment Plants for controlling the biological reactions because these are time-varying, ill-defined and non-linear processes (Chen et al., 2001) (Tsai et al., 1994) (Müller et al., 1997). Fuzzy controllers can be constructed using only on-line measurement sensors (Fiter et al., 2004) or model simulations (Esteben et al., 1997; Traore et al., 2003). In SBR, the process fuzzy controllers are used for controlling the length cycle and for detecting endpoints reactions in the monitored profiles. The fuzzy techniques in SBR processes has been applied alone (Peng et al., 2002; Peng et al., 2003) or in the combination of Neural Nets techniques (Cohen et al., 2003). They use on-line measurement sensors and historic quality analytical values from effluents.
Software sensors calculate the variables that can not be obtained with an instrumentation sensor. In Wastewater Treatment Systems these are applied for obtaining predictions about process behaviour and for improving the applied control strategies. Software sensors have been obtained using mass balance models for the dynamical behaviour of wastewater process (Bernard et al., 2001) or using the measured values from real instrumentation and other off-line data saved in monitoring (Onnerth et al., 1996).

In the next sections, the SBR pilot plant is outlined. Then the applied On/Off and fuzzy DO controllers and the related software sensors are shown. Finally, the DO and OUR profiles obtained in aerobic stages of several cycles are depicted and conclusions are related.

**SBR PILOT PLANT**

The used SBR pilot plant is fed with the same wastewater of a real WWTP (Puig et al., 2004) but working independently. This fact supposes an important disturbance for controlling the Dissolved Oxygen in the reactor, because the influent wastewater composition varies throughout the time and it affects the reaction time in the biological reactions.

![Figure 1. SBR Pilot Plant, scheme and picture.](image)

In Figure 1 a picture of the pilot plant and a scheme of the equipment are shown. The measured signals in the SBR pilot plant are pH, ORP, DO and Temperature. In this work, only DO signal is necessary for building the fuzzy controller and for obtaining OUR software sensor. The air flow is got with an air compressor, it is an aluminium pipe of 20 millimetres of diameter and four diffusers located at the bottom of the reactor. Air flow is a switch on or off inside the reactor with a valve that does not allow the regulation of air flow automatically by the monitoring program. For applying the fuzzy controller the compressor was changed for one which allows regulating the air flow, also a mass flow meter was introduced in the pipe for measuring the incoming air in the reactor. The plant is also equipped with an acquisition card PCI-6025E from National Instruments® and a computer where the control and supervision programs run. They have been developed in LabView® software from National Instruments. In this work, the fuzzy control library for LabView® is used. The cycle applied in the plant (Vives et al., 2001) has a fixed length of eight hours, it is showed in Figure 2. It consists of six groups (steps) of feeding, aerobic and anoxic stages (step-feed strategy). The cycle has also sedimentation and extraction stages. The step-feed strategy affects the way of building the fuzzy controller because the volume of water inside the reactor increases in every stage.
DO CONTROL
During aerobic stages is necessary to provide an external air flow inside the reactor and DO control concentration with the aim of achieving the biological reactions that happen in this stage. The control objective is to provide air flow enough for achieving DO set point which is fixed in 2 mg/l. The applied DO feedback control technique depends on available aeration instrumentation characteristics: sensors (air flow mass meter) and actuators (air compressor and valves). They had been changed for adapting the control method. During a period of one year an on/off controller was applied in aerobic stages because available actuators were an on/off valve and an air compressor that provided a fixed air flow.

Feedback ON/OFF controller function consists in switching on or off actuators depending on a condition. An ON/OFF controller is very simple, but the most important disadvantage is the cycling behaviour of the controlled variable. When DO concentration is higher than the set point the monitoring program switch OFF the valve and when DO concentration is lower than the set point the monitoring program switch ON the valve. In this case the air flow is fixed. The DO profile obtained with this type of control is shown in Figure 5. The DO concentration has a cycling behaviour during aerobic stages. The DO oscillations do not allow obtaining a continuous value of OUR as is described in next section and, so, on/off control force to calculate OUR in a specific way.

In order to allow the implementation of better control strategies, the compressor was improved in a way that the air flow could be regulated using a frequency inverter. Then, the non linearity of biological reactions (Olsson and Newell, 1999), the operational working points of the actuators and the various composition and volume of wastewater in the reactor, did not allow to use classical linear controllers. Then, a fuzzy logic controller was implemented. The structure given for the fuzzy controller is shown in Figure 3.

