DEVELOPMENT AND EVALUATION OF A PARTITIONED UPFLOW ANAEROBIC SLUDGE BLANKET (UASB) REACTOR FOR THE TREATMENT OF DOMESTIC SEWAGE FROM SMALL VILLAGES

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ABSTRACT

This paper presents the development and field evaluation of a partitioned UASB reactor, conceived for the treatment of domestic sewage from small villages and areas with large variation of the daily flowrate. In such situations, conventional single compartment UASB reactors are submitted to very extreme hydraulic conditions, that can disturb the behaviour of the treatment system. In the partitioned reactor, which is constituted of three digestion compartments, three gas separation devices and a single settler compartment, an adequate distribution of the variable incoming wastewater into one, two or three digestion chambers, allows the establishment of more stable up flow velocities and less occurrence of dead zones. As a result, a better contact between substrate and biomass can be achieved and an improved performance of the system can be expected.

The partitioned UASB reactor was evaluated during a period of 16 months of continuous operation. The system presented a very good performance during most of the operational period, showing very high efficiencies when the reactor was operated at a HRT of 7.5 hours. In this phase, the unit presented COD removal efficiencies around 80% and an average SS concentration in the final effluent of 32 mgSS/L. The research is still going on, focusing on the evaluation of the system under higher hydraulic loads and on the assessment of sludge activity and dehydration potential.

Due to the operational simplicity and low cost of the system, it is believed that this type of reactor can become a very attractive alternative for domestic sewage treatment in small villages, particularly in Brazil where the number of rural areas with wastewater treatment is negligible. © 1999 Published by Elsevier Science Ltd on behalf of the IAWQ. All rights reserved.

KEYWORDS

Domestic sewage; low cost treatment; partitioned reactor; UASB reactor.

INTRODUCTION

This work is part of a large research project that is actually going on in Brazil, named "National Research Program on Basic Sanitation - PROSAB". This part of the work focused on the investigation of a partitioned UASB reactor, which is constituted of three digestion compartments, three gas separation devices and a single settler compartment (see Figure 1). The working principle of the treatment system, with the three
digestion compartments operating in parallel, aims to provide a more stable hydraulic regime inside the reactor. Hence, the adequate distribution of the variable incoming wastewater, that can be directed into one, two or three digestion chambers, allows the establishment of more stable upflow velocities and less occurrence of dead zones.

In single chamber conventional UASB reactors, the occurrence of large flowrate variations of the incoming wastewater can pose very high upflow velocities, particularly in the apertures to the settler compartment. These high upflow velocities can induce sludge washout with subsequent efficiency drop due to the presence of particulate material in the final effluent. In the partitioned reactor, the variation of upflow velocities in each digestion chamber is much smaller, what in fact, besides allowing the maintenance of optimised mixing conditions in each chamber, also contributes to minimising the solids washout to the settler compartment. As a result, a better contact between substrate and biomass can be achieved and an improved performance of the system can be expected. Also, it is foreseen to have a more clarified effluent, due to a smaller flux of solids into the settler and better operational conditions of this important reactor component.

The partition of a single digestion compartment (conventional reactor) into tree chambers that operate in parallel (partitioned reactor) does not pose any significant extra cost to reactor structure, because this can be accomplished with cheap materials (e.g. a cement board, a thin brick wall etc.). On the contrary, the full cost of the reactor is expected to be much lower due to the fact that the total volume can be around 25% smaller than conventional single cell reactors.

For field evaluation, a 9 m³ reactor was constructed and operated during approximately 500 days. The reactor was fed with raw wastewater (after preliminary treatment) from a suburb area of Itabira City, which is located 100 km far from Belo Horizonte City (Brazil). During this 16-month operational period, the reactor was exposed to two different loading conditions, according to the hydraulic retention times tested (9.0 and 7.5 hours).

OBJECTIVES

This work had as the main objective the development and evaluation of a new concept of UASB reactor - a partitioned reactor - as well as the search for simpler construction methods and building materials in order to minimise the implementation and operation costs of the treatment unit. In reality, the gains in terms of construction costs are based on the reduction of the hydraulic retention time in the reactor, without efficiency loss. The performance of the system was evaluated during nearly 500 days of continuous operation, in relation to the removal of organic matter and presence of suspended solids in the final effluent. This was carried out for the reactor operating under different hydraulic retention times.

MATERIAL AND METHODS

Experimental units

The experiments have been carried out in a demonstration scale plant that is constituted of a partitioned UASB reactor, a sludge drying bed and a control house. The main design and construction characteristics of the reactor are presented in Table 1. A schematic of the reactor is shown in Figure 1.

