SBR technology for high ammonium loading rates
A. Galí, J. Dosta, S. López-Palau and J. Mata-Álvarez

ABSTRACT
This paper focuses on the study of high ammonium concentrated wastewater with SBR reactors. Four type of wastewaters, landfill leachates ($T = 20^\circ C$) and the reject water ($T = 35^\circ C$) coming from mesophilic anaerobic digesters of sewage sludge, pig slurry and organic fraction of municipal solid waste (OFMSW), were studied in four SBR during 6 months. The removal of nitrogen was done in all the cases with nitrification/denitrification via nitrite obtaining high removal nitrogen conversions for the three types of reject water (0.75–0.85 kg N day$^{-1}$ m$^{-3}$) and lower for landfill leachates due to temperature requirements (0.3 kg N day$^{-1}$ m$^{-3}$).

Key words | leachate, reject-water, SBR, supernatant, nitrite

INTRODUCTION
Taken into account the stricter legislation about nitrogen discharges, NH$_4^+$-N is an important pollutant to be efficiently treated at low cost, especially when it is present at high concentrations in wastewaters (>500 mg NH$_4^+$-N L$^{-1}$). That kind of pollutant can be found in several types of wastewaters being the most extended the landfill leachates and the supernatants from anaerobic digestion process of sewage sludge, pig slurry and the organic fraction of municipal solid wastes (OFMSW). Considering the high concentrations of NH$_4^+$-N in these wastewaters, the Sequencing Batch Reactor (SBR) technology seems to be one of the most appropriate alternatives. The main features of the SBRs are their flexibility, which allows widely different ranges of concentration and streams to be worked with, and its compaction, which leads to different sequences of treatment being done in the same tank (Ketchum 1997; Artan et al. 2001; Macé & Mata-Álvarez 2002).

The most widespread method to remove ammonia from wastewater is the well known nitrification/denitrification process. From an economic point of view, it is better to develop nitrification/denitrification over nitrite since the inhibition of nitrate formation has two important benefits: the saving of 25% of oxygen consumption and 40% of organic carbon source in denitrification. There are different ways to benefit nitritation in front of nitratation. Nitritation can be achieved working at temperatures over 20$^\circ$C and sludge retention time (SRT) below 2 days (Hellinga et al. 1999; Van Dongen et al. 2001), maintaining the pH between 8–9 (Anthonisen et al. 1976; Hellinga et al. 1999) or working with dissolved oxygen concentrations (DO) below 1 mg L$^{-1}$ (Pollice et al. 2002). In an SBR the nitrite route is achieved correctly working with low DO and controlled pH range (7.5–8.5) (Galí et al. 2007).

Water alkalinity is another important parameter in nitrification. The latter wastewaters are characterized by low bicarbonate to ammonium ratio (Hellinga et al. 1998). Since denitrification supposes a partial recovering of the alkalinity consumed during nitrification, alternation of oxic/anoxic subcycles could represent a good solution to avoid the use of external alkalinity addition.

The aim of the paper is to present the real lab-scale SBR technology application with different kind of wastewaters highly ammonia concentrated in order to be treated biologically with nitrification/denitrification via nitrite.
METHODS

Experimental devices

Treatment of highly ammonia concentrated wastewater was carried out at lab scale, where N removal was developed in SBRs of 3 L (Figure 1). Each reactor was equipped with 3 pumps (2 Cole-Parmer Instrument 7553-85 and 1 EYELA Micro Tube Pump MP-3), 1 oxygen valve and 1 mechanical stirrer. Moreover, it was controlled and monitored by a computer with an acquisition data card (PCL-812PG), a control box and an interphase card (PCL-743/745) connecting both systems. The computer worked with Bioexpert version 1.1 x. Temperature was maintained at T °C by means of a thermostatic bath (RM6 Lauda) and pH was monitored with an electrode (Crisson Rocon 18). Temperature, pH and dissolved oxygen concentration (DO) profiles were monitored and these data were then exported and represented in each cycle.

Substrate and inoculum

Supernatants from the different anaerobic digesters were taken: Sludge and OFMSW reject water were obtained from mesophilic anaerobic digesters of a WWTP and an ECO-PARC situated in the Barcelona metropolitan area (Spain). Leachates were obtained from a local landfill placed also in the Barcelona metropolitan area and pig reject water was obtained from a pig manure mesophilic anaerobic digester plant situated in Lleida (Spain). The effluents were collected and kept at 4°C in the laboratory until its treatment. Microorganisms were taken from the sludge withdraws of a WWTP and were acclimated to nitrification/denitrification process in a SBR.