The DO error (eDO) and the DO variation (dDO) are the inputs and the compressor voltage (VP) is the output. The eDO is obtained by comparing the measure of DO with the setpoint (SP). A FIR (Finite Impulse Response, Colomer and Meléndez, 2001) filter is used to obtain dDO. The operating cycle of the plant consists of six groups of feeding, aerobic and anoxic stages (step-feed strategy) in a way that there is a feeding stage before each aerobic stage. It means that the volume of wastewater in the reactor depends on the number stage. For this reason six fuzzy controls have been synthesized. In the schema of Figure 3, the variable “stage” that is provided by the supervision system allows us to determine what fuzzy controller to execute. That is, IF stage = “aerobic3” THEN run FuzzyController3.
Three fuzzy sets have been chosen for the eDO and dDO input variables: Negative (NE), Zero (ZE) and Positive (PS) whereas five fuzzy sets are used for the control signal sQa: V0, V1, V2, V3, V4, and V5 (Figure 4). The number of fuzzy sets for the control signal sQa is the same for the six fuzzy controls, only change the parameters of each fuzzy set which depend of the volume of wastewater in the reactor. Then, nine inference rules (Table 1) are used to evaluate the output with Mamdani Max-Min fuzzy inference method. Finally Centre of Gravity method is used to calculate sQa.

![Figure 4. Fuzzy set for the 3rd aerobic stage](image)

<table>
<thead>
<tr>
<th>eDO</th>
<th>NE</th>
<th>ZE</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>dDO</td>
<td>V2</td>
<td>V0</td>
<td>V0</td>
</tr>
<tr>
<td>ZE</td>
<td>V4</td>
<td>V3</td>
<td>V2</td>
</tr>
<tr>
<td>PS</td>
<td>V6</td>
<td>V5</td>
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Table 1. Inference rules

**OUR softsensors**

Oxygen uptake rate (OUR) is the parameter that indicates the DO consumption velocity for microorganisms and indicates the biological activity during aerobic stages. OUR parameter can be estimated on-line using the measurements of DO and air flow provided in the reactor. The on-line OUR calculation can be used for the optimisation of the SBR process with the aim of reducing energy consumption produced by the aeration energy and increasing the plant capacity by reducing the time needed for the treatment (Johansen et al., 1997). In next sections two different ways for OUR calculation are described. Both methods are implemented in the monitoring program as software sensor. DO measurements are necessary for both calculations.

**Based on Respirometry method**

The most used method for on-line estimation of OUR is the respirometry. The respirometry is the measurement and interpretation of the respiration rate of activated sludge reaction which is defined as the amount of oxygen per unit of volume and time that is consumed by the microorganisms in the activated sludge. Respiration rate reflects the biomass growth and their consumption. (Spanjers et al., 1998) reports about respirometry techniques applied in wastewater treatment and how the respiration rate measurement must be interpreted in relation with the characteristics of sludge and microorganisms. A respirometer is a reactor where DO is measured using a sensor and external air can be apportioned in the reactor. In a simple respirometer the external aeration is controlled with an ON/OFF control with a DO concentration set point. Calculation of OUR is based on the DO mass balance in the reactor when aeration is OFF (eq. 1).

\[
d\text{DO}/dt = -\text{OUR} \quad \text{ (eq.1) When the aeration is OFF.}
\]
If only aerobic stages are considered in a SBR with an ON/OFF control of DO, it can be used as a respirometer (Corominas et al., 2004). So, the respirometry method is the most applied in Sequencing Batch Reactors (Johansen et al., 1997; Vanrolleghem et al., 2003). According with the expression (eq.1) it is possible to have a measure of OUR each time the valve was closed by acquiring DO values over time and adjusting them to a linear regression obtaining the slope of the curve. The inconvenient of this method is that OUR values are not continuous in time. Only when aeration is off a new value is achieved and it is valid until next OFF cycle.

**Based on the mass balance of oxygen transfer**

The continuous mass balance model of oxygen transfer is represented by (eq.2, and 4). They can be used for a continuous on-line OUR estimation during aerobic stage. But it is necessary to measure the air flow rate and only can be used if a continuous DO control avoids abrupt changes in this variable. The previous described fuzzy controller satisfies this conditions.

\[
\frac{d\text{DO}}{dt} = \text{Kla} * (\text{DO}_{\text{sat}} - \text{DO}) - \text{OUR} \quad \text{eq.2}
\]

\[
\text{Kla} = \text{Ka} * \text{qa} \quad \text{eq. 3}
\]

\[
\text{Ka} = \alpha \eta \frac{\text{FractionO}_2}{\text{V DO}_{\text{sat}}} \quad \text{eq. 4}
\]

