Minimisation of Sequencing Batch Reactor Volume by Optimisation of the Hydraulic and Solids Retention Time

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Outline

• Introduction
• Approach
• Methodology
• Results and Discussions
• Conclusion
Introduction

- Sequencing batch reactor (SBR) is a variant of the activated sludge process that combines all treatment steps (reaction, clarification) in a single vessel.
- SBR is uniquely suited for wastewater treatment applications characterized by low or intermittent flow conditions.
- The operation is based on a fill-and-draw principle consisting of five steps as shown below:
Introduction

- The main operating parameters associated with the SBR are: hydraulic retention time (HRT); solids retention time (SRT); length of treatment phases; and the number of cycles per day.

- **SBR volume** can be **minimised** by reducing the HRT, which consequently **increases** the organic loading rate (OLR).

\[
HRT = \frac{V}{Q}, \quad OLR = \frac{Q \times S_{\text{FEED}}}{V} = \frac{S_{\text{FEED}}}{HRT}
\]

- For a fixed SRT, reducing the HRT will be limited by **high biomass concentration**, with a decrease in the settling rate and increase in the aeration requirements per unit of reactor volume.

- Thus, decreasing the HRT while keeping the SRT fixed can potentially cause the process to fail.
This potential problems can be overcome by appropriate manipulation of the SRT

- Decreasing the SRT, at a fixed HRT, decreases the biomass concentration in the reactor and the oxygen consumption.

\[
SRT = \frac{V \cdot X}{Q_w \cdot X + Q_{\text{eff}} \cdot X_{\text{eff}}}
\]

- However, reducing the SRT can potentially compromise the effluent quality.

In order to minimise the reactor volume, the HRT and SRT need to be reduced (optimised) simultaneously.

- The question now is: to which point can the HRT and SRT be decreased for a given wastewater?
Approach

This study addresses the question with both experimental and modelling approaches.

1. Experimental investigations of the behaviour of lab-scale SBRs operated in a range of HRT, SRT and OLR values with synthetic wastewaters at a fixed composition.

2. To verify if the process performance at the various values of HRT and SRT can be predicted from batch kinetic tests and mathematical modelling.
Experimental

• An experiment of ten different SBR runs was carried out on the wastewater in a lab scale SBR .....(i.e. more runs to be carried out )

• A synthetic wastewater composed of 1 g/l of glucose was used.
  ▪ The inoculum was a soil from Craibstone farm in Aberdeen.
  ▪ Performance was recorded in terms of substrate removal and biomass concentration.

Lab-scale glass reactors operating as SBR (picture taken during the settle phase).
### Experimental design

**Table 1.** Operational characteristics of the SBR for each run. Sludge withdrawal was done manually.

<table>
<thead>
<tr>
<th>Run</th>
<th>HRT (days)</th>
<th>OLR (g COD/l/day)</th>
<th>Sludge Withdrawal Rate (ml/day)</th>
<th>No of Cycles (per day)</th>
<th>Length of the Phases (min)</th>
<th>Volume Fed Per Day (ml/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fill (aerated) React Settle Effluent Withdrawal</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>0.27</td>
<td>250</td>
<td>4</td>
<td>2 300 58 2</td>
<td>250</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>0.27</td>
<td>90</td>
<td>4</td>
<td>2 300 58 2</td>
<td>250</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>0.27</td>
<td>35</td>
<td>4</td>
<td>2 300 58 2</td>
<td>250</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>0.27</td>
<td>18</td>
<td>4</td>
<td>2 300 58 2</td>
<td>250</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>0.27</td>
<td>0</td>
<td>4</td>
<td>2 300 58 2</td>
<td>250</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1.07</td>
<td>1000</td>
<td>4</td>
<td>5 300 55 5</td>
<td>1000</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1.07</td>
<td>350</td>
<td>4</td>
<td>5 300 55 5</td>
<td>1000</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1.07</td>
<td>0</td>
<td>4</td>
<td>5 300 55 5</td>
<td>1000</td>
</tr>
<tr>
<td>9</td>
<td>0.5</td>
<td>2.14</td>
<td>100</td>
<td>4</td>
<td>10 295 55 10</td>
<td>2000</td>
</tr>
<tr>
<td>10</td>
<td>0.25</td>
<td>4.28</td>
<td>70</td>
<td>6</td>
<td>10 190 40 10</td>
<td>2000</td>
</tr>
</tbody>
</table>

