Treatment of winery wastewater in a sequencing batch biofilm reactor

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Abstract Pilot-scale experiments were carried out applying the SBBR process (Sequencing Batch Biofilm Reactor) for the treatment of winery wastewater. The aim was the evaluation of the SBBR performance and the development of a control strategy based on dissolved oxygen (DO) for the optimisation of the SBBR treatment cycle and the minimisation of the energy supply. The results of the experimentation have confirmed the applicability of the SBBR process pointing out high COD removal efficiencies between 86% and 99%, with applied loads up to 29 gCOD m⁻² d⁻¹, corresponding to 8.8 kgCOD m⁻³ d⁻¹. The on-line monitoring of DO concentration appeared as a good indicator of the progress in the COD biodegradation. The control strategy for the ending of the SBBR cycles was based on the time derivative of the DO concentration. The optimised control strategy makes it possible to obtain a steady quality of the effluent wastewater with an average daily applied load of 6.3 kgCOD m⁻³ d⁻¹ rather than 3.5 kgCOD m⁻³ d⁻¹ for the non-optimised SBBR cycle. The possibility of optimising the SBBR cycle through a simple control of the DO in the mixed liquor could be an interesting solution for the biological pre-treatment of winery wastewater to be discharged into sewerage or as a single-stage of a combined treatment plant for the discharge into surface water.

Keywords DO control; fixed biomass; Sequencing Batch Biofilm Reactor; winery wastewater

Introduction
Winery wastewater poses some difficulties in its treatment through biological options due to the high organic substance concentrations and the load fluctuations. The *Sequencing Batch Reactor* (SBR) has demonstrated in the last decades good potential in industrial wastewater biological treatment (*inter alia* Torrijos and Moletta, 1997). SBR systems applied to organic carbon removal offer various advantages including minimal space requirements and possibility of cycle modifications during the plant operation. The option of combining the advantages of both SBR technology and a fixed biomass system such as the MBBR (*Moving Bed Biofilm Reactor*) is even more interesting. In fact the MBBR system allows for the treatment of high organic loads, the reduction of the required volume for biological treatment and the possibility to avoid bulking problems (Rusten *et al.*, 1999). The resulting configuration, SBBR (*Sequencing Batch Biofilm Reactor*) corresponds to the management of a fixed biomass grown on plastic media by a sequencing cycle.

In this study, pilot-scale experiments were carried out applying the SBBR process to treat the wastewater generated in a winery factory in the province of Trento (Italy). The winery factory processes 28,000 tons of grapes per year and produces 25 millions of bottles per year. Owing to the high production capacity of the factory, the development of an adequate wastewater treatment option was required. This option should be capable of reducing area and volume of the treatment plant and guaranteeing high removal efficiency and energy cost minimisation. The experimentation lasted from September (coinciding with the vintage) to June, in order to follow the complete production cycle of the industry in a year. The aim was the evaluation of the SBBR performance and the development of a control strategy based on dissolved oxygen (DO) for the optimisation of the SBBR treatment cycle and the minimisation of the energy supply.
Materials and methods

Pilot plant configuration

The scheme of the SBBR pilot-plant is represented in Figure 1. The influent degritted wastewater was stored for a day in a storage tank and was pumped into the pilot plant with a maximum flow rate of up to 100 L h⁻¹. The reactor was made up of an aerated tank with a 40 L capacity and aerated with a fine bubble membrane with an air flow rate of 15 NL min⁻¹. The experimentation was carried out at a temperature of approximately 20°C, by arranging a temperature-controlled chamber around the reactor. Neutralisation of acidic pH (in particular for values below 6.5) was provided in the storage tank by sodium hydroxide addition.

The SBBR was filled with KMT carriers made of polyethylene, with a density of 0.96 g cm⁻³ and dimensions of approximately 7–10 mm (Rusten et al., 1999). The filling ratio of KMT plastic media was equal to 67% of the empty volume of the reactor (the specific growth surface was about 300 m² m⁻³). The plastic material filled almost 10% of the total volume of the reactor. Mixing was guaranteed by the air supply. KMT plastic media have been widely applied in the last decade for the treatment of both municipal and industrial wastewater. The literature, in particular, has made reference to this application for several kinds of industries, such as cheese factory (Rusten et al., 1996), poultry processing (Rusten et al., 1998) and paper mills (Broche-Due et al., 1997), but no application for winery wastewater treatment has been developed yet.