The term \(\text{Kla} * (\text{DO}_{\text{sat}} - \text{DO})\) represents the transfer of oxygen from the air into the water so that can be utilised by the biomass. DO is the measurement of Dissolved Oxygen in the reactor. \(\frac{d\text{DO}}{dt}\) is calculated using a FIR filter (Colomer and Meléndez, 2001). \(\text{DO}_{\text{sat}}\) is the saturated oxygen in the reactor, and \(\text{Kla}\) is the oxygen transfer coefficient that can be written as a function of the air flow rate \(\text{qa}\) measured by the flow mass sensor. It has to be remarked that DO and qa are filtered in a way that the delay in all the measured variables is the same and no missalignments are produced. \(\text{Ka}\) is a constant which must be determined for a particular installation at a particular operating point. It represents the relation between the area and tank volume for an open tank without aeration devices. \( \alpha \) is calculated with the expression (eq.4) where \( \alpha = \frac{\text{K}_{\text{a}}(\text{wastewater})}{\text{K}_{\text{a}}(\text{tapwater})} \), the oxygen transfer rate is different for wastewater than for clean water. \( \eta \) is the standard efficiency, 0.07. \( \text{FractionO}_2 = 0.21 \) is the oxygen partial pressure, and \( \text{V} \) is the volume of sludge in the reactor. This volume increases in every feed stage and it has a diluted effect. \( \text{Kla} \) can also be empirically found as in (Chatellier and Audic, 2001).

**RESULTS AND CONCLUSIONS**

![Graphs](image)

*Figure 5. DO and OUR profiles obtained with ON/OFF controller.*

a) The profile is showed for a cycle. b) A detail for the third aerobic stage in the same cycle of a).
ON/OFF Control

Figure 5 shows DO and OUR profiles obtained with ON/OFF control during a cycle and, in a more detailed way, for an aerobic stage of this cycle. In this case, DO profile has oscillations around 2 mg/l to the set point, with maximum values greater than 4 mg/l and minimum values lower than 1.5 mg/l. The band amplitude around the set point is caused by the delay of the DO sensor and the own process equipment dynamics. It seems clear that this is not the best way of controlling DO. Nevertheless, OUR estimation is quite direct. As commented before it consists in calculate the decreasing slope by fitting DO measurements with a linear regression when aeration is OFF. The only inconvenient is that OUR profiles are not continuous throughout the time, since they can only be updated around two times per aerobic stage.

![Figure 6. DO and OUR profiles obtained with the fuzzy controller.](image)
a) The profile is showed for a cycle. b) A detail for the first aerobic stage in the same cycle of a).

Fuzzy control

Figure 6 shows DO and OUR profiles obtained with fuzzy control during a cycle and, in a more detailed way, for an aerobic stage of this cycle. In this case the DO profile is better than that obtained with the On/Off controller. Apart from an initial 25% maximum overshoot the DO is controlled around 2 mg/l with little oscillations in a band of 0.1 mg/l. This allows a better behaviour of the process. However, the OUR estimation is more difficult. The continuous mass balance model must be applied. OUR value is updated each sampling time with a delay caused by the FIR filters applied to qa and So measurements and in the dDO calculation (in this case 10 sampling periods). As conclusion, the fuzzy DO control allows a better DO behaviour and a continuous on-line OUR estimation. Figure 7 shows the on-line values of DO, its derivative (dDO), the air flow (qa), Kla and OUR obtained in a cycle. Figure 8 is a detail of these values in the first aerobic stage of the same cycle of Figure 7 where the delay introduced in filtered signals can be observed better.

The most important difficulty for obtaining the fuzzy controller was the disturbance that the variant wastewater composition introduces in the Dissolved Oxygen dynamics in the reactor, but it has been demonstrated that fuzzy logic allows achieving a robust controller for controlling Dissolved Oxygen in this SBR pilot plant conditions.
Figure 7. On-line values of DO, dDO/dt, filtered qa, Kla and OUR for a cycle.

Figure 8. On-line values of DO, dDO/dt, filtered qa, Kla and OUR for the first aerobic stage in the Figure 7 cycle. Delays introduced by filtered signals can be observed better.
References


Cell-Phone Maintenance

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Abstract

Cell-phones are devices. In this IT device to be used as an example of cell-phones information is available. Should an ace be efficiently delivered and resolved?

Keywords

Cellular phone

INTRODUCTION

Industrial plant systems, of skilled workers. Under with a smaller number of peak around year 2007, industrial plant systems. The anix

Networked IT systems have workers who can operate and IT systems used to assist facility information system accumulates des. The information service to the unskill (Acquisition) system allows and sewage plants that are able to better maintain a