Analytical methods

Analyses of chemical oxygen demand (COD), alkalinity, suspended solids (SS) and volatile suspended solids (VSS) were performed according to the Standard Methods for the Examination of Water and Wastewater (APHA 1995). Ammonium was determined by an ammonia-specific electrode (Crisson, model pH 2002). Nitrogen compounds, such as nitrates and nitrites were analysed by capillary electrophoresis (Hewlett Packard 3D). Once the samples were withdrawn of the reactor, they were immediately centrifuged at 10,000 rpm for 10 min and, for capillary electrophoresis analysis they were filtered through 0.45 µm cellulose paper filters.

RESULTS AND DISCUSSION

Wastewater characterisation

The proposed wastewaters to be treated were landfill leachates and the reject water coming from mesophilic
Anaerobic digesters of sewage sludge, pig slurry and OFMSW. Table 1 shows the average concentrations of the different wastewaters where the main pollutant is NH\text{+4} -N.

Considering that nitrification consumes 2 moles of bicarbonate per mole of NH\text{+4} -N oxidised and denitrification recovers the half alkalinity consumed in nitrification, the molar ratio bicarbonate/ammonia must be at least above 1.0, in order to avoid external addition of alkalinity to cover a nitrogen removal higher than 90%. As stated in Table 1, it would be possible to cover complete nitrification/denitrification process with all types of wastewaters tested with a good cycle strategy inside each SBR.

**Optimising the SBR operational cycle via nitrite for each wastewater**

Four SBR, one for each substrate, were operated with similar operational conditions during 6 months as it can be seen in Table 2. Eight hour cycle (on average 5 hour nitrification; 2.25 hour denitrification: 0.5 settling; 0.25 withdrawing) were chosen to be operated continuously in each SBR considering the experiments reported by Gali et al. (2007). In order to better use the alkalinity and to avoid the NO\text{2} -N accumulation that could lead to toxicity problems, internal aerobic/anoxic (nitrification/denitrification) periods were fixed. Moreover, the filling of the reactor was done at the beginning of the first nitrification period or was spread during the other nitrification or denitrification periods depending on the COD characteristics of each wastewater. Normally, the most part of chemical oxygen demand (COD) of the wastewaters under study is non biodegradable or refractory as it can be seen from the BOD5/COD ratio in Table 1. Therefore, at the beginning of each anoxic period the stoichiometric ratio of methanol was added in order to carry out the denitrification due to the lack of readily biodegradable COD to denitrify.

**Sludge reject water**

The 8 hour cycle was operated during 6 months following an internal three aerobic/anoxic sub-cycle strategy to control nitrate accumulation and alkalinity limitations, as

