The use of upflow anaerobic sludge blanket reactors in the treatment of poultry slaughterhouse wastewater

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Abstract This work studied the performance of the dissolved air flotation (DAF) system and the start-up and the operation of two 450 m³ UASB reactors in a poultry slaughterhouse in Sorocaba, Brazil. The DAF presented reduction efficiency of grease and fats, suspended solids and COD 50% higher. The reactors were seeded with non-adapted sludge. The average COD of the reactor influent was 2,695mg/L; and the initial organic loading rate (OLR) and the initial sludge loading rate at the start-up were 0.51 kg COD/m³.day and 0.04 kg COD/kg VTS.day, respectively. The start-up period was 144 days. During this time the reactor flow rate and OLR were gradually increased. At the reactor start-up, the maximum OLR value was 2.1 kg COD/m³.day, the COD reduction was higher than 80%, and the concentration of volatile fatty acids (VFA) was below 100mg/L. The COD reductions, considering the reactor effluent raw COD and soluble COD were similar throughout the period studied in both reactors. The reactor effluent raw COD was approximately 10% higher than the soluble COD until the 225th day of operation. From the 225th day of operation this value increased 20% - 30% due to the sludge washout. The effluent soluble COD reduction, the effluent VFA concentration and the operational stability attested the good performance of UASB reactors in poultry slaughterhouse wastewater treatment.

Keywords Poultry slaughterhouse wastewater; anaerobic digestion; UASB reactor start-up; UASB reactor operation

Introduction

The poultry slaughter industry is of great importance to the São Paulo State and the southern part of Brazil. The poultry slaughter activity and the sale of ready-for-consumption poultry began in the 70s in Brazil, with an initial production of 270 tons. The development of this industry in the last decades, the technological and organizational improvements contributed to the significant increase in this industry, reaching 5.715 million tons in 2000. Nowadays, Brazil is the world’s second producer and third exporter of poultry (APA, 2000; Moraes and Paula Jr., 1999).

Poultry slaughterhouses generate wastewater, both in the process itself and in the washing of equipment and premises, characterized by high organic matter concentrations (DQO), suspended solid, grease and fats, nitrogen and phosphorus. However, wastewater characteristics vary from plant to plant, depending on the industrial process and the water consumption per fowl slaughtered.

The treatment systems used to treat this kind of liquid effluents usually consist of preliminary treatment, primary treatment and biological treatment. The preliminary treatment system is usually composed of rotary and static screens used to remove coarse solids (bowels and feathers). A dissolved-air flotation (DAF) system may be used as the primary system, which allows the removal of fine solids and fats, necessary to make the biological treatment system viable. High concentrations of grease and fats and suspended solids may interfere with the biological processes because they induce flotation of sludge, in the case of grease and fats, and overload of system units, in the case of suspended solids (when the systems were not designed to receive suspended solids).
Many slaughterhouses utilize upflow anaerobic sludge blanket (UASB) reactors as a biological treatment.

In Brazil, the UASB reactors were first used at plant-scale in 1983, and presently there are 228 units in operation. Slaughterhouses and meat processing factories, dairy factories, beer and soft-drink factories, food canning factories are among the industrial activities that make the most use of the anaerobic technology when treating their liquid effluents, according to a survey carried out by CETESB (1999).

The lack of adapted anaerobic sludge to be used as seed sludge, the complexity of the microbial relation and the need of control of the environmental factors, etc., make the start-up of the UASB reactors one of the most important phases in the establishment of an active microbial population in the reactor (Zeeuw, 1984). Moreover, the adequate monitoring and operational strategies contribute to the proper performance of the reactors. Despite the importance of the anaerobic reactor start-up and operation, general and specific reports on these phases in plant-scale reactors are scarce.

The objective of this work is to show the performance of the primary treatment system composed of a DAF system and the start-up characteristics and the operation data for two UASB reactors, belonging to a poultry slaughterhouse wastewater treatment system.

