Integrated upflow anaerobic sludge blanket and radial-flow aerobic reactors for sewage treatment.

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Abstract Integrated anaerobic/aerobic systems have been considered feasible alternatives concerning technical and economic aspects for treating domestic wastewaters.

The main modification in the UASB reactor concerns this association with the RAIB. The UASB effluent was distributed through openings along its side walls to the RAIB, allowing the elimination of collecting channels and feeding devices from the latter reactor.

The objective of this work was to promote organic matter (raw and soluble) and nitrogen removal from domestic sewage.

Organic matter (as COD) and volatile suspended solids removal achieved efficiencies of 80 % and 89 %, respectively. Under stable operational conditions, the system effluent presented COD and volatile suspended solids values of 110 mg·L⁻¹ and 16 mg·L⁻¹, respectively. Efficiencies of 90 % for COD and volatile suspended solids removal were achieved with an organic loading rate of 4.0 kg COD·m⁻³·d⁻¹.

Keywords UASB, radial reactor, domestic sewage, nitrification, denitrification, pilot scale.

Introduction Anaerobic effluents’ characteristics are frequently inappropriate to obey the standard discharge established by environmental protections agencies for treated wastewater. Frequently, a post-treatment system must be applied to remove part of the residual organic matter fraction and nutrients. A complementary system must be provided, depending on the final destination of the effluents.

The combined anaerobic/aerobic systems have been successfully used for domestic sewage treatment with economical benefits regarding implantation and operation costs. The anaerobic unit can remove up to 80% of the influent organic matter at very limited energy costs and low excess-sludge production, while the aerobic phase can be proceeded at reduced energy consumption and with limited waste sludge to be treated and disposed.

VIEIRA et al. (2000) suggested a combined system composed of two fixed-bed reactors, including a radial-flow aerobic immobilized biomass (RAIB) and a horizontal-flow anaerobic immobilized biomass (HAIB). The system has shown promising results and has produced effluents containing COD concentrations below 40 mg·L⁻¹ and approximately 95% of nitrogen removal.

GARBOSSA (2003) developed a radial-flow anaerobic/aerobic immobilized biomass reactor (RFAAIB) combining anaerobic and aerobic chambers in a single reactor, aiming organic matter, solids and nutrients removal. The system achieved efficiency of 88%, 86% and 95% in the bio-
chemical oxygen demand reduction process, volatile suspended solids retention and nitrification, respectively. Additionally, operational conditions favored simultaneous nitrification and denitrification (SND), resulting in a 99% NH$_4^+$-N and a 70% NO$_3^-$-N removal.

This paper intend to present the results obtained from the operation of a new reactor configuration, consisted of a central unit – an upflow anaerobic sludge blanket reactor (UASB) associated to a radial-flow aerobic immobilized-biomass (RAIB). The system has shown to be efficient in respect to COD (chemical oxygen demand) and SS (suspended solids). The UASB effluent was distributed to the RAIB through openings along its side walls, allowing the elimination of collecting channels in the first reactor and feeding devices in the latter reactor. The RAIB reactor was meant to promote solids retention and UASB effluent nitrification. However, contrarily to expectations based on the previous studies with RAIB, nitrification was poor, probably due to the position of the aeration device in respect to the fixed bed. Internal modifications in the RAIB reactor are going to be made for improving nitrification.

**Material and methods**
The following stages were considered through this work: - System designing data (UASB+ RAIB), obtained from anaerobic biotechnology background. – System operation. – Data analysis for detecting possible operational problems aiming a better performance and functioning of the system. – Performance evaluation of the integrated anaerobic/aerobic system in the organic matter and solids removal.

**UASB reactor**
The UASB reactor was constructed with a reinforced plastic with fiber glass (RPFG) material with 2.0 m height, 450 mm diameter and a working volume of 286 L. A photo of the reactor is presented in Figure 1a.

On its base, an inverted cone provides high velocity at the bottom which decreases along the cone height. The velocity gradient imposed was meant to create conditions for sludge granulation. At the top, at 1.48 m above the reactor base, the effluent flows through a perforated distributor with 12 holes of 3 cm each, displayed at the UASB reactor lateral wall. Five collecting points are located along the UASB reactor as presented in Figure 1a.

**RAIB reactor**
The former RAIB reactor was developed and operated by GARBOSSA (2003), and consisted of a unique reactor composed of anaerobic and aerobic chambers disposed along the reactor’s radius. In this research, the RAIB reactor is coupled to the UASBB reactor. It was also constructed with reinforced plastic with fiber glass (RPFG). It was 57 cm height, 980 mm diameter, resulting in the working volume of 215 L. A scheme of the reactor is presented in Figure 1b. The RAIB was composed of two chambers separated by a stainless steel screen with 580 mm diameter. On the first chamber, with a working volume of 47 L, 12 porous stones were equally distributed and connected to an air compressor to provide proper aeration and mixing during aerobic stage. The second chamber (working volume of 168 L) contained the material used for the biomass immobilization.
Biomass immobilization support
The fixed bed for biomass immobilization was composed of polyurethane foam matrices with 20 mm sides, apparent density of 23 kg·m$^{-3}$ and porosity of approximately 95%.

Inoculation sludge
The UASB reactor was inoculated approximately with 40 L of sludge from a UASB reactor taken from the Wastewater Treatment Plant in USP and immediately placed in the pilot reactor. Before the beginning of the operation the transferred sludge was kept in contact with the raw wastewater for 24 hours.