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit</th>
<th>Sludge reject water</th>
<th>Piggery reject water</th>
<th>OFMSW reject water</th>
<th>Landfill leachates</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>mg L\textsuperscript{-1}</td>
<td>700 ± 25</td>
<td>3,800 ± 300</td>
<td>810 ± 20</td>
<td>600 ± 25</td>
</tr>
<tr>
<td>COD</td>
<td>mg L\textsuperscript{-1}</td>
<td>1,700 ± 300</td>
<td>3,200 ± 500</td>
<td>11,500 ± 1,500</td>
<td>8,200 ± 500</td>
</tr>
<tr>
<td>BOD\textsubscript{5}</td>
<td>mg L\textsuperscript{-1}</td>
<td>120 ± 20</td>
<td>590 ± 75</td>
<td>580 ± 300</td>
<td>2,000 ± 200</td>
</tr>
<tr>
<td>BOD\textsubscript{5}/COD</td>
<td>–</td>
<td>0.07 ± 0.01</td>
<td>0.18 ± 0.01</td>
<td>0.05 ± 0.01</td>
<td>0.25 ± 0.01</td>
</tr>
<tr>
<td>NH\textsubscript{2} -N</td>
<td>mg L\textsuperscript{-1}</td>
<td>850 ± 50</td>
<td>2,200 ± 90</td>
<td>1,725 ± 75</td>
<td>3,800 ± 100</td>
</tr>
<tr>
<td>P-total</td>
<td>mg L\textsuperscript{-1}</td>
<td>19 ± 1</td>
<td>7 ± 0.1</td>
<td>11 ± 1</td>
<td>20 ± 1</td>
</tr>
<tr>
<td>HCO\textsubscript{3} /N ratio</td>
<td>mol mol\textsuperscript{-1}</td>
<td>1 ± 0.1</td>
<td>1.8 ± 0.2</td>
<td>1.56 ± 0.06</td>
<td>1.0 ± 0.1</td>
</tr>
<tr>
<td>pH</td>
<td>–</td>
<td>8 ± 0.1</td>
<td>8.7 ± 0.1</td>
<td>8 ± 0.1</td>
<td>8.5 ± 0.1</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>35 ± 0.5</td>
<td>37 ± 0.5</td>
<td>37 ± 0.5</td>
<td>20 ± 0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operational conditions</th>
<th>Units</th>
<th>Sludge reject water</th>
<th>Piggery reject water</th>
<th>OFMSW reject water</th>
<th>Landfill leachates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal subcycles</td>
<td>L</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>32 ± 0.5</td>
<td>32 ± 0.5</td>
<td>32 ± 0.5</td>
<td>20 ± 0.5</td>
</tr>
<tr>
<td>pH range</td>
<td>–</td>
<td>7.5–8.5</td>
<td>7.5–9.3</td>
<td>7.5–8.8</td>
<td>7.6–8.1</td>
</tr>
<tr>
<td>DO (aerobic periods)</td>
<td>mg L\textsuperscript{-1}</td>
<td>1</td>
<td>1.5</td>
<td>1.4</td>
<td>1</td>
</tr>
<tr>
<td>VSS</td>
<td>mg L\textsuperscript{-1}</td>
<td>2,500 ± 250</td>
<td>7,500 ± 500</td>
<td>4,000 ± 500</td>
<td>2,900 ± 300</td>
</tr>
<tr>
<td>SRT</td>
<td>day</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>HRT</td>
<td>day</td>
<td>1</td>
<td>2.7</td>
<td>2.3</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Table 1 | Year average composition of the used wastewaters (WW)

Table 2 | SBR operational conditions
it is shown in Figure 2. Each cycle consisted of nine stages: aerobic fill (0.25 h), aerobic (1.75 h), anoxic (0.75 h), aerobic (1.50 h), anoxic (0.50 h), aerobic (1.50 h), anoxic (0.75 h), settle (0.50 h) and draw (0.25 h). Only a sole filling at the beginning of each cycle was spread to prevent alkalinity lacks at the end of the two first aerobic periods (see Table 2 for operational parameters). The profiles of $\text{NH}_4^+ - \text{N}$, $\text{NO}_2^- - \text{N}$, $\text{DO}$ and $\text{pH}$ in each cycle are shown in Figure 2, where 300 mg $\text{NH}_4^+ - \text{N}$ L$^{-1}$ were properly nitrified to $\text{NO}_2^- - \text{N}$ and then denitrified obtaining an effluent with 35 mg $\text{NH}_4^+ - \text{N}$ L$^{-1}$ and 5 mg $\text{NO}_2^- - \text{N}$ L$^{-1}$ which gave a total nitrogen efficiency of 0.8 kg N day$^{-1}$ m$^{-3}$.

**Pig reject water**

An optimal SBR performance was obtained working during 6 month. Since the wastewater tested had a relatively high $\text{pH}$ (8.5–8.8), the quantity of wastewater fed to the SBR was split into 3 additions to avoid high $\text{NH}_4^+ - \text{N}$ concentrations at basic $\text{pH}$ that could inhibit ammonia oxidation bacteria and would lead to a loss by stripping of $\text{NH}_3$. Apart of this modification, the strategy of operation was the used in the

![Figure 2](https://iwaponline.com/wst/article-pdf/58/2/467/437094/467.pdf)

**Figure 2** | Concentration and pH profiles inside sludge reject water SBR: $\text{NH}_4^+ - \text{N}$ (−−−), $\text{NO}_2^- - \text{N}$ (−), $\text{NO}_3^- - \text{N}$ (−), $\text{NH}_4^+ - \text{N}$ (−), $\text{DO}$ (solid line), $\text{pH}$ (bold solid line). N: nitrification, D: denitrification, S: sedimentation.