Glucose concentration in the effluent was measured both as total carbohydrates and as COD.
Results

SBR performance

- Glucose removal for the first set of runs (HRT = 4 days)

- > 98% substrate removal for all the runs (1-5)
Results

- Glucose removal for the second set of runs (HRT ≤ 1 day)

- Partial substrate removal for runs 6 and 7 (< 27 % glucose removal)

**SBR performance**

- Run 6: HRT = 1 day; SRT = 1 day
- Run 7: HRT = 1 day; SRT = 1.7 days
- Run 8: HRT = 1 day; SRT = 37 days
- Run 9: HRT = 0.5 days; SRT = 2.5 days
- Run 10: HRT = 0.25 days; SRT = 3.1 days

*Process failed at SRT ≤ 1.7 days*
Results

SBR performance

- Solids in the reactor for the first set of runs (HRT = 4 days)

- Biomass concentration in the reactor increases with SRT
Results

SBR performance

- Solids in the reactor for the second set of runs (HRT ≤ 1 day)

![Graph showing SBR performance with various runs and VSS measurements over time.

- Run 6: HRT = 1 day; SRT = 1 day
- Run 7: HRT = 1 day; SRT = 1.7 days
- Run 8: HRT = 1 day; SRT = 37 days
- Run 9: HRT = 0.5 days; SRT = 2.5 days
- Run 10: HRT = 0.25 days; SRT = 3.1 days]
Results

Caption of the reactors for SRT = 27.3 days (right) vs SRT = 1 day (left)
## Results

### Summary of the results

**Table 2.** Summary of the steady state performance for each SBR run. Standard deviations in brackets. Total carbohydrates and COD are measured in the reactor effluent.

<table>
<thead>
<tr>
<th>Run</th>
<th>HRT (days)</th>
<th>OLR (g COD/1/day)</th>
<th>Calculated SRT (days)</th>
<th>Total carbohydrates (mg/l)</th>
<th>COD (mg/l)</th>
<th>Biomass concentration (mg/l)</th>
<th>% glucose removal (total carbohydrates)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>0.27</td>
<td>4</td>
<td>17 (2)</td>
<td>91 (7)</td>
<td>470 (55)</td>
<td>98</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>0.27</td>
<td>8.7</td>
<td>15 (0.5)</td>
<td>51 (5)</td>
<td>836 (8)</td>
<td>99</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>0.27</td>
<td>16.3</td>
<td>14 (3)</td>
<td>62 (16)</td>
<td>1088 (146)</td>
<td>99</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>0.27</td>
<td>27.3</td>
<td>11 (2)</td>
<td>43 (6)</td>
<td>1357 (47)</td>
<td>99</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>0.27</td>
<td>65.3</td>
<td>3 (2)</td>
<td>18 (14)</td>
<td>1695 (113)</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1.07</td>
<td>1</td>
<td>949 (21)</td>
<td>972 (7)</td>
<td>76 (26)</td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1.07</td>
<td>1.7</td>
<td>801 (9)</td>
<td>815 (32)</td>
<td>190 (42)</td>
<td>27</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1.07</td>
<td>37</td>
<td>3 (3)</td>
<td>13 (3)</td>
<td>6613 (85)</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>0.5</td>
<td>2.14</td>
<td>2.5</td>
<td>17 (8)</td>
<td>26 (13)</td>
<td>1680 (42)</td>
<td>98</td>
</tr>
<tr>
<td>10</td>
<td>0.25</td>
<td>4.28</td>
<td>3.1</td>
<td>8 (3)</td>
<td>24 (10)</td>
<td>4338 (145)</td>
<td>99</td>
</tr>
</tbody>
</table>

