

On-line Oxygen Uptake Rate as a new tool for monitoring and controlling the SBR process

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Abstract

This paper focuses on the on-line Oxygen Uptake Rate (OUR) as a new tool for identifying the state of the plant during the aerobic phases of the SBR cycle and as a control parameter to optimize the SBR process. A real-time control system has been designed to adjust the aerobic phases length using on-line OUR as the endpoint of the aerobic phase. The control system implementation has permitted the aerobic phase length reduction around 11% implying significant savings in management costs.

Keywords: On-line Oxygen Uptake Rate (OUR), Sequencing Batch Reactors (SBR), real-time control, wastewater.

1. Introduction

Wastewater treatment facilities can be designed to operate in continuous flow mode (i.e. the classical activated sludge process) or in a cyclic or sequenced batch mode such as the Sequencing Batch Reactor (SBR). One of the consequences of operating under batch conditions is the possibility to treat the wastewater using a separate cycle following a fill-react-draw basis (Irvine et al, 1979; Mace and Mata-Alvarez, 2002 and Vives, 2004). Biological treatment can be performed in SBR reactors under a combination of aerobic, anoxic and anaerobic conditions. Under these conditions, the on-going biological reactions during one cycle are conducted in an unsteady state from a high initial concentration of pollutants (mainly organic matter, nitrogen and phosphorous) to the final treated wastewater, which the pollutants concentrations have been reduced to the desired level. The aerobic biological reactions are responsible for the oxidation of ammonia to nitrite and nitrate (the nitrification process), as well as, the biological conversion of organic matter into carbon dioxide.

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To achieve the aerobic conditions, an injection of oxygen (i.e. compressed air) must be supplied in order to transfer and maintain the desired dissolved oxygen level in the biological reactor. The oxygen consumption in the liquid phase or the Oxygen Uptake Rate (OUR) could be a useful tool for knowing the state of the plant. In recent years, the OUR analysis has demonstrated that it is a useful off-line tool for wastewater or biomass characterization in terms of biodegradable fractions, biological nitrification tests or modelling purposes (Brouwer *et al*, 1998; Gutierrez, 2003; Spanjers and Vanrolleghem, 1998).

In this paper, an on-line OUR measurement has been developed and applied to a pilot plant SBR treating urban wastewater as new tool for indicating the state of the plant in real-time and as a control parameter to optimize the aerobic phases length of the SBR cycles.

2. Methods

2.1 Pilot Plant SBR and operational cycle

The 1 m³ Pilot Plant SBR was set up at the Cassà Wastewater Treatment Plant (Girona, N.E. Spain). The Pilot Plant treated 600 liters of influent wastewater per day. Figure 1 presents a schematic overview of the plant.

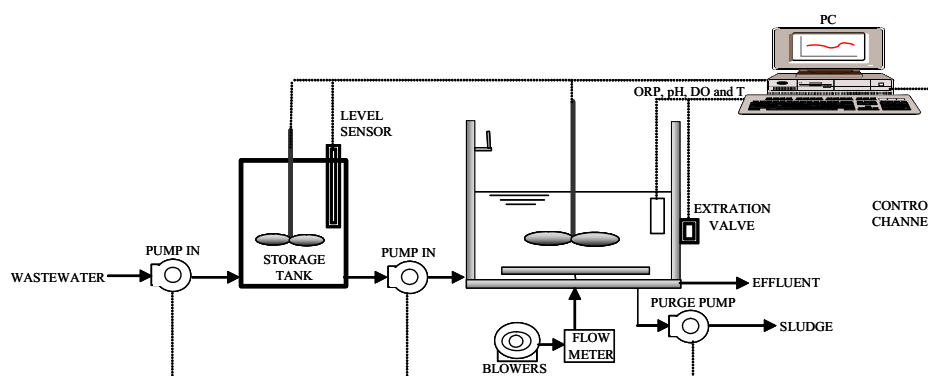


Figure 1. Schematic overview of the Pilot Plant SBR.

The Pilot Plant was equipped with a monitoring and control scheme consisting of interface cards (PCI-6025E and SC-2062 from National Instruments®). On-line monitoring of pH, Oxidation-Reduction Potential (ORP), Dissolved Oxygen (DO) and Temperature was achieved by data acquisition from Endress-Hausser® probes (CPF81, CPF82 and OXYMAX-W COS-41, respectively) and transmitters (CPM 223). The Pilot Plant was controlled by means of a data acquisition and control software developed using LabView® (Puig *et al.*, 2004). An eight hour SBR cycle, repeated continuously over time, was adapted from Vives (2004) and is presented in Figure 2 as a sequence of anoxic-aerobic phases and, a step-feed filling strategy to enhance nitrogen removal. Aerobic phases were controlled at 2.0 mg DO•L⁻¹ by means of an ON/OFF control strategy applied to the air injection flow.