Flow distribution

Initially, a very simple splitting box was adopted as a flow distribution system. Conventional brick walls were used to structure the box and valves and weirs used for flow control and distribution. The feeding of a specific reactor chamber was determined by the occurrence of a specific flowrate (minimum, mean or maximum), by adjusting the height of a corresponding weir.

During the second phase of the research a completely automated feeding system was implemented. This system is capable of measuring, controlling and distributing the flow to each reactor compartment. For this, a dedicated control software was developed that is capable of controlling and maintaining the operational conditions previously set by the user. The automation system is composed of one turbine valve for flow
measurement, three acting valves for flow control and two computer boards for electrical signal reception, process and transmission.

Table 1. Main reactor characteristics

<table>
<thead>
<tr>
<th>Description</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Depth (m)</th>
<th>Construction material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank structure</td>
<td>3.40</td>
<td>1.20</td>
<td>3.00</td>
<td>reinforced concrete</td>
</tr>
<tr>
<td>Three-phase separator (03 units)</td>
<td>bottom: 0.90</td>
<td>bottom: 0.90</td>
<td>0.52</td>
<td>coated steel</td>
</tr>
<tr>
<td>(03 units)</td>
<td>top: 0.20</td>
<td>top: 0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digestion chamber (03 units)</td>
<td>1.00</td>
<td>1.00</td>
<td>1.60</td>
<td>reinforced concrete and internal brick walls</td>
</tr>
</tbody>
</table>

Figure 1. Schematics of the partitioned UASB reactor.

Digestion chambers

The partition of the digester compartment into three chambers was simply achieved by the construction of two brick walls (10 cm wide), without any special coating. Since these partitions are aimed only to separate the upward flow, the walls do not need to be watertight and can be even thinner.

Control house

A control house was built in the area in order to provide operational support to the pilot plant. This unit has a small laboratory and an office from where the automation valves are controlled. Figure 2 depicts the reactor and control house.

Construction aspects

For cost and facility reasons the three-phase separators were fabricated in steel. The three devices received a protective epoxy coating to avoid corrosion and after 16 months of reactor operation this measure has shown to be adequate.
System start up

The start up of the system was proceeded with the inoculation of around 1.5 m$^3$ of sludge from the full scale UASB reactor located in the same area. A full load was applied from the second day of operation, resulting in a HRT of 9 hours and in a sludge load of 0.48 kgCOD/kgVTS.day. Despite these extreme operational conditions, the reactor performed very well.

Operational conditions

According to the conception previously defined for the research, the three reactor compartments were fed as follows. A summary of the operational conditions during phases I and II is presented in Table 2.

- feeding of only one chamber when the incoming flowrate was near the expected minimum;
- feeding of two chambers when the incoming flowrate was near the expected average;
- feeding of three chambers when the incoming flowrate was near the expected maximum.

<table>
<thead>
<tr>
<th>Operational phase</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRT (h)</td>
<td>9.0</td>
<td>7.5</td>
</tr>
<tr>
<td>Minimum flowrate (m$^3$/h)</td>
<td>0.50</td>
<td>0.60</td>
</tr>
<tr>
<td>Average flowrate (m$^3$/h)</td>
<td>1.00</td>
<td>1.20</td>
</tr>
<tr>
<td>Maximum (m$^3$/h)</td>
<td>2.00</td>
<td>2.40</td>
</tr>
<tr>
<td>Minimum upflow velocity (m/h)</td>
<td>0.50</td>
<td>0.60</td>
</tr>
<tr>
<td>Average upflow velocity (m/h)</td>
<td>0.50</td>
<td>0.60</td>
</tr>
<tr>
<td>Maximum upflow velocity (m/h)</td>
<td>0.67</td>
<td>0.80</td>
</tr>
</tbody>
</table>

System monitoring

The monitoring program involved the accomplishment of the following main parameters: pH, temperature, alkalinity, total and filtered COD, total and filtered BOD, TSS and VSS. Composite samples were taken for the analysis of COD, BOD and solids. All analyses were performed according to the Standard Methods for the Examination of Water and Wastewater (AWWA/APHA/WEF, 1995).

RESULTS AND DISCUSSION

Operational performance

The main results obtained during the operational period are depicted in Table 3 and in Figures 3, 4 and 5. During phase I, which extended for a period of 213 days, three different periods were observed in terms of reactor performance. Two of those three periods were considered non typical, with the system showing low efficiencies, the first related to reactor start up (up to day 30) and the second related to a phase prior to
sludge withdrawal (day 150 to 195). In this last period of phase I, a significant expansion of the sludge blanket and solids wash out was noticed, with the reactor efficiency dropping to around 55% in terms of COD removal. However, in the intermediate period (day 30 to 150) the reactor performance was considered fairly satisfactory, with an average COD removal efficiency of 73% and an average effluent SS concentration of 50 mgSS/l being observed. For this removal efficiency, the average COD concentration in the final effluent was 191 mgCOD/l.

