Performance evaluation of a UASB – activated sludge system treating municipal wastewater

M. von Sperling*, V.H. Freire and C.A. de Lemos Chernicharo
*Department of Sanitary and Environmental Engineering, Federal University of Minas Gerais
Av. Contorno 842 – 7o andar, 30110-060 Belo Horizonte, Brazil (E-mail: marcos@desa.ufmg.br)

Abstract Recent research has indicated the advantages of combining anaerobic and aerobic processes for the treatment of municipal wastewater, especially for warm-climate countries. Although this configuration is seen as an economical alternative, it has not been investigated in sufficient detail on a worldwide basis. This work presents the results of the monitoring of a pilot-scale plant comprising of an UASB reactor followed by an activated sludge system, treating actual municipal wastewater from a large city in Brazil. The plant was intensively monitored and operated for 261 days, divided into five different phases, working with constant and variable inflows. The plant showed good COD removal, with efficiencies ranging from 69% to 84% for the UASB reactor, from 43% to 56% for the activated sludge system only and from 85% to 93% for the overall system. The final effluent suspended solids concentration was very low, with averages ranging from 13 to 18 mg/l in the typical phases of the research. Based on the very good overall performance of the system, it is believed that it is a better alternative for warm-climate countries than the conventional activated sludge system, especially considering the total low hydraulic detention time (4.0 h UASB; 2.8 h aerobic reactor; 1.1 h final clarifier), the savings in energy consumption, the absence of primary sludge and the possibility of thickening and digesting the aerobic excess sludge in the UASB reactor itself.

Keywords Municipal wastewater; anaerobic processes; aerobic processes; UASB; activated sludge; post-treatment

Introduction

The activated sludge process has been widely applied for the treatment of domestic and industrial wastewaters, due to its high efficiency, operational flexibility, possibility for nutrient removal, among other advantages. However, there are some disadvantages, namely: high mechanisation level, high construction and operational costs, sophisticated operation and the need for treating a substantial amount of sludge (von Sperling, 1997). In the past few years, the high-rate anaerobic processes, especially the UASB (Upflow Anaerobic Sludge Blanket) reactor has shown to be a technology capable of overcoming some of the disadvantages of the mechanised aerobic systems, especially because of the absence of energy consumption and lower excess sludge generation. Nevertheless, the treated effluent is usually unable to comply with most existing discharge standards (Chernicharo, 1997).

Aiming at balancing the advantages and disadvantages of both systems, recent research has indicated the benefits in combining the processes, with the anaerobic stage being followed by the aerobic stage. The advantages of the combination are: (a) lower energy consumption; (b) lower chemical consumption for dewatering; (c) less sludge to be disposed of; (d) less equipment required; (e) higher operational simplicity (von Sperling and Chernicharo, 1998).

Figure 1 presents the flowsheets of a conventional activated sludge plant and the UASB-activated sludge system. In either case, the sludge lines are also taken into account. In the alternative of UASB-activated sludge, an important feature of the system is the return of the aerobic excess sludge to the anaerobic reactor, where the solids undergo stabilisation, considerably simplifying the plant flowsheet and the sludge processing. This approach of
returning the activated sludge wastage to the UASB reactor has been tested experimentally by Souza and Foresti (1996) and Charleston et al. (1996) and showed to give good results.

In spite of the various advantages of the combined interaction of the UASB and the activated sludge systems, it has been the subject of little investigation for municipal wastewater treatment, even at a worldwide level. Some of the research undertaken is described below.

Colleti et al. (1997) investigated under laboratory scale an activated sludge plant, treating the effluent from a compartmentalised UASB reactor, which received municipal wastewater. The main objective was to determine the stoichiometric and kinetic coefficients of the activated sludge process working as a post-treatment of the UASB reactor. The system achieved removal efficiencies of 95% (BOD) and 88% (COD).

Souza and Foresti (1996) worked with a system composed of a UASB reactor followed by two aerobic Sequencing Batch Reactors in parallel. The system received synthetic wastewater. The removal efficiencies averaged 95% for COD and 85% for TKN.

Silva et al. (1995) investigated a pilot-scale UASB-activated sludge system, receiving an influent comprised of approximately 90% of industrial wastewater flow. The UASB

Figure 1  Comparison between the flowsheets of a conventional activated sludge system and an UASB-activated sludge system
reactor achieved removal efficiencies around 70% for COD and 80% for BOD. The activated sludge process was predominantly very unstable and subjected to filamentous bulking. In the more stable periods the removal efficiencies for the aerobic stage alone averaged 42% for COD and 63% for BOD. The instability was attributed to the high percentage of industrial wastewater flow.