SRT was calculated from the concentrations of solids in the reactor and in the effluent as:

\[
SRT = \frac{V \cdot X}{Q_w \cdot X + Q_{eff} \cdot X_{eff}}
\]
From the results, for glucose wastewater at OLR of 4.28 g COD/l/day: HRT of 0.25 days and SRT of 3.1 days are the minimum values for calculating the reactor volume, while still maintaining acceptable values of the biomass concentration and satisfying effluent quality requirement.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Length of cycle (hour)</th>
<th>SRT (days)</th>
<th>OLR (g COD/l/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beun et al. (2002)</td>
<td>4</td>
<td>4</td>
<td>1.15</td>
</tr>
<tr>
<td>Serafirm et al. (2004)</td>
<td>8</td>
<td>10</td>
<td>0.9</td>
</tr>
<tr>
<td>Dionisi et al. (2008)</td>
<td>6</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Li et al. (2008)</td>
<td>8</td>
<td>14.5 - 25</td>
<td>1.2</td>
</tr>
<tr>
<td>Hajiabadi et al. (2009)</td>
<td>24</td>
<td>5</td>
<td>1.4</td>
</tr>
<tr>
<td>Ge et al. (2013)</td>
<td>3</td>
<td>2 - 3.8</td>
<td>1.4 - 2.8</td>
</tr>
<tr>
<td>Rodríguez et al. (2013)</td>
<td>8</td>
<td>30</td>
<td>3.24</td>
</tr>
<tr>
<td><strong>This study</strong></td>
<td><strong>6</strong></td>
<td><strong>3.1</strong></td>
<td><strong>4.28</strong></td>
</tr>
</tbody>
</table>
Model approach

A kinetic model developed by Dionisi et al. (2016) that calculates the steady state conditions of SBR was adopted for this approach.

Batch kinetic tests were carried out on the glucose wastewater at various initial substrate to biomass ratio, and range of values of the kinetic parameters were estimated for the model application.
Results

- Batch experiments were carried out as respirometric tests which measures the oxygen uptake rate (OUR) as a function of time.

![Graph showing experimental and fitted OUR values over time]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial substrate/biomass</td>
<td>2.4</td>
</tr>
<tr>
<td>$\mu_{\text{max}}$ (day$^{-1}$)</td>
<td>1.608</td>
</tr>
<tr>
<td>$K_S$ (kg COD/m$^3$)</td>
<td>0.128</td>
</tr>
<tr>
<td>$b$ (day$^{-1}$)</td>
<td>0.098</td>
</tr>
<tr>
<td>$Y_{X/S}$ (kg Biomass/ kg COD)</td>
<td>0.579</td>
</tr>
</tbody>
</table>

- Values of the kinetic parameters were used to simulate the steady state conditions in terms of biomass and substrate concentration at the various values of HRT and SRT.
Steady state predictions of the SBR using the kinetic parameters from the *batch test*.

First set of runs (HRT = 4 days)
Of course, the other batch tests will predict a performance slightly different due to the range of values estimated in the tests.
Results

Biomass produced
\[
\left( \frac{\text{g biomass}}{\text{day} \cdot \text{L}} \right) = X \frac{HRT}{SRT}
\]

Oxygen consumption
\[
\left( \frac{\text{g O}_2}{\text{day} \cdot \text{L}} \right) = (S_0 - S) - X \frac{HRT}{SRT} \cdot 1.42
\]
Conclusion

- In order to minimize the SBR volume, the HRT and SRT have to be reduced simultaneously and set to their minimum.

- Achieving a successful operation at OLR of 4.28 g COD/l/day and SRT of 3.1 days is better than most of the reported values in the literature for aerobic activated sludge processes.

- Batch kinetic tests are indeed able to predict the performance of the process with the appropriate kinetic model and simulation procedure such as the one developed by Dionisi et al. (2016).

- This strategy of reducing the HRT by decreasing the SRT can potentially lead to even lower reactor volumes and higher OLR values for successful treatments.
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Thank you for listening

Question everything