Treatment of anaerobically treated domestic wastewater using rotating biological contactor

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Abstract A small-scale pilot plant consisting of a three-stage RBC has been investigated for the removal of E. coli, COD fractions and ammonia from the effluent of an UASB reactor treating domestic wastewater. The results obtained reveal that a three-stage system operated at a HRT of 3.0 h represents an effective post-treatment process. The remaining COD in the final effluent was only 51 (± 7) mg/l. Ammonia concentration was reduced by 67 (± 7.6) %. The overall E. coli reduction was 1.39 log10 at an influent count of 6.5 log10 corresponding to an overall removal efficiency of 95.8 (± 4.7) %. However, according to prevailing standards, residual E. coli counts are still high for unrestricted reuse for irrigation purposes. When the system was operated at a HRT of 10 h, overall E. coli removal and ammonia reduction were 99.9 (± 0.05)% and 92 (± 6.5) % respectively. At a HRT of 10 h, recirculation of the 3rd stage effluent to the 1st stage reduced the residual of E. coli in the final effluent from 2 × 103 to 9.8 × 102/100ml. Moreover, the recirculation of nitrified effluent from the 3rd stage to the 1st stage increased ammonia removal in the stage 1 from 23 to 43 %. This relatively high ammonia removal likely can be attributed to the supply of nitrifiers from 3rd stage to the 1st one.

Keywords COD, E. coli; nitrification, post-treatment; RBC; recirculation

Introduction

The Up-flow Anaerobic Sludge Blanket (UASB) reactor represents a good system for the pre-treatment of domestic wastewater (Zeeman and Lettinga, 1999). However, pathogen removal in anaerobic reactors is insignificant. Also ammonia concentration in the UASB effluent is relatively high. Consequently a post-treatment aerobic step is generally required. Due to its relative low cost and simple operation and maintenance, the rotating biological contactor (RBC) is considered by many engineers to be an appropriate post-treatment technique.

The efficiency of RBC for improving physico-chemical characteristics of wastewater has been extensively investigated (Castillo et al., 1997). Recently, Tawfik et al. (2002) studied not only COD reduction and the nitrification rate, but also the fate of E. coli in the system. The results showed that the use of a two-stage RBC system for the treatment of UASB effluent has substantially reduced E. coli counts, but residual numbers were higher than the limits set by WHO (1989). In an attempt to improve the microbiological quality of the effluent, the use of a three-stage RBC has been investigated. The results of this study are presented in this paper.

The objectives of this study are,

- to evaluate the efficiency of a three-stage RBC operated at different HRT or OLR for E. coli, COD fractions removal and nitrification rate.
- to evaluate the effect of recirculation of the final effluent on the performance of the three-stage RBC system.
Material and methods
The experimental arrangements (Figure 1) consisted of a three-stage RBC system fed with the anaerobic effluent of a 6.0 m³ UASB pilot plant, which had been previously investigated by Grin et al. (1985). The UASB was fed with raw domestic wastewater collected in a combined sewer system of the village of Bennekom, The Netherlands. The UASB reactor was operated at an average water temperature of 14°C.

UASB effluent
The main characteristics of the UASB reactor effluent, which in fact did not perform satisfactorily during this experimental period, are summarised in Table 1.

RBC characteristics
The RBC consisted of three stages. The first two stages are provided with internal settling tank polystyrene foam disks (diameter 0.6 m and thickness 0.02 m). The last stage is provided with polyurethane rotating disks (specific surface area 1,000 m²/m³), the diameter of which are 0.6 m and the thickness 0.01 m. The surface areas of 1st, 2nd and 3rd stages of the RBC are 6.5, 6.5 and 45.0 m². In the 1st and 2nd stage of the RBC about 40% of the rotating discs are submerged. In the 3rd stage 33% of the discs are submerged. The rotational speed of the disks was fixed at 5 rpm throughout the period. A variable speed motor device drives all the RBC stages. The net volume of the 1st, 2nd and 3rd stages are 60 l, 60 l and 35 l, making up a total net volume of 155 l.