Methods
The study was carried out at the wastewater treatment system of Granja Céu Azul, Ltda., located in Sorocaba, São Paulo State, Brazil. This system has rotary and fixed screens and a DAF system (pretreatment and primary treatment), and two UASB reactors (biological treatment). The rotary screens remove solids larger than 1,000 µm (feathers and bowels) and, sequentially, the static screens remove solids larger than 750 µm (fine solids). The effluent of the screens is directed to a 142 m³ equalization tank. After a coagulation process, the liquid fraction of the blood is also conducted to the equalization tank. Afterwards, the liquid effluent is directed to the DAF system (saturation chamber and flotation tank) and then to two 450 m³ UASB reactors. The final treated effluent is directed to the sewage system. The preliminary and primary systems received during the entire study period (342 days) a total industrial effluent flow rate of 600 m³/day on average.

The seed sludge used was obtained from the sludge digester of a municipal sewage treatment plant. The criterion used for the reactor start-up was to gradually increase the flow rate and the organic loading rate (OLR) until reaching the total flow rate of industrial liquid effluents. The flow rate was increased whenever the reactor COD reduction was higher than 80% in relation to the soluble COD concentration and the concentration of volatile fatty acids (VFA) was lower than 100 mg/L. On some of the days the reactor flow rate was reduced due to the decrease in the industrial liquid effluent generation. Alkali was added to the reactors influents in order to keep the pH around 7.0. The DAF system and the reactor design parameters are shown in Table 1, and the industrial effluent and seed sludge characterization and operational parameters are shown in Table 2.

The samples of the industrial effluent (equalization tank), reactor influent and effluent were collected monthly during the whole operation period. They were collected every 30 minutes during approximately 17 hours, preserved in ice and composed in relation to the flow rate. The samples were analyzed at the Laboratory of Sanitation at Universidade de São Paulo, São Carlos. The characterization parameters were: pH, COD, BOD, VFA, alkalinity, grease and fats, total (NTK) and ammoniac nitrogen (N-NH₃), phosphate (P-PO₄), and total suspended solids (TSS). The physiochemical analyses, except for VFA, followed the methods found in The Standard Methods for the Examination of Water and Wastewater (1998). The VFA determination was done according to Dillalo and Alberton (1961). The reactor effluents were analyzed in relation to the raw and soluble COD.
Results and discussion

Dissolved-air flotation system (DAF)

Figure 1 shows the data for grease and fats of the industrial and flotation tank effluents as a function of the flow rate. The concentration of grease and fats in the industrial effluent ranged from 379 mg/L to 730 mg/L (average of 566 mg/L) and the concentration in the flotation tank effluent ranged from 152 mg/L to 327 mg/L (average of 266 mg/L). The average removal of grease and fats in the flotation tank was 68%, ranging from 55% to 75%.

Figure 2 shows the data of TSS of the industrial and flotation tank effluents as a function of the flow rate. The concentration of TSS in the industrial effluent ranged from 790 mg/L to 1520 mg/L (average of 1102 mg/L) and the concentration in the flotation tank effluent ranged from 372 mg/L to 718 mg/L (average of 540 mg/L). The average removal of TSS in the flotation tank was 51%.

Figure 3 shows the COD concentrations of the industrial and flotation tank effluents as a function of the flow rate. The COD concentration in the industrial effluent ranged from 3,960 mg/L to 6,560 mg/L (average of 5,253 mg/L) and the concentration in the flotation tank effluent ranged from 1,890 mg/L to 3,150 mg/L (average of 2,631 mg/L). The average COD removal in the flotation tank was 50%.

The results obtained were below the potentiality of the DAF system for the wastewater treatment using chemical products (coagulation and flocculation), as observed in studies of DAF in forest, foodstuff and vegetal oil industries (Viitasaari et al., 1995; Campos, 1997).

However, the removal of grease and fats, TSS and DQO in the flotation system contributed to the application of lower loads to the reactors, which enabled a better operational control.