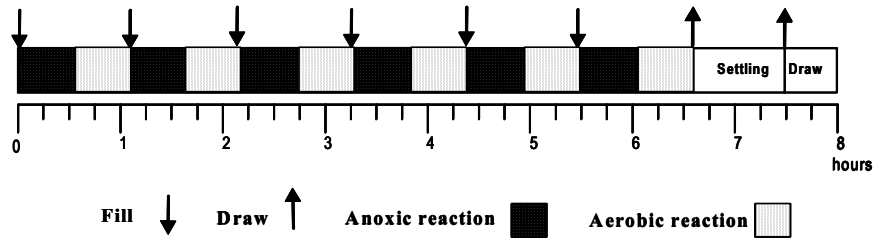


Figure 2. Operational periods of the SBR Pilot Plant with filling strategy..

2.2 On-line OUR calculation

During the aerobic phases of a cycle, when no influent wastewater is added to the SBR and assuming a complete mix reactor, a dissolved oxygen mass balance could be represented by equation 1.

$$OUR = K_{LA}(DO_{sat} - DO) - \frac{dDO}{dt} \quad (1)$$

where OUR is the calculated Oxygen Uptake Rate ($\text{mg} \cdot \text{L}^{-1} \cdot \text{h}^{-1}$), DO the dissolved oxygen in the SBR ($\text{mg} \cdot \text{L}^{-1}$); DO_{sat} the saturation or maximum dissolved oxygen as a function of temperature ($\text{mg} \cdot \text{L}^{-1}$); and, K_{LA} the oxygen mass transfer coefficient (h^{-1}) as a function of compressed air flow and air diffusers efficiency.

As stated above, the control applied to maintain the DO level is a simple ON/OFF air injection strategy that increases of DO during air ON periods and reduces of DO during air OFF periods after the set-point has been reached. Thus, according to equation 1, it was possible to measure the 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. It must be taken into account the dynamic of the sensor and so the first measurements (50 seconds) after deactivating the aeration system were not used. Next DO values were acquired until the valve was opened again, and finally the linear regression was obtained (Corominas et al., 2004).

3. Research Results

The Pilot Plant SBR was set up at Cassà Wastewater Treatment Plant, treating fresh wastewater from the sewers arriving at the facility. The Pilot Plant SBR operated with the 8-hour cycle for more than six months with a high organic matter and nitrogen removal efficiencies (Puig et al, 2004).

To improve the SBR's performance, a new tool based on on-line calculated OUR was implemented in order to know the state of the plant and to control the aerobic phases length of each cycle. Figure 3 presents the calculated OUR, according to equation 1, during a typical aerobic phase of a SBR cycle. In addition, on-line monitoring of the pH is shown in this figure. Different stages related to the biological reactions could be identified in the OUR evolution. In the first stage, the OUR values decrease, from 110 to $95 \text{ mg O}_2 \cdot \text{L}^{-1} \cdot \text{h}^{-1}$, for the degradation of rapidly biodegradable organic matter in the SBR. In the next stage, B, the calculated OUR values stabilize because of the oxidation of ammonia and the degradation of the biodegradable organic matter. After the 13th

minute, stage C, a huge decrease in the OUR values, around 50% of the initial OUR value, can be observed due to ammonia depletion. We call this OUR decrease α_{OUR} . (Puig et al., 2005). At the same time, a decrease and then increase tendency in the pH profile is observed. The resulting minimum pH point is called *Ammonia Valley*, and indicates, as well as α_{OUR} , the end of the nitrification process (Plisson-Saune et al., 1996). Finally, in the last stage the OUR decrease slowly, the tail shape, when the slowly biodegradable organic matter is removed until it stabilizes at the 24th minute when endogenous respiration is achieved. In this moment, the oxygen consumption is used only for biomass maintenance and the organic matter and ammonia are completely removed.