Passing et al. (1999) presented one-year operational data from a full-scale UASB-activated sludge plant treating domestic wastewater for a design population of 100,000 inhabitants in Brazil. The average effluent concentrations were 174 mg/l (COD) and 47 mg/l (BOD). The plant had not yet needed wastage of the aerobic excess sludge.

The present paper investigates the performance of a pilot-scale UASB-activated sludge plant operated for a period of 261 days. The plant received actual municipal wastewater pumped from the main intercepting line of a large city in Brazil (Belo Horizonte, 2.0 million inhabitants). The plant is situated in the Pilot Installations Laboratory of the Department of Sanitary and Environmental Engineering, Federal University of Minas Gerais, Belo Horizonte.

**Methodology**

The UASB reactor has a volume of 416 L, feeding, besides the activated sludge system, other post-treatment lines. The activated sludge reactor has a volume of 23 L. The average frequency of sampling was 2 to 3 times per week. The aeration was by diffused air, and the DO level was kept around 2.0 mg/l. The operating period of 261 days was divided into the following five phases (see also Table 1):

- **Phase I**: Unseeded start-up of the activated sludge system (UASB reactor had been already previously started-up). Constant inflow.
- **Phase II**: Reduction of the Hydraulic Retention Time (HRT) in all units. Constant inflow.
- **Phase III**: Same average HRT as in previous phase. Variable inflow, simulating a typical diurnal pattern (peristaltic pump adjusted to follow a polynomial curve).
- **Phase IV**: Reduction of the HRT (volume) of the settler in the UASB reactor. This reduction was to force a lowering in the COD removal efficiency of the UASB reactor, aiming at exciting the activated sludge system more. Variable inflow (same flow and pattern as in previous phase).
- **Phase V**: 20% of the inflow by-passing the UASB reactor and entering the activated sludge system, in order to further excite the activated sludge system. Variable inflow (same flow and pattern as in previous phase).

**Table 1** Main characteristics of the five operational phases

<table>
<thead>
<tr>
<th>Phase</th>
<th>Duration (days)</th>
<th>UASB reactor</th>
<th>Aerobic reactor</th>
<th>Final settler</th>
<th>Total HRT</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>62</td>
<td>6.0</td>
<td>3.7</td>
<td>1.5</td>
<td>11.2</td>
<td>Constant inflow</td>
</tr>
<tr>
<td>II</td>
<td>48</td>
<td>4.0</td>
<td>2.8</td>
<td>1.1</td>
<td>7.9</td>
<td>Constant inflow</td>
</tr>
<tr>
<td>III</td>
<td>69</td>
<td>4.0</td>
<td>2.8</td>
<td>1.1</td>
<td>7.9</td>
<td>Variable inflow</td>
</tr>
<tr>
<td>IV</td>
<td>52</td>
<td>4.0</td>
<td>2.8</td>
<td>1.1</td>
<td>7.9</td>
<td>Reduction in volume of UASB settler</td>
</tr>
<tr>
<td>V</td>
<td>30</td>
<td>4.0</td>
<td>2.8</td>
<td>1.1</td>
<td>7.9</td>
<td>20% raw sewage by-pass to activated sludge</td>
</tr>
</tbody>
</table>

**Results and discussion**

The summary statistics of the results from each operational phase are presented in Table 2. The average COD removal efficiencies are summarised in Table 3. Figure 2 presents the
box-and-whisker plot of the final effluent COD distribution in the five operational phases. The box-and-whisker plot shows the minimum and maximum values (whiskers), together with the 25, 50 and 75 percentiles (box). The stepwise reduction in the average COD and SS concentrations, from the influent, effluent from UASB and final effluent are shown in Figures 3 and 4, respectively. Figure 5 plots the time series of the MLVSS concentration in the reactor of the activated sludge system. Other parameters have been monitored and analysed, being covered in detail in Freire (1999). BOD data has been collected, but the