Operation
The research was conducted for 127 days. The start of the system was carried out at the flow rate of 6 L·h$^{-1}$, which was progressively increased, as the system presented operational stability, up to the design flowrate (36 L·h$^{-1}$).

Based on the values recommended in the literature, the UASB reactor was operated at the HRT (hydraulic retention time) of approximately 8 hours. As reported by VIEIRA et al. (2000), the HRT of 4 hours was enough to promote nitrification in the RAIB. For this reason, a HRT of 6 hours was adopted, resulting in the total HRT of 14 hours for the integrated system (UASB+RAIB). The system was operated at room temperature.

Results and discussion

Influent and effluent characteristics
Average values of the UASB and RAIB reactors influents and effluents obtained for each parameter are presented in Tabela 1.
**Table 1:** Summary of the results obtained during the system operation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>n° samples</th>
<th>Raw Influent</th>
<th>UASB Effluent</th>
<th>RAIB Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity</td>
<td>mgCaCO₃·L⁻¹</td>
<td>18</td>
<td>77 ± 39</td>
<td>103 ± 42</td>
<td>110 ± 46</td>
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<tr>
<td>AVT</td>
<td>mgHAc·L⁻¹</td>
<td>18</td>
<td>54 ± 22</td>
<td>29 ± 35</td>
<td>30 ± 12</td>
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<tr>
<td>COD</td>
<td>mg·L⁻¹</td>
<td>15</td>
<td>564 ± 261</td>
<td>181 ± 54</td>
<td>110 ± 42</td>
</tr>
<tr>
<td>CODf</td>
<td>mg·L⁻¹</td>
<td>15</td>
<td>206 ± 69</td>
<td>108 ± 41</td>
<td>85 ± 40</td>
</tr>
<tr>
<td>pH</td>
<td>---</td>
<td>18</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
</tr>
<tr>
<td>TS</td>
<td>mg·L⁻¹</td>
<td>11</td>
<td>534 ± 154</td>
<td>355 ± 77</td>
<td>330 ± 62</td>
</tr>
<tr>
<td>TSS</td>
<td>mg·L⁻¹</td>
<td>11</td>
<td>185 ± 108</td>
<td>42 ± 19</td>
<td>11 ± 6</td>
</tr>
<tr>
<td>VSS</td>
<td>mg·L⁻¹</td>
<td>11</td>
<td>153 ± 86</td>
<td>34 ± 14</td>
<td>16 ± 24</td>
</tr>
<tr>
<td>FSS</td>
<td>mg·L⁻¹</td>
<td>11</td>
<td>28 ± 24</td>
<td>8 ± 10</td>
<td>2 ± 3</td>
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<tr>
<td>TDS</td>
<td>mg·L⁻¹</td>
<td>11</td>
<td>369 ± 61</td>
<td>313 ± 68</td>
<td>321 ± 61</td>
</tr>
<tr>
<td>VDS</td>
<td>mg·L⁻¹</td>
<td>11</td>
<td>225 ± 68</td>
<td>154 ± 41</td>
<td>165 ± 59</td>
</tr>
<tr>
<td>FDS</td>
<td>mg·L⁻¹</td>
<td>11</td>
<td>133 ± 33</td>
<td>159 ± 48</td>
<td>153 ± 36</td>
</tr>
</tbody>
</table>

**Chemical oxygen demand**

CODt variations for the two reactors, during the experiment are illustrated in Figure 2a. The influent CODt varied from 230 up to 1160 mg·L⁻¹, however its average throughout the operation period was 570 mg·L⁻¹ and 260 mg·L⁻¹ as standard deviation. Besides the influent CODt variations shown, both the effluents (UASB and RAIB) behaved steadily with 64 mg·L⁻¹, 272 mg·L⁻¹ and 180 mg·L⁻¹ as minimum, maximum and average values respectively for the UASB reactor and 50 mg·L⁻¹, 176 mg·L⁻¹ and 110 mg·L⁻¹ as minimum, maximum and average values respectively for the RAIB.

**Bicarbonate alkalinity**

The average BA value in the UASB was 40.5 mg·L⁻¹ ± 42.5 mg·L⁻¹, in the influent, and 83.0 mg·L⁻¹ ± 44.0 mg·L⁻¹, in the effluent. In being so, a BA production can be noticed, probably due to the sin-trofism among microorganisms involved in organic acids, H₂ and CO₂ production and methano-genesis. However, the RAIB effluent value for BA was 89.0 mg·L⁻¹ ± 49.0 mg·L⁻¹, indicating that no nitrification occurred.

**Solids**

Values for TSS in both UASB and RAIB along the experiment are illustrated in Figure 2b. This figure shows the temporal variation on the influent TSS value, 185 mg·L⁻¹ ± 108 mg·L⁻¹. Concerning the UASB and RAIB effluents, TSS values presented a steady behavior during the experiment, 42 mg·L⁻¹ ± 19 mg·L⁻¹ e 11 mg·L⁻¹ ± 6 mg·L⁻¹ respectively, showing a high retention rate of the integrated system.
Figure 2: (a) Concentrations of COD influent (●), COD UASB effluent (■) and COD RAIB effluent (▲). (b) Concentrations of TSS influent (●), TSS UASB effluent (■) and TSS RAIB effluent (▲).

Conclusions
The integrated system, composed of the UASB reactor and the RAIB, presented very good performance concerning organic matter (raw and soluble) and solids (total, suspended and soluble) removal. Although expected, nitrification was not obtained with the actual RAIB configuration.

References