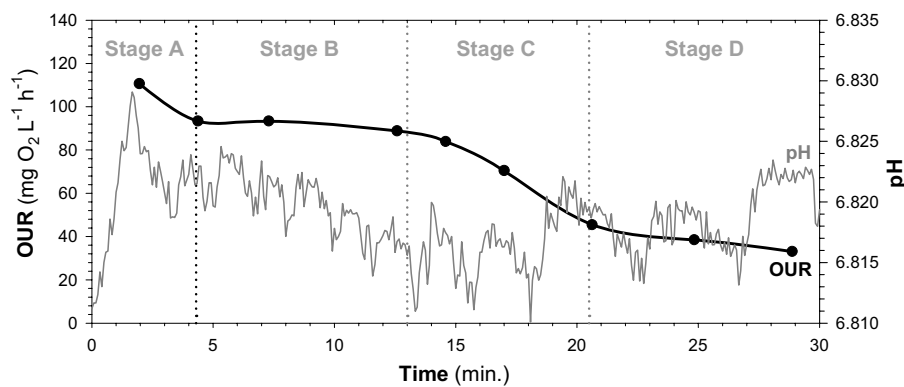


Figure 3. Identifying the state of the pilot plant SBR using the calculated OUR and on-line pH during a typical aerobic phase of the 8-hour cycle.

In order to design a real-time control system to optimize the aerobic phases length for ammonia and organic matter depletion, we analysed the on-line calculated OUR during the last aerobic phase of several SBR cycles with high nitrogen and carbon efficiencies (Figure 4). Until the 5th minute, which we define t_{MIN} , the OUR values increase due to the activation of microorganisms, which is caused by the changing conditions (from the anoxic to aerobic phase). This transient response of the activate sludge most likely from the sequence of intracellular reactions involved in substrate degradation by the activated sludge (Vanrolleghem et al., 2004). In the Figure 3 after the t_{MIN} and in the stage C there is a decrease in the calculated OUR values. Then, the OUR values stabilize to an OUR of 35 mg O₂·L⁻¹·h⁻¹ for any aerobic phase. For this reason, a minimum OUR value, called OUR_{MIN} , was defined which corresponds with the complete removal of ammonia and biodegradable organic matter.

From the OUR evolution analysis (Figure 4), we can see that the OUR_{MIN} is easily reached before the fixed time (T_{MAX}) of the aerobic phase. So that, it is possible to adjust the aerobic phase using the OUR_{MIN} as an endpoint for the aerobic phases. Normally, this optimization is based on the *Ammonia Valley* as a control parameter of the length of aerobic phases (Kishida et al., 2003; Yu et al., 2001), but because of its oscillations due to the ON/OFF oxygen control, the OUR_{MIN} value has been used as the control parameter of the aerobic phase.

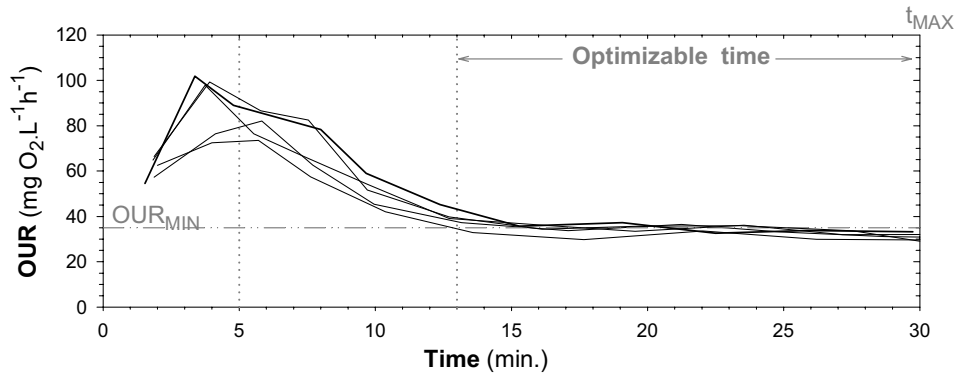


Figure 4. OUR profiles of the last aerobic phase of several cycles (Puig et al., 2005).

Figure 5 presents the real-time control strategy diagram for the aerobic phases for treating urban wastewater in the Pilot Plant SBR. First, the control system calculates the OUR value. Then, it waits a certain delay time (t_{MIN}) before starting to check the signal. It then compares the calculated OUR value with the OUR_{MIN} . If the value is lower than the OUR_{MIN} the endpoint will have been detected. Then, a safety time is applied (t_{WAIT}) before changing to the next phase. There is also a maximum time (t_{MAX}) for the phase, which is checked at each time interval once the t_{MIN} has been exceeded and which corresponds with the aerobic time in the 8-hours cycle.