Operating conditions
The system was operated under ambient temperature ranging from 11.0 to 17.0°C was evaluated. E. coli and COD fractions removals as well as the nitrification rate at HRT of 3 and 10 h were determined.

Recirculation set up
In one of the experimental runs, effluent of the 3rd stage was circulated to the 1st stage. In this study, the recirculation ratio was defined as the ratio of the returned flow to that of the inlet. The effect of effluent recirculation on the overall removal of E. coli, COD fractions and the nitrification rate was examined at HRT of 10 h.

Table 1 Characteristics of the UASB effluent

<table>
<thead>
<tr>
<th></th>
<th>COD mg l⁻¹</th>
<th>NH₄-N mg l⁻¹</th>
<th>TKN mg l⁻¹</th>
<th>E. coli /100ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>total</td>
<td>274 ± 39</td>
<td>64 ± 21</td>
<td>113 ± 48</td>
<td>55 ± 8</td>
</tr>
<tr>
<td>Sus.</td>
<td>104 ± 31</td>
<td>43 ± 14</td>
<td>55 ± 8</td>
<td>3.5 × 10⁶ ± 0.2 × 10⁶</td>
</tr>
<tr>
<td>Coll.</td>
<td>113 ± 48</td>
<td>43 ± 14</td>
<td>55 ± 8</td>
<td>3.5 × 10⁶ ± 0.2 × 10⁶</td>
</tr>
<tr>
<td>Sol.</td>
<td>55 ± 8</td>
<td>3.5 × 10⁶ ± 0.2 × 10⁶</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1 Schematic description of the RBC systems
Sampling and analytical methods

48 hr composite samples of the influent and the effluent of each reactor were collected in containers stored in the fridge at 4°C for analyses. COD was analysed using the micro-method as described by Jirka and Carter (1975). Ammonia, nitrite and nitrate were determined using an auto-analyser (SKALAR-SA 9000). Total Kjeldahl nitrogen was measured according to the Dutch Standard Normalised Methods, (1969). E. coli examination was performed according to the method described by Havelaar et al. (1988).

Results and discussion

Efficiency of three-stage system

COD fractions removal. The results presented in Table 2 show that increasing the overall HRT of the three-stage RBC system from 3.0 to 10.0 h achieved a minor increase in the removal of different COD fractions. The average residual COD total values decreased from 51 to 43 mg litre⁻¹. Moreover, the measured COD total, COD suspended, COD colloidal and COD soluble concentrations of the two-stage RBC effluent (at total HRT of 2.5 h and OLR of 24 g COD m⁻².d⁻¹) were 65, 13, 2 and 50 mg litre⁻¹ respectively. This indicates that only 14 mg litre⁻¹ of COD total were removed in the 3rd stage. These results emphasise previous findings of Tawfik et al. (2002) who indicated that a two-stage RBC system operated at a HRT of 2.5 h and OLR of 24 g COD m⁻².d⁻¹ is recommended when the treated wastewater is used for restricted irrigation.

Furthermore the results in Table 2 show that most of COD particulate (COD colloidal and COD suspended) was removed in the 1st stage and almost completely removed in the 2nd stage at HRT of 2.5 h. Only small fraction of COD particulate was removed in the 3rd stage of the system (see Table 2). This indicates that entrapment of COD suspended and adsorption of COD colloidal takes place on the surface of the biofilm.

Nitrification. Increasing the overall HRT of the three-stage RBC from 3.0 to 10.0 h, a considerable improvement of ammonia removal was achieved as shown in Table 3. The average residual value of ammonia in the final effluent decreased from 12.0 to 2.2 mg litre⁻¹ and consequently, the nitrate concentration increased from 20 to 39 mg litre⁻¹.