The adopted SBBR configuration was different compared to the typical SBR system, since sludge settlement did not occur in the same tank as oxidation, but in a separated final settler following the oxidation stage. This configuration unfortunately does not give the great advantage of the SBR that is the reduction of plant volume, however it is necessary since sludge settlement worsens in presence of the plastic elements once aeration is stopped.

The pilot plant was equipped with on-line probes of dissolved oxygen (DO), pH and ORP. Data were monitored and recorded continuously by a data acquisition system running under the graphical interface Labview™ (National Instruments).

Lab analyses

Lab analyses such as total COD (totCOD), 0.45-µm-filtered COD (fCOD), Total Suspended Solids (TSS), nitrogen and phosphorus compounds in the influent and effluent wastewater were carried out according to Standard Methods (1995). TSS and Volatile Suspended Solids (VSS) of the biofilm grown on the plastic elements were measured on a known volume suspension obtained detaching the biomass from a known number of...
elements with sonication and sodium hydroxide. Removal efficiencies were calculated considering fCOD in the effluent.

**Winery wastewater characterisation**

The influent wastewater coming into the pilot-plant was previously degritted and homogenised in the equalisation tank of the full-scale plant in order to minimise the daily load variation. The winery wastewater showed relatively high total COD concentration, equal to 2,170 mg L\(^{-1}\) on average (range of 370–4,167), whose a percentage, approximately 50%, is made up of soluble organic fraction (fCOD was equal to 1,074 mg L\(^{-1}\) on average). pH was usually acidic due to concentrated discharges, but cleaning operations using sodium hydroxide could give higher pH values. Since the winery wastewater showed a low content of nutrients (nitrogen and phosphorus), additions of urea (0.11 g urea/gCOD) and orthophosphoric acid (0.018 g H\(_3\)PO\(_4\)/gCOD) were needed to guarantee the process of cellular synthesis.

**Results and discussion**

During the first stage of the experimentation the winery wastewater was treated with a timed non-optimised cycle. On the basis of these results a DO-based strategy was chosen for the SBR cycle. Subsequently, the SBR cycle was optimised through the characterisation of the relevant points of the DO dynamic.

**Timed non-optimised SBBR cycle**

Initially, the duration of the SBBR cycle was set on the basis of fixed intervals. The typical cycle applied to the SBBR was chosen as follows: influent wastewater filling (9 minutes), aerobic reaction (up to 4.5 hours) and finally treated wastewater discharge (9 minutes). Settlement does not form a part of this cycle, as explained in Materials and Methods. The ratio between the influent wastewater filled at the beginning of the SBBR cycle and the volume of the reactor, indicated as “filling ratio”, was set at 0.37. This is the maximum value for the discharged portion of the bulk liquid in order to ensure that the plastic elements remain submerged in the reactor. Daily influent flow rate varied between 30 and 108 L d\(^{-1}\). Each day 5 timed SBBR cycles of 288 minutes were performed.

With the timed cycle a high COD removal efficiency may be obtained with average values in the range 78–97%. Effluent fCOD concentration was in the range of 50–317 mg L\(^{-1}\), with an average value of 149 mg L\(^{-1}\). The removed surface loads ranged between 0.8 and 30.2 gCOD m\(^{-2}\) d\(^{-1}\) (average value 11.4). These values correspond to volumetric loads in the range of 0.3–9.1 kgCOD m\(^{-3}\) d\(^{-1}\) (average value 3.5).

The operating conditions for the timed non-optimised SBBR cycle are summarised in Table 1. The results of the removal efficiency and the applied and removed loads are indicated in Figure 5, in comparison with the results obtained for the optimised cycle.