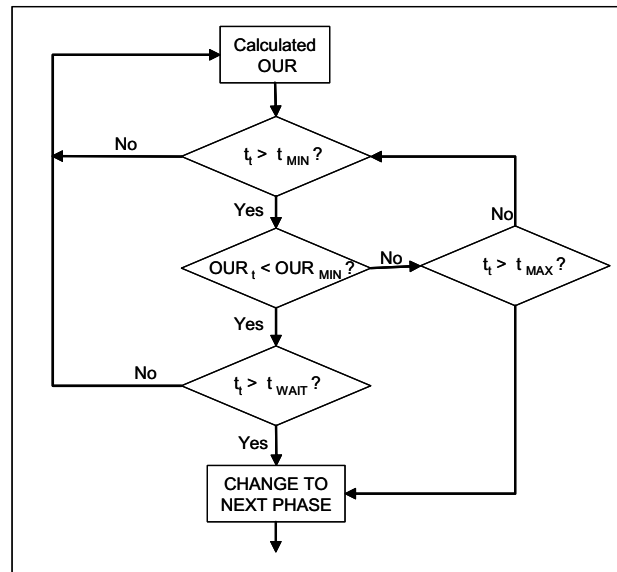


Figure 5. Real-time control strategy flow diagram in the aerobic phase.

On-line OUR control was applied in the Pilot Plant SBR during three months, treating urban wastewater. The control system acted in the aerobic phase using the OUR minimum value as a condition to adjust the aerobic time length and the effluent ammonia concentration. The ammonia and organic matter concentrations achieved, $1.6 \text{ mg}\cdot\text{L}^{-1} \text{ N-NH}_4^+$ and $51 \text{ mg}\cdot\text{L}^{-1} \text{ COD}$ on average, respectively, at the end of the SBR

cycle proved that the OUR minimum value was enough to achieve the complete ammonia (97%, on average) and organic matter removal (90 %, on average). These values were lower than the European Directive 91/271/CEE that regulates organic matter and nitrogen discharge into the rivers. Furthermore, the aerobic phase adjustment optimize the air supply and reduced management costs associated with aeration costs by around 11% on average.

4. Conclusions

In a predefined 8-hour cycle, the state of the plant during the aerobic phases of the SBR was identified by means of a simple on-line OUR calculation. OUR analysis of the aerobic phases allowed us to achieve an OUR minimum value (OUR_{MIN}) and, an initial aerobic activation time of the aerobic microorganisms (t_{MIN}). OUR_{MIN} and t_{MIN} are control parameters of the designed control algorithm that can optimise the aerobic phases of the SBR cycle. The final implementation during three months in the SBR proved to be useful for treating real urban wastewater with high organic matter and ammonia removal efficiencies. The aerobic phase were reduced by 11%, twenty minutes on average, is associated to a significant operational cost reduction.

References

- Brouwer H., A. Klapwijk and K.J. Keesman, 1998, *Wat. Res.* 32(4), 1240-1254.
- Corominas Ll., M. Rubio, S. Puig, J. Melendez, J. Colomer, M.D Balaguer and J. Colprim, 2004. Proceedings of 6th Specialist Conference on Small Water & Wastewater Systems.
- Gutierrez O., 2003, PhD. Thesis. Girona University. Spain (in Catalan).
- Irvine R.L. and A.W. Busch, 1979, *Journal WPCF* 51 (2), 235-243.
- Kishida N., J.H. Kim, M. Chem, H. Sasaki and R. Sudo, 2003, *J. Biosci. Bioeng.* 96 (3), 285-290.
- Mace S. and J.R. Mata-Alvarez, 2002, *Ind. Eng. Chem. Res.*, 41(23), 5539-5553.
- Plisson-Saune S., B. Capdeville, M. Mauret, A. Deguin and P. Baptiste, 1996, *Wat. Sci. & Tech.*, 33(1), 275-280.
- Puig S., M.T. Vives, Ll. Corominas, M.D. Balaguer and J. Colprim, 2004, *Wat. Sci. & Tech.* 50(10), 89-96.
- Puig S., Ll. Corominas, M.T. Vives, J. Colomer, M.D. Balaguer and J. Colprim, 2005, *Ind. Eng. Chem. Res.*, submitted.
- Spanjers H. and P.A. Vanrolleghem, 1995, *Wat. Sci. & Tech.* 31(2), 105-114.
- Vanrolleghem P.A., G. Sin and K.V. Gernaey, 2004, *Biotechnol. Bioeng.*, 88(3), 277-290.
- Vives, M.T., 2004, PhD. Thesis. Girona University. Spain.
- Yu, R..F., S.L. Liaw, B.C. Cho and S.J. Yang, 2001, *Wat. Sci. & Tech.*, 43(3), 107-114.

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