The results presented in Table 3 show that nitrification in the 1st stage of the three-stage RBC at HRT of 1.25 and 4.0 h consequently OLR of 47 and 15.3 g COD total m⁻².d⁻¹ was very limited. This was due to the presence of an insufficient NH₄-N oxidiser population at high OLR, as they cannot compete with heterotrophs for space and oxygen. It is clear as the results presented in Table 3 indicate, as in fact could be expected, that the nitrification mainly proceeded in the 2nd and 3rd stages of the system, where the residence time of nitrifiers is relatively high here as a result of the relatively low growth of heterotrophic organisms at low OLR. The influence of OLR is clearly reflected by the results depicted in Table 3. These results demonstrate that at an OLR exceeding 25 g COD m⁻².d⁻¹, heterotrophic bacteria still prevailed in the 2nd stage of the three-stage RBC. The nitrifying

Table 2 COD fractions removal at different HRT

<table>
<thead>
<tr>
<th>Total HRT</th>
<th>Stage no.</th>
<th>UASB eff.</th>
<th>3 h</th>
<th>10 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRT/stage</td>
<td></td>
<td>1st stage</td>
<td>2nd stage</td>
<td>3rd stage</td>
</tr>
<tr>
<td>1.25 h</td>
<td></td>
<td>1.25 h</td>
<td>0.5 h</td>
<td>4 h</td>
</tr>
<tr>
<td>CODtotal</td>
<td>272 ± 44</td>
<td>133 ± 22</td>
<td>65 ± 7</td>
<td>51 ± 7</td>
</tr>
<tr>
<td>CODsuspended</td>
<td>90 ± 38</td>
<td>53 ± 22</td>
<td>13 ± 8</td>
<td>3 ± 3</td>
</tr>
<tr>
<td>COD colloidal</td>
<td>63 ± 12</td>
<td>15 ± 12</td>
<td>2 ± 2</td>
<td>2 ± 2</td>
</tr>
<tr>
<td>COD soluble</td>
<td>119 ± 35</td>
<td>66 ± 15</td>
<td>50 ± 9</td>
<td>46 ± 8</td>
</tr>
</tbody>
</table>
bacteria were dominant in the 3rd stage of the RBC when the OLR dropped to 1.8 g COD m\(^{-2}.d^{-1}\), almost complete nitrification was observed.

**E. coli removal.** The results in Figure 2a show that increasing the overall HRT of the three-stage system from 3.0 to 10.0 h achieved a significant reduction of E. coli counts from \(1.3 \times 10^5\) to \(2.0 \times 10^3/100\text{ml}\) corresponding to the overall removal efficiency of 95.8 \(\pm\) 4.7 and 99.9 \(\pm\) 0.05\% respectively. The RBC effluents E. coli count can be used for restricted irrigation but still does not comply with the limits set by WHO (1989), for reuse in unrestricted irrigation.

The results in Figure 2b show that the removal of E. coli only significantly improves once the concentration of the dispersed COD\(_{\text{suspended}}\) and COD\(_{\text{colloidal}}\) have become very low, and HRT has increased from 3.0 to 10 h. This indicates the importance of the removal of dispersed COD to achieve a satisfactory E. coli removal. Part of the E. coli will be removed in the 1st stage as a result of adsorption and sedimentation i.e. the fraction of pathogenic bacteria attached on the suspended solids. The free dispersed E. coli was adsorbed in the subsequent stages.

**Effect of recirculation of nitrified effluent on the performance of RBC system**

**COD removal.** The results presented in Figure 3a show that the COD values of the final effluent were almost the same with and without recirculation. On the other hand residual COD\(_{\text{total}}\) in the 1st stage system of the three stages decreased from 118 mg l\(^{-1}\) (without recirculation) to 76 mg l\(^{-1}\) (with recirculation). This can be due to the supply of dissolved oxygen from 3rd stage to the 1st stage as a result of the recirculation of final effluent.