Table 2 Summary statistics from the five operational phases

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Phase I</th>
<th>Phase II</th>
<th>Phase III</th>
<th>Phase IV</th>
<th>Phase V</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD average (mg/L)</td>
<td>958</td>
<td>137</td>
<td>105</td>
<td>734</td>
<td>114</td>
</tr>
<tr>
<td>COD number</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>SS average (mg/L)</td>
<td>443</td>
<td>25</td>
<td>23</td>
<td>251</td>
<td>32</td>
</tr>
<tr>
<td>SS number</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>VSS average (mg/L)</td>
<td>329</td>
<td>20</td>
<td>17</td>
<td>205</td>
<td>28</td>
</tr>
<tr>
<td>VSS number</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>MLSS average (mg/L)</td>
<td>562</td>
<td>1414</td>
<td>1415</td>
<td>1335</td>
<td>1055</td>
</tr>
<tr>
<td>MLSS number</td>
<td>7</td>
<td>8</td>
<td>18</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>MLVSS average (mg/L)</td>
<td>430</td>
<td>1235</td>
<td>1218</td>
<td>1158</td>
<td>928</td>
</tr>
<tr>
<td>MLVSS number</td>
<td>7</td>
<td>8</td>
<td>18</td>
<td>13</td>
<td>13</td>
</tr>
</tbody>
</table>

Infl: influent to UASB; InAS: influent to activated sludge (effluent from UASB); Effl: final effluent, from activated sludge

Table 3 Average COD removal efficiencies in four operational phases

<table>
<thead>
<tr>
<th>Phase</th>
<th>UASB</th>
<th>Activated sludge</th>
<th>UASB – activated sludge</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>84%</td>
<td>56%</td>
<td>93%</td>
</tr>
<tr>
<td>III</td>
<td>85%</td>
<td>43%</td>
<td>91%</td>
</tr>
<tr>
<td>IV</td>
<td>69%</td>
<td>51%</td>
<td>85%</td>
</tr>
<tr>
<td>V</td>
<td>68%</td>
<td>50%</td>
<td>–</td>
</tr>
</tbody>
</table>

Figure 2 Box-and-whisker plot of the distribution of the final effluent COD in four operational phases
number of samples is insufficient to support the same level of interpretation. Due to practical difficulties, sludge settleability tests and microbiological analyses have not been undertaken. In Figures 2, 3 and 4, only Phases II to V have been considered. Phase I was not included, because it did not represent a typical operation of the plant, being mainly associated with the specific condition of the start-up of the activated sludge plant.

Based on the tables, figures and additional analysis, the following comments are made:

- The average final effluent COD concentrations in Phases II, III and IV were around 55 mg/l, well below the discharge standard of 90 mg/l, set out by the State Environmental Agency.
- The Analysis of Variance undertaken with the final effluent COD indicated that there were no significant differences between Phases II, III and IV (Phase V is untypical,
because of the raw sewage by-pass to the activated sludge. An important consequence of this analysis is the conclusion that the variable inflow did not affect the performance of the activated sludge process.

- The reduction of the HRT in the UASB settler (Phase IV) resulted in a decrease in the COD removal efficiency of the UASB reactor, from 85% to 69%. However, the activated sludge was able to cope with the load increase, and the final effluent quality was not affected (as shown by the Analysis of Variance mentioned above).
- Phase I showed lower COD removal efficiencies in the activated sludge system, resulting from the acclimation of the biomass during the start-up period.
- The final effluent concentrations of SS during Phases II, III and IV were able to satisfy commonly applied international discharge standards.
- The higher values of SS in the final effluent during Phase V, which was characterised by the by-pass of 20% of raw sewage to the activated sludge, was due to sludge bulking. The bulking was only occasional during the other phases, but was systematic in Phase V.
- The MLVSS concentration in the reactor of the activated sludge system had average values around 1000 mg/l, but was highly variable during the operational phases. It took approximately 60 days for the biomass to reach the average value. This average value of 1000 mg/l was half of the design value adopted for the plant (2000 mg/l). However, the F/M ratio in Phases II, III and IV was within typical design values of conventional activated sludge plants.

Conclusions
In the more typical operational phases (II, III and IV), the overall performance was very good, as seen by the following results:

- Average COD removal efficiencies between 85% and 93%.
- Average final effluent COD concentrations between 50 and 58 mg/l.
- Average final effluent SS concentrations between 13 and 18 mg/l.

The combined system (UASB - activated sludge) showed to be a very good alternative for the treatment of municipal wastewaters, based on the performance of the system and the compactness of the treatment units (total hydraulic retention time of 7.9 h, computing the UASB reactor, activated sludge reactor and final clarifier).

References