Table 1 Design and operational parameters of the flotation system and UASB reactors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Flotation tank</th>
<th>Reactors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation chamber Pressure (atm)</td>
<td>4</td>
<td>Height (m) each reactor</td>
</tr>
<tr>
<td>Hydraulic retention time (h)</td>
<td>1.5</td>
<td>Area (m²) each reactor-total</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>48</td>
<td>Volume (m³) each reactor-total</td>
</tr>
<tr>
<td>Flow rate (m³/h)</td>
<td>30</td>
<td>Diameter (m)</td>
</tr>
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</table>

Table 2 Industrial effluent and seed sludge characterization and anaerobic reactors start up parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data</th>
<th>Parameter</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average COD of industrial effluent (mg/L)</td>
<td>5,253</td>
<td>Average N-NH₃ of reactors influent (mg/L)</td>
<td>92</td>
</tr>
<tr>
<td>Average COD of reactors influent (mg/L)</td>
<td>2,631</td>
<td>Average P-P₂O₅ of reactors influent (mg/L)</td>
<td>58</td>
</tr>
<tr>
<td>Average grease and fats of industrial effluent (mg/L)</td>
<td>566</td>
<td>Seed sludge volume for each reactor (m³)</td>
<td>200</td>
</tr>
<tr>
<td>Average grease and fats of reactors influent (mg/L)</td>
<td>206</td>
<td>Volatile total solids (VTS) in the seed sludge (g/L)</td>
<td>30</td>
</tr>
<tr>
<td>Average alkalinity of reactors influent (mg/L)</td>
<td>343</td>
<td>Initial flow rate for each reactor (m³/day)</td>
<td>85</td>
</tr>
<tr>
<td>Average total suspended solids (TSS) of industrial effluent (mg/L)</td>
<td>1102</td>
<td>Daily operation time (h)</td>
<td>17</td>
</tr>
<tr>
<td>Average total suspended solids (TSS) of reactors influent (mg/L)</td>
<td>540</td>
<td>Initial sludge loading rate (kg COD/kg VTS day)</td>
<td>0.04</td>
</tr>
<tr>
<td>Average NTK of reactors influent (mg/L)</td>
<td>182</td>
<td>Initial OLR for each reactor (kg COD/m³.day)</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reactor influent COD/BOD ratio</td>
<td>2</td>
</tr>
</tbody>
</table>
of the anaerobic biological system as well as the reduction of costs related to the operation of the reactor itself.

Start up and operation of anaerobic reactors

Figure 4 shows the values of the flow rate and OLR of Reactor A (RA) and Reactor B (RB) in the period of 342 days. Each reactor received half of the industrial liquid effluent rate in this period. It may be observed that the flow rate and the reactor OLR were gradually increased in the first 141 days, until they reached 270 m$^3$/day and 2.11 kg COD/m$^3$.day, respectively. From the 163rd to the 251st operation day the flow rate was temporarily decreased due to some variation in the industrial process, thus discontinuing the gradual increase in the flow rate and OLR. On the 342nd day of operation the flow rate reached a peak of 306 m$^3$/day and the reactor OLR was 1.67 kg COD/m$^3$.day.

The classic definition of the first start-up of a reactor seeded with non-adapted seed sludge is the period needed for the development of the first microscopic sludge granules. A practical definition of UASB reactor start-up is the period needed for the reactor to receive the design flow rate and OLR, with adequate COD reduction, dynamic biochemical equilibrium among the microbial populations participating in the process, and adequate concentrations of TSS, VFA, etc. in the reactor effluent (Zeeuw, 1984).

Nevertheless, the classical and practical definition of start-up can be difficult to apply to some plant-scale reactors due to variations in the industrial process, which give rise to liquid effluents and reactor effluents with varied quantitative and qualitative characteristics, as for the industry in question. In this case, 144 days will be considered as the start-up period of RA and RB, with maximum flow rate and OLR values for this period of 270 m$^3$/day and 2.1 kg COD/m$^3$.day, respectively. The soluble COD reduction of the reactors was higher than 80% (the COD reduction efficiency with respective to the raw effluent was not considered) and VFA concentration below 100 mg/L. This period has been cited in start-up studies using non-adapted sludge as seed (Zeeuw, 1984; Speece, 1996).