The SBBR process may be efficiently controlled by carrying out “track studies” and monitoring in real-time the main parameters. During the experimental period pH, ORP and

<table>
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<tr>
<th>Table 1 Operating conditions of the timed non-optimised SBBR cycle</th>
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<tr>
<td>Cycle time</td>
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<td>Number of cycles per day</td>
</tr>
<tr>
<td>Filling ratio</td>
</tr>
<tr>
<td>Flow rate of the influent wastewater</td>
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<tr>
<td>HRT</td>
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<tr>
<td>Effluent COD concentration</td>
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<tr>
<td>totCOD removal efficiency</td>
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<tr>
<td>Removed COD load</td>
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DO were continuously monitored, recorded on PC and graphics were visualised in real-time. DO control has a key role in the COD removal (Figure 2A). When the organic matter is broken down, the oxygen demand decreases and the DO concentration in the mixed liquor increases up to a steady level, which shows that the process is completed and the SBBR cycle can be interrupted (Figure 2A). As a consequence, the operator can find in real-time the exact moment in which the organic substance is totally oxidised. From the diagram of DO concentration in Figure 2A, four stages can be distinguished: (1) rapid decrease immediately after the filling of the raw wastewater; (2) plateau at low concentration of DO in coincidence with the oxidation of a high fraction of readily biodegradable COD; (3) rapid increase of DO concentration during the depletion of soluble COD removal; (4) reaching of a DO plateau in coincidence with the complete depletion of soluble biodegradable COD concentration.

Because of the high content of RBCOD in the winery wastewater it was not possible to maintain a DO concentration of over 0.2 mg O₂ L⁻¹ in the stage (2) of the SBBR cycle.

The final plateau can be easily detected calculating the derivative function of the DO concentration indicated in Figure 2B. The time derivative of DO concentration (dDO/dt) was calculated on the basis of the last 15 values of DO (the data acquisition system was set to acquire a DO value every minute). dDO/dt is correlated with the Oxygen Uptake Rate (OUR) during COD removal and the re-oxygenation of the system through air supply. In particular, when biodegradable COD was completely consumed, the DO was quite steady and the derivative decreased to values near zero. The cycle may be interrupted and the

**Figure 2** Dynamics during a typical SBBR cycle: (A) DO concentration and track-study of the residual soluble COD concentration; (B) time derivative of DO concentration calculated on the previous 15 values of DO.
treated wastewater discharged on the basis of this behaviour, since prolonging the cycle causes an unnecessary increase in energy consumption.

The dynamics of pH and ORP during the timed not-optimised SBBR cycle are shown in Figure 3A and 3B respectively. ORP decreased during the removal of readily biodegradable COD and then increased in relation to the increase in DO concentration. The minimum point and the following plateau were well defined suggesting the possibility of applying a similar algorithm developed specifically for the DO diagram. The main limitation was the fact that ORP probe was not always steady during the measurement, making it difficult to obtain reproducible dynamics. The pH diagram shows a decrement in the first portion due to acidic hydrolysis in the reactor and then an increase possibly related to CO₂ stripping. In the pH diagram it does not indicate relevant points during the SBBR cycle to improve the control strategy.

**SBBR cycle optimised on the basis of DO control**

For the optimisation of the SBBR system, each cycle should be interrupted after reaching the plateau in the DO diagram. Figure 4A indicated a typical diagram of the DO concentration during the optimised cycles. Time derivative of the DO concentration is shown in Figure 4B. The optimisation algorithm interrupts the cycle when the value of DO concentration derivative corresponds to the threshold around zero, taking into account that this point occurs only after the maximum peak. The horizontal dotted line in Figure 4B indicates the threshold where SBBR cycle has to be interrupted, in order to optimise the operations.

The amount of wastewater filled at the beginning of each cycle remained steady at 15 Litres (filling ratio equal to 0.37), but the number of cycles in a day increased. The operating parameters for the optimised SBBR cycle are summarised in Table 2.

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**Figure 3** Track study of a typical SBBR cycle: (A) pH; (B) ORP
The strategy optimised on the basis of DO derivative guaranteed high efficiency in the range between 85% to 99% (Figure 5). The filled flow rate ranged from a value of 90 L d\(^{-1}\) to the maximum value of 192 L d\(^{-1}\). The average value of 133 L d\(^{-1}\) was approximately twice that of the flow-rate filled in the non-optimised strategy, equal to 61 L d\(^{-1}\) on average. The COD removed load (Figure 5) increased up to 21.0 gCOD m\(^{-2}\) d\(^{-1}\) (range of 15.4\textasciitilde29.0), that corresponds to a volumetric load of 6.3 kgCOD m\(^{-3}\) d\(^{-1}\).