![Figure 3](https://iwaponline.com/wst/article-pdf/58/2/467/437094/467.pdf)

**Figure 3** | Concentration and pH profiles inside pig reject water SBR: $\text{NH}_4^+ - \text{N}$ (−−−), $\text{NO}_2^- - \text{N}$ (−−), $\text{NO}_3^- - \text{N}$ (−−−), $\text{pH}$ (solid line), $\text{DO}$ (bold solid line). N: nitrification, D: denitrification, S: sedimentation.

![Figure 4](https://iwaponline.com/wst/article-pdf/58/2/467/437094/467.pdf)

**Figure 4** | Concentration and pH profiles inside OFMSW reject water SBR: $\text{NH}_4^+ - \text{N}$ (−−−), $\text{NO}_2^- - \text{N}$ (−−), $\text{NO}_3^- - \text{N}$ (−−−), $\text{pH}$ (solid line), $\text{DO}$ (bold solid line). N: nitrification, D: denitrification, S: sedimentation.
sludge reject water and the other operational parameters are reported in Table 2.

The experimental profiles of \( \text{NH}_4^+ \), \( \text{NO}_2^- \), \( \text{NO}_3^- \), pH and DO during a representative SBR cycle are presented in Figure 3, where it is observed that three additions of wastewater were performed at the beginning of every aerobic period. Oxygen concentration was maintained between 0.8–1.0 mg O\(_2\) L\(^{-1}\) and pH was reduced during the oxidation of \( \text{NH}_4^+ \) to \( \text{NO}_2^- \). When \( \text{NH}_4^+ \) was depleted, a rising of DO was observed due to the diminution in oxygen uptake rate and an increase of pH was detected due to stripping of CO\(_2\). The total nitrogen removal was 0.87 kg N day\(^{-1}\) m\(^{-3}\).

OFMSW reject water

The SBR was operated during 6 months using the same cycle strategy than in the sludge pig reject water in order to avoid the pH to be out of range during the first aerobic period. The experimental profiles of \( \text{NH}_4^+ \)-N, \( \text{NO}_2^-\)-N, \( \text{NO}_3^-\)-N, pH and DO during a representative SBR cycle are presented in Figure 4 where the total nitrogen removal was 0.75 kg N day\(^{-1}\) m\(^{-3}\).

Leachates wastewater

The SBR to treat leachates wastewater was operated at conditions that differed a bit from the three previous mentioned (see Table 2). The most important was working temperature that was selected to be 20°C because the landfill does not work under mesophilic conditions. The latter fact made decrease the kinetics of the process dues to the high influence of them by temperature. The operational strategy proposed was to work with only one subcycle considering the wastewater pH and the HRT that could be reached. The total nitrogen removal achieved was of 0.3 kg N day\(^{-1}\) m\(^{-3}\).

Discussion

After considering the profiles from Figures 2 to 4 there is in Table 3 a summary of the efficiencies of the different reactors. The N removal efficiency was the same obtaining similar effluent nitrogen concentrations, whereas the conversion nitrogen factors were different. The SBRs treating the three types of reject water obtained similar high conversions (>0.75 kg N day\(^{-1}\) m\(^{-3}\)), whereas in the landfill leachates SBR the conversion was very low. The latter is explained by the operating temperature: the effluents from mesophilic anaerobic digestion can be treated at relatively high temperatures if the system is well isolated, but landfill leachates treatment must be carried out at lower temperatures. The concentration of VSS inside each reactor was also different because this parameter depends on the bacterial growth rate and the solids of the effluent. What it is important to remark is that in all the four reactors the nitrification/denitrification was carried out properly over nitrite, with the operational conditions of Table 2, with nearly no nitrate presence which leads to saving aeration and denitrification costs.

**CONCLUSIONS**

In the present article it has been demonstrated that SBRs are very appropriate reactors to treat highly concentrated ammonia effluents via nitrite. The different kinds of wastewaters were treated properly but their efficiencies
and conversions varied depending on their characteristics.
To sum up it can be said that:
1. High ammonia concentrated wastewater treatment with SBR appears to be a very satisfactory alternative for meeting local discharge requirements.
2. In order to avoid the use of external additives to control the pH in an optimum interval (7.5–8.5), the best strategy consists on alternating different aerobic-anoxic sub-phases during the operational cycle with methanol as a carbon source for denitrification.
3. The nitrite route is achieved correctly combining the pH range and the low dissolved oxygen concentration inside the reactor, fact that also allows saving costs.

ACKNOWLEDGEMENTS

The authors thank the MMA (344/2006/2-4.3 and 4.3-255/2005/3-B) for financial support.

REFERENCES


