Treatment of poultry processing wastewater using sequencing batch reactors

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Lo, K.V. and Liao, P.H. 1990. Treatment of poultry processing wastewater using sequencing batch reactors. Can. Agric. Eng. 32:299-302. Three 5-litre bench-scale sequencing batch reactors were used to treat poultry processing plant wastewater. The reactors were operated at three different temperatures (10, 22 and 35°C) and a cycle of four hours. Two litres of wastewater were treated each 4-hour cycle. The mean hydraulic retention time (HRT) was 10 hours for each reactor. High levels of reduction in biochemical oxygen demand and chemical oxygen demand were achieved. The reduction for biochemical oxygen demand was over 89%. There was no noticeable difference in the mean treatment efficiency of the sequencing batch reactors operating at 22 and 35°C. However, the treatment efficiency of the low-temperature reactor (10°C) was lower. Denitrification was found to occur at the beginning of the react phase for the high-temperature (22 and 35°C) reactors, while no obvious denitrification or nitrification processes took place in the low-temperature reactor. The settling characteristics of the sludge were good with the sludge volume index ranging between 70 and 108.

INTRODUCTION

Sequencing batch reactor systems are receiving increasing use for the treatment of municipal, industrial and agricultural wastewaters (Irvine and Busch 1979; Alleman et al. 1979; Lo et al. 1988). However, reports on the application of the SBR process to food processing wastewaters are scarce (Norcross et al. 1987). The research reported here was initiated at the request of a small local poultry processing company. This study examined the effectiveness of SBRs in the treatment of poultry processing wastewater. It also studied the effect of changes in operating temperature on treatment efficiency.

The choice of the SBR system for the biological treatment of the wastes was made on the basis that these systems are more dynamic and flexible in terms of operation, and are kinetically more advantageous than continuous-flow systems (Goronszy 1979; Irvine and Busch 1979). The SBR system, a modern version of the fill-and-draw activated sludge process, consists of one or more tanks. The number of tanks is dependent on influent flow patterns and the sophistication of the control system. Each tank is capable of waste stabilization and solids separation, and is operated through a succession of five periods: fill, react, settle, draw, and idle.

METHODS

Poultry processing wastewater

The volume of wastewater produced per day by the poultry processing plant ranged from 20,000 to 32,000 litres. The composition of the wastewater is shown in Table I. The wastewater had biochemical oxygen demand (BOD) and chemical oxygen demand (COD) concentrations which varied from 274 to 403 mg/L and 523 to 622 mg/L, respectively. The wastewater pH measured between 5.8 and 6.6. During the course of the experiment, the pH of the reactors was not controlled. To maintain the pH value of the reactors around 7, calcium hydroxide was used to adjust the pH of the wastewater to 9 before feeding to the reactors.

SBR reactor operation

Three 5.0 litre acrylic plastic reactors (460 mm in height and 138 mm in diameter) were set-up in the laboratory. Reactor 1 was maintained at 10 ± 0.5°C using a continuously-circulated coolant from a refrigerated waterbath (Julabo, Model F40). Reactor 2 was operated at room temperature, which ranged around 22 ± 1°C. Reactor 3 was wrapped with a heating pad connected to a temperature feedback controller with a thermocouple set to maintain the reactor temperature at 35 ± 1°C.

Based on previous findings (Lo et al. 1988), a 4-hour cycle was adopted. The standard sequencing was used: fill (8 min), react (2 hr), settle (1 hr 45 min), draw (4 min) and idle (15 min). The fill phase coincided with the beginning of aeration. Two litres of wastewater were treated each 4 hr cycle resulting in a mean hydraulic retention time (HRT) of 10 hours for each reactor.

Sludge removal was undertaken once per day during the last 30 minutes of the aeration period. This was done by wasting the appropriate amount of mixed liquor; that is, wasting 500 ml out of 5.0 litres of the mixed liquor yielded a mean cell residence time (MCRT) of 10 days. MCRT was maintained at 10 days during the course of the experiment.