Figure 5 shows the COD reduction efficiencies in relation to the raw and soluble efflu-
ents of RA and RB as a function of flow rate. The COD reduction, considering the soluble COD of the reactor effluent, ranged from 84.2% to 93.6% for RA and 81.0% to 93.0% for RB. These results show that the reactor start-up criterion was adequate, which may be corroborated by the results shown in Figure 6, where the VFA concentration of the RA and RB effluents ranged from 46 mg/L to 90 mg/L and from 44 mg/L to 95 mg/L, respectively. These values are adequate for this type of system and denote equilibrium among the microbial populations active in the process.

The COD reduction efficiencies, considering the raw COD of the reactors, presented values ranging from 71.3% and 84.4% for RA and from 75.7% to 83.4% for RB until reaching the flow rate of 225 m3/day, which produced values approximately 10% lower in relation to the soluble COD. As from the flow rate of 250 m3/day, the COD reduction efficiency dropped significantly in relation to the raw COD of the reactor effluents, due to the increase in the concentration of suspended solids, as shown in Figure 7. These values ranged from 47.8% to 73.2% for RA and from 54.5% to 69.5% for RB, which were from 20% to 30% lower than the COD reduction values in relation to the soluble COD of the reactor effluents.

The washout of finely dispersed sludge along with the reactor effluent is customary due to the expansion of the sludge blanket caused by the increase in the hydraulic load, by the microbial population growth as well as by the production of gas, contributing to microbial selection. Figure 7 shows that from the flow rate of 250 m3/day (for each reactor), the sludge washout increased. According to Speece (1996), the sludge washout may cause instability in the anaerobic process as it may not be possible for the biomass to recover fast enough to replace the waste. However, this behavior did not cause the disturbance in the process, according to the COD reduction in the reactors and VFA concentration in the effluents (Figures 5 and 6), probably due to the sufficient quantity of anaerobic sludge kept in the reactor.
According to Hulshoff Pol and Lettinga (1986), the sufficient and constant removal of the lighter fraction of the sludge is essential for microbial selection, growth and aggregation. The sludge washout decreased on the 342nd day of operation (306 m³/day), indicating that the selection process of the anaerobic sludge through the washout of finely dispersed sludge was probably ending in the period studied.

Figure 8 shows the concentrations of grease and fats of RA and RB effluents as a function of the flow rate, which ranged from 35 mg/L to 78 mg/L and 44 mg/L to 100 mg/L, respectively. As from the 202 m³/day rate for each reactor, there was an observable increase in the concentration of grease and fats, however, it was always below 100 mg/L.

Conclusions
- The DAF system showed a reduction in the concentrations of grease and fats, SST and DQO higher than 50%, contributing to the application of lower loads to the reactors.
- The start-up of plant-scale UASB reactors may follow specific criteria due to the variation inherent in industrial processes.
- The start-up period of 141 days is adequate, considering that the seed sludge utilized was non-adapted anaerobic sludge.
- The decrease in the flow rate and in the OLR applied after the start-up period occurred due to the industrial process, not because of operational problems or the unbalance among the microbial populations present in the reactors, which may have required a decrease in the flow rate.
- During the operation time the COD reduction efficiency in relation to the soluble effluents, the VFA concentration in the effluents and the operational stability were adequate and in accordance with the start-up criteria adopted in this work.
- The reduction in the COD reduction efficiency, in relation to the raw COD of the reactors effluents, was observed as from the 225th day of operation due to the increase in the concentration of suspended solids in the effluent.
- The performance of the UASB reactors in the treatment of wastewater of the poultry slaughterhouse in question was satisfactory.

References