**Nitrification.** Recirculation of the final effluent reduced ammonia concentration in the effluent of the 1st stage by 43\% as compared to 23\% (without recirculation) at a recirculation ratio of 1 and at OLR of 15 g COD m\(^{-2}.d^{-1}\) as shown in Figure 3a. This relatively high

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**Table 3** Ammonia removal at different HRT or OLR

<table>
<thead>
<tr>
<th>Total HRT stage no.</th>
<th>UASB eff.</th>
<th>3 h</th>
<th>10 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRT/stage</td>
<td>1st stage</td>
<td>2nd stage</td>
<td>3rd stage</td>
</tr>
<tr>
<td>OLR (gCOD m(^{-2}.d^{-1}))</td>
<td>1.25 h</td>
<td>25</td>
<td>1.8</td>
</tr>
<tr>
<td>47</td>
<td>25</td>
<td>1.8</td>
<td>52 ± 16</td>
</tr>
<tr>
<td>Ammonia (mg l(^{-1}))</td>
<td>25 ± 11</td>
<td>12 ± 6</td>
<td>52 ± 16</td>
</tr>
<tr>
<td>Nitrate (mg l(^{-1}))</td>
<td>0.4 ± 0.4</td>
<td>2.8 ± 1.5</td>
<td>1.5 ± 1.1</td>
</tr>
<tr>
<td>52 ± 10</td>
<td>44 ± 11</td>
<td>14 ± 13</td>
<td>58 ± 6</td>
</tr>
<tr>
<td>TKN (mg l(^{-1}))</td>
<td>32 ± 6</td>
<td>20 ± 11</td>
<td>5.4 ± 4</td>
</tr>
<tr>
<td>Nitrif. rate (gNO3.m(^{-2}.d^{-1}))</td>
<td>0.3</td>
<td>1.2</td>
<td>0.3</td>
</tr>
</tbody>
</table>

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**Figure 2a** The effect of staging RBC treating UASB effluent on the E. coli removal

**Figure 2b** The relationship between COD\(_{\text{suspended}}\), COD\(_{\text{colloidal}}\) and E. coli removal in an RBC
ammonia reduction can be attributed to the supply of nitrifiers from 3rd stage to the 1st one as a result of the recirculation of nitrified effluent.

E. coli removal. From the results are presented in Figure 3b it is clear that recirculation improves the E. coli removal in the 1st stage of the three-stage RBC. The reduction increased from 1.1 without recirculation to 1.8 \( \log_{10} \) with recirculation. Average residual E. coli values in the final effluent decreased from \( 0.2 \times 10^4 \) to \( 9.8 \times 10^2/100 \text{ml} \). Consequently, the median count of E. coli in the final effluent satisfies WHO criteria for unrestricted irrigation (1989). This could be attributed to the fact that recirculation of the final effluent which is rich in ciliates, nematodes and other E. coli predators like Vorticella, Carchesium, Trachelophylum Pusillum, Paramecium Candatum, Rotifers, Nematoda allows their presence in all stages of the RBC system where freely colloidal E. coli are easily predated by these organisms (Green et al., 1997).

Conclusions
- The addition of a 3rd stage RBC to the two-stage RBC slightly improved the overall removal efficiency of COD\(_{\text{total}}\), COD\(_{\text{suspended}}\), COD\(_{\text{colloidal}}\) and COD\(_{\text{soluble}}\) by only 8.0, 13, 2 and 6% respectively. Therefore, if the aim is only COD removal and partial removal of ammonia and E. coli, a two-stage RBC system operated at HRT of 2.5 h and OLR of 24 g COD\(_{\text{total}}\) m\(^{-2}\) d\(^{-1}\) is recommended.
- The additional 3rd stage achieved significantly better results for the overall removal of ammonia (52%). Therefore, if nitrification is the main objective, a three-stage RBC system at HRT of 3 h is recommended. Our previous studies showed also that the two-stage RBC system can achieve almost complete nitrification but at longer HRT of 5 h (Tawfik et al., 2002).
- If E. coli removal is required to use the treated wastewater for unrestricted irrigation purposes, a three-stage RBC at HRT of 10 h is recommended.
- The recirculation (50%) of the final effluent at a HRT of 10 h, reduced residual E. coli in the final effluent from \( 2.0 \times 10^3 \) to \( 9.8 \times 10^2/100 \text{ml} \) but improved neither the overall COD removal efficiency nor the nitrification rate.

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References