During phase II the reactor was operated with a HRT of 7.5 hours and its performance surpassed the expectation. The average COD removal efficiency reached 79% and the solids concentration in the effluent showed an average value of 32 mg/l. For this removal efficiency, the average COD concentration in the final effluent was 144 mgCOD/l. It is important to mention that the results usually reported in the literature for conventional UASB reactors treating domestic sewage, under the same environmental conditions, indicate efficiency removals below 70% (in terms of COD) and suspended solids in the final effluent around 60 to 100 mgSS/l (van Haandel & Lettinga, 1984). In terms of BOD, the results were also very satisfactory, with an average removal of 74% and a final effluent concentration of around 75 mgBOD/l.

Table 3. Basic statistics of the system performance during phase II

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Number of data</th>
<th>Average value</th>
<th>Standard deviation</th>
<th>Variation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent COD&lt;sub&gt;i&lt;/sub&gt; (mg/l)</td>
<td>24</td>
<td>712</td>
<td>154</td>
<td>0.22</td>
</tr>
<tr>
<td>Effluent COD&lt;sub&gt;e&lt;/sub&gt; (mg/l)</td>
<td>24</td>
<td>144</td>
<td>52</td>
<td>0.36</td>
</tr>
<tr>
<td>CODt removal (%)</td>
<td>24</td>
<td>79</td>
<td>8</td>
<td>0.10</td>
</tr>
<tr>
<td>Influent BOD&lt;sub&gt;i&lt;/sub&gt; (mg/l)</td>
<td>24</td>
<td>312</td>
<td>91</td>
<td>0.29</td>
</tr>
<tr>
<td>Effluent BOD&lt;sub&gt;e&lt;/sub&gt; (mg/l)</td>
<td>24</td>
<td>75</td>
<td>43</td>
<td>0.57</td>
</tr>
<tr>
<td>BODt removal (%)</td>
<td>24</td>
<td>74</td>
<td>16</td>
<td>0.22</td>
</tr>
<tr>
<td>Influent SS (mg/l)</td>
<td>23</td>
<td>386</td>
<td>220</td>
<td>0.57</td>
</tr>
<tr>
<td>Effluent SS (mg/l)</td>
<td>21</td>
<td>32</td>
<td>19</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Notes: COD<sub>i</sub> = total COD; BOD<sub>i</sub> = total BOD

Figure 3. Results of influent and effluent COD.
Cost evaluation

A complete cost evaluation was carried out for the partitioned UASB reactor used in the experiments, leading to a total figure of approximately US$3,960.00. Considering the actual hydraulic operating condition (HRT=7.5 hours) and also a per capita wastewater contribution of 100 l/inhab.day (which is appropriate for small villages), one can estimate that a population equivalent of 285 inhabitants is contributing to the reactor, resulting in a per capita cost of around US$14.00. This can be considered very low when compared to the usual average costs of conventional UASB reactors in Brazil, which are usually ranging from 25 to US$35 per capita. Since the ultimate goal of this research is to reach a stable and efficient reactor operation condition at a 5-hour HRT, the reactor would present a final cost of less than US$10.00 per capita (for a population equivalent of around 430 inhabitants).

CONCLUSION

The reactor showed a good performance when operated at the hydraulic retention time frequently adopted for UASB reactors (HRT = 9 h). However, a better response of the system was achieved with the reduction of the HRT to 7.5 hours, when the average COD and BOD removal efficiencies were 79% and 74%, respectively. For these removal efficiencies, the average COD and BOD concentrations in the final effluent were 144 mgCOD/l and 75 mgBOD/l. Also, very low SS concentrations were observed in the final effluent, with an average figure of 32 mgSS/l.
Also during the start up period the reactor showed a good performance, although a high sludge load was applied (0.48 kgCOD/kgVTS.day). One can notice that this load is well above that usually referred to in the specialised literature: 0.05 to 0.15 kgCOD/kgVTS.day.

In relation to cost estimation, the reactor presented costs which were much lower than those usually observed for full-scale conventional UASB reactors (Chernicharo, 1997), even when scale factors were not considered. Hence, it can be stated that the partitioned UASB reactor can present a great technical and economical viability, being therefore very appropriate for the treatment of domestic sewage from small villages in Brazil.

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