The comparison between the COD removed loads in the DO-controlled cycle and in the timed non-optimised cycle is shown in Figure 5.

Applied organic loads in the SBBR configuration were significantly higher than those usually applied in a conventional SBR system. An application of a conventional SBR configuration without moving bed for the treatment of winery wastewater is referred by Torrijos and Moletta (1997); the authors indicated a volumetric applied organic load equal to 0.8 kgCOD m\(^{-3}\) d\(^{-1}\) on average (up to 1.30 kgCOD m\(^{-3}\) d\(^{-1}\)) to guarantee a removal efficiency higher than 90%.

Regards to the amount of biofilm grown on the plastic elements, the fixed biomass resulted in the range of 4\textasciitilde5 kgTSS m\(^{-3}\), while the suspended biomass in the reactor was in the range of 0.3\textasciitilde1.4 kgTSS m\(^{-3}\). This biomass, bound to the final settler, showed good

**Table 2** Operating conditions of the DO-controlled SBBR cycle

<table>
<thead>
<tr>
<th>Cycle time</th>
<th>Controlled on the basis of time derivative of DO</th>
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<tr>
<td>Number of cycles per day</td>
<td>&gt; 5</td>
</tr>
<tr>
<td>Filling ratio</td>
<td>0.37</td>
</tr>
<tr>
<td>Flow rate of the influent wastewater</td>
<td>90\textasciitilde192 L d(^{-1})</td>
</tr>
<tr>
<td>HRT</td>
<td>5\textasciitilde10.7 h</td>
</tr>
<tr>
<td>totCOD removal efficiency</td>
<td>85\textasciitilde99%</td>
</tr>
<tr>
<td>Effluent COD concentration</td>
<td>105 mg L(^{-1}) (range 14\textasciitilde336)</td>
</tr>
<tr>
<td>Removed COD load</td>
<td>15.4\textasciitilde29.0 gCOD m(^{-2}) d(^{-1}) (4.6\textasciitilde8.8 kgCOD m(^{-3}) d(^{-1}))</td>
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![Figure 4](https://iwaponline.com/wst/article-pdf/45/12/347/424855/347.pdf)  
**Figure 4** (A) Dynamics of DO concentration in the cycles of the optimised SBBR; (B) time derivative of DO concentration calculated on the previous 15 values of DO. Threshold is indicated as a horizontal dotted line.
settleability (SVI < 100 mL gTSS\(^{-1}\)). TSS concentration measured in a conventional SBR system was equal to about 3.2 kg TSS m\(^{-3}\), as found by Torrijos and Moletta (1997).

**Conclusions**

The SBBR system, combining the advantages of *Sequencing Batch Reactors* and *Moving Bed Biofilm Reactors*, seems to be an interesting option for the treatment of winery wastewater. Advantages of this plant configuration may be summarised as follows: (a) high removal of organic load as a result of the high-surface biofilm system; (b) possibility to control on-line the biodegradation process in the reactor on-line and therefore to change in real time the duration of the typical cycle; (c) sludge recycle is not necessary and therefore the plant configuration is simpler than for instance activated sludge systems and management is also easier. The results of the experimentation have confirmed the applicability of the SBBR process for the treatment of winery wastewater. COD removal efficiency was between 85% and 99%, with applied loads of up to 29 gCOD m\(^{-2}\) d\(^{-1}\) (8.8 kgCOD m\(^{-3}\) d\(^{-1}\)).

The on-line monitoring of dissolved oxygen concentration appeared as a good indicator of the progress in the COD biodegradation. The optimised control strategy made it possible to obtain a steady quality of the effluent wastewater with an average daily applied load of 6.3 kgCOD m\(^{-3}\) d\(^{-1}\) rather than 3.5 kgCOD m\(^{-3}\) d\(^{-1}\) for the non-optimised SBBR cycle.

In conclusion, the possibility of optimising the SBBR cycle through a simple control of the dissolved oxygen in the mixed liquor could be an interesting solution for the biological pre-treatment of winery wastewater to be discharged into sewerage or as a single stage of a combined treatment plant for the discharge into surface water.

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**References**