ANALYSIS

Following standard methods (APHA 1985), the major parameters monitored were COD, 5-day biochemical oxygen demand (BOD5), total suspended solids (TSS), volatile suspended solids (VSS), Ammonia-nitrogen (NH3-N) and nitrite-plus-nitrate-nitrogen (NO2+NO3-N) were monitored by a Technicon Auto-Analyser II.

Influent-effluent analysis was conducted and the results were used to calculate the reactor treatment efficiency. In addition, six sets of track analyses were carried out. This track analysis monitored the state of the mixed liquor versus time during the react phase. The mixed liquor samples were allowed to settle for 90 minutes before subsampling the supernatant fraction for analysis. Dissolved oxygen (DO) levels in the reactors were also monitored using an oxygen meter (YSI57).
Table I: Characterization of influents and effluents treatment efficiency.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influent Concentration (mg L⁻¹)</th>
<th>Treatment Effluent (mg L⁻¹)</th>
<th>Average Removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Range</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>BOD₅</td>
<td>336 ± 53</td>
<td>274 - 403</td>
<td>35 ± 6</td>
</tr>
<tr>
<td>COD</td>
<td>549 ± 49</td>
<td>523 - 622</td>
<td>60 ± 13</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>16 ± 2.9</td>
<td>12 - 17</td>
<td>18 ± 2</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>less than 0.1</td>
<td>—</td>
<td>0.15 ± 0.08</td>
</tr>
<tr>
<td>TSS</td>
<td>526 ± 65</td>
<td>433 - 572</td>
<td>220 ± 59</td>
</tr>
<tr>
<td>SVI</td>
<td>—</td>
<td>—</td>
<td>83 ± 21</td>
</tr>
</tbody>
</table>

* The average of 6 analyses

RESULTS AND DISCUSSION

One hundred and twenty treatment cycles were conducted for each reactor in this experiment. All SBR runs were started with biological seed obtained from the swine wastewater SBR treatment facility. The MCRT was maintained at 10 days. The organic loading rates varied between 0.23 and 0.35 g BOD g⁻¹ MLSS day⁻¹ for all three reactors. The settling characteristics of the sludge were good, with sludge volume index (SVI) ranging between 70 and 108. The SVI indicates sludge compactability. In general, higher SVIs were obtained for reactor 1 (Table I).

This study was primarily concerned with the bio-oxidation phase of the process and the overall treatment efficiency. The influent-effluent analyses are presented in Table I. Very low effluent BOD₅ concentrations were obtained in this experiment. The mean effluent BOD₅ were 35.5, 20.5, and 21.8 mg L⁻¹ for reactors 1, 2, and 3, respectively. Very high and consistent treatment efficiencies in terms of percentage removal were also obtained. Even at the lowest operating temperature, effluent BOD₅ removal efficiencies of over 89% were achieved by the reactors. BOD₅ removal efficiency for reactor 1 (10°C) was less than for reactors 2 and 3. The experimental results showed that for the range of organic loading tested, there was no effect on BOD₅ removal efficiency between operating temperatures of 22°C and 35°C. This also indicated that within this range, the reactors could possibly manage higher organic loading rates before the effects of temperature on the process would become noticeable. The percentage BOD₅ removal in all three reactors was higher than COD removal. COD treatment efficiency ranged from 88 to 90%. The influent-effluent TSS analyses are also presented in Table I. It was found that the higher removal efficiency was obtained in the reactor 1 (10°C) than the others. No satisfactory explanation can be given.

A typical track analyses, as shown in Figs. 1 and 2, traced the supernatant BOD₅ and COD in the reactors as a function of time. The influent BOD₅ and COD concentrations were 342 and 524 mg L⁻¹ respectively. All reactors showed a similar trend in BOD₅ and COD removal. The concentrations increased during the fill phase, then declined as the react phase progressed. It should be noted that the fill was started when the react phase began. It only took 8 minutes to deliver 2 litres of the poultry wastewater into each reactor. Carbon removal was largely completed within the first 30-40 minutes of aeration. These observations are consistent with those reported by other researchers (Alleman et al. 1979; Dennis and Irvine 1979;...
After this initial period, substrate removal from the supernatant practically ceased. Based on the track analyses, the reaction rate constants and their temperature coefficients were calculated. The reaction kinetics in the initial stage (approximately the first 40 minutes) can be assumed to be an overall second-order reaction; first order with respect to substrate concentration and first order with respect to biomass concentration (Dennis and Irvine 1979). The kinetic equation can therefore be written as follows:

\[ \frac{dc}{dt} = K \cdot C \cdot M \]  

where \( \frac{dc}{dt} \) = rate of change of substrate concentration; \( K \) = reaction rate constant; \( C \) = substrate concentration; \( M \) = biomass concentration; and \( t \) = time.

However, since the change in biomass concentration is negligible as compared with the initial biomass, the biomass concentration can be assumed constant (Irvine and Richter 1976; Dennis and Irvine 1979). A pseudo first-order kinetic equation with respect to \( C \) can therefore be adopted:

\[ \frac{dc}{dt} = K' \cdot C \]  

where \( K' = KM \). After rearrangement and integration,

\[ \ln c - \ln c_0 = K't \]  

where \( c_0 \) = initial substrate concentration.

The kinetic constant \( K \) can be obtained by dividing the slope of the regression line \( K' \) by the average biomass concentration during the test cycle. This is only valid for the initial stage of the reaction phase, when active substrate consumption is taking place. The temperature coefficients for the reaction rate constants were then computed by finding the slope of the regression line of \( K \) versus temperature. The results of the computation are summarized in Table II. The data indicated that the BOD5 reaction rate constants are temperature dependent. A higher initial reaction-rate constant was obtained with a higher operating temperature.

Table II: Kinetic coefficient of BOD5 removal from linear regression of \( \ln (\text{BOD5}) \) VS reaction time.

<table>
<thead>
<tr>
<th>Reaction rate constant ( K ) (litre mg(^{-1}))</th>
<th>Temp. coefficient ( K' ) (litre mg(^{-1})°C(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor 1 (10°C)</td>
<td>0.0014 (0.98)</td>
</tr>
<tr>
<td>Reactor 2 (22°C)</td>
<td>0.0098 (0.96)</td>
</tr>
<tr>
<td>Reactor 3 (35°C)</td>
<td>0.0109 (0.97)</td>
</tr>
<tr>
<td>Reactor 3 (35°C)</td>
<td>3.76 x 10(^{-4}) (0.90)</td>
</tr>
</tbody>
</table>

* Correlation coefficient.

Fig. 3 displays the dissolved oxygen profile for the three reactors. The shapes of the DO profile were similar for all the trials monitored. The fill period was started when aeration commenced. The DO concentration therefore decreased until the end of the fill period. After this the DO level increased steadily until the end of the react period. Fig. 4 shows track analyses of supernatant ammonium and nitrate nitrogen. The data indicated that ammonia removal from the wastewater was about 38% at the higher temperature (35°C). Ammonia removal was insignificant for the reactors operated at 10°C and 22°C. Nitrate concentrations dropped rapidly in reactors 2 and 3 (higher temperatures) immediately after feeding. A rapid denitification process took place for reactors 2 and 3. The nitrification process occurred only after the DO levels of the reactors were increased. However, no nitrification process was observed in reactor 1. The nitrate concentration remained very low (less than 0.1 mg L\(^{-1}\)) in this reactor. The denitrification process using a primary-sludge carbon source in SBR was reported upon previously by Abufayed and Schroeder (1986). As denitrification is carried out by heterotrophic facultative
bacteria that use nitrate as an alternative electron acceptor to oxygen in an anoxic environment, feeding is required to provide a carbon and energy source. The rate of denitrification was understood to be determined by the release of organic and nitrogenous matter from the feed.

The results of track analyses of BOD5 and nitrate indicated that the soluble substrate was removed from the solution in the first 30-40 minutes of the aeration, while ammonium nitrogen was converted to nitrate form at the point of inflection of the DO curve. Peil and Gaudy (1975) concur with these results.

In conclusion, this preliminary study showed that SBR technology can be used successfully in the treatment of poultry processing wastewater.

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REFERENCES


