Nutrient removal from piggery effluent using vertical flow constructed wetlands in southern Brazil


* Department of Sanitary and Environmental Engineering, Federal University of Santa Catarina, Campus Universitário, Trindade, Florianópolis, SC, CEP:88.010-970, Brazil
(E-mail: phsezerino@hotmail.com.br; lsp@ens.ufsc.br)

** Department of Chemical Engineering and Food Engineering, Federal University of Santa Catarina, Campus Universitário, Trindade, Florianópolis, SC, CEP:88.010-970, Brazil
(E-mail: reginatto@enq.ufsc.br; soares@enq.ufsc.br)

*** Department of Rural Engineering, Federal University of Santa Catarina, Campus Universitário, Trindade, Florianópolis, SC, CEP:88.010-970, Brazil
(E-mail: monica.santos@sadia.com.br)

**** Institute of Sanitary Engineering and Waste Management, University of Hannover, Welfengarten 1, D-30167 Hannover, Germany
(E-mail: kayser@isah.uni-hannover.de; kunst@isah.uni-hannover.de)

Abstract Santa Catarina State, southern Brazil, has the greatest swine breeding activities of Latin America. Generally, the piggery wastewater is treated in pond systems that are able to remove organic material according to local environmental legislation. However, these systems do not remove nitrogen and phosphorus efficiently. This work deals with a post-treatment system, using vertical flow constructed wetlands. The experiment was conducted in a swine production farm which has 45,000 animals. Although the pond system was able to partially remove the content of nutrients, their concentration in the effluent was high for environmental disposal. A four-bed vertical flow constructed wetland pilot plant, using Typha spp., was built. The pilot plant operated for 280 days for beds 2–4 (sand 2). However, the experiments with beds 1–3 (sand 1) were stopped after 111 days of operation, when a reduction in the wastewater drainage was observed. The beds with sand 2 showed a 33% COD removal, and about 49% of nitrification was observed from 111 days until the end of the operation. PO4-P removal was 45% with a loading rate of around 1.36 g m–2 d–1.

Keywords Constructed wetlands; nutrient removal; piggery wastewater; pond system; post-treatment

Introduction Brazilian swine production is the 4th largest in the world with 34 million animals, where Santa Catarina State, southern Brazil, occupies the leading position with the greatest swine breeding activities of all Latin America, producing 4.5 million swine (Belli Filho et al., 2001). This activity generates about $10^7$ m$^3$ of piggery waste per year, representing a populational equivalent of 7.0 million inhabitants. Additionally, raw wastewater nitrogen and phosphorus concentrations are very high, about 2,500 and 600 mg L$^{-1}$, respectively (Costa et al., 2000). Generally, the piggery wastewater in Brazil is treated by pond systems that are able to remove organic matter (reducing BOD, COD and VSS from 90% to 98%) and pathogens (around $10^3$ MPN 100 mL$^{-1}$) according to local environmental legislation (Medri, 1997; Zanotelli et al., 2000). However, these systems do not remove nitrogen and phosphorus efficiently. Discharge of these nutrients into the environment promotes serious environmental problems such as eutrophication and oxygen depletion in water bodies (Water Pollution Control Federation, 1983).

Therefore, it is necessary to look for post-treatment processes that are able to increase the effluent quality. Soil filtration, such as biological sand filters and constructed wetlands,
have been used as an economical alternative to remove nutrients from pond system effluents (Sievers, 1997; Gschlößl et al., 1998).

Biological sand filters and vertical flow constructed wetlands are able to biologically oxidize ammonium to nitrate and adsorb phosphorus (Nielsen et al., 1993; Kadlec and Knight, 1996; Kadlec et al., 2000). Several authors have shown the efficiency of constructed wetlands in removing N and P from low strength wastewater such as domestic sewage, applying low loading rates (Philippi et al., 1999; Platzer, 1999; Huang et al., 2000; Sundaravadivel and Vigneswaran, 2001). Few researches have been carried out with high nitrogen concentrated streams, such as piggery wastewater (Finlayson et al., 1987; Sievers, 1997; Kantawanichkul et al., 1999, 2001). This work deals with a post-treatment system, using vertical flow constructed wetlands for nitrification and phosphorus removal from piggery wastewater treated by a pond system.

**Methods**

The experiment was conducted for 12 months (October/2000–October/2001) in a swine production farm, located in the west of the Santa Catarina State, southern Brazil, which has 45,000 animals producing about 600 m$^3$ d$^{-1}$ of wastewater. During the first three months, a vertical flow constructed wetland pilot plant was built after the pond system.

**Pond system**

The pond system, operating since 1996, is composed of 7 sequential ponds and the samples were collected at 5 different points, located after the settling tank (P1), anaerobic pond 2 (P2), facultative pond (P3), aerated pond (P4) and final effluent (P5). The last sampling point, which is the final effluent, is used to feed the vertical flow constructed wetland pilot plant. The sequence of the pond system with its sampling points is shown in Figure 1.

**Vertical flow constructed wetlands**

A four-bed vertical flow constructed wetland pilot plant, using *Typha* spp. as the macrophyte species, was built where two different kinds of sand were tested as the filter media. A layout of the pilot plant is shown in Figure 2 and the physico-chemical characteristics of the sands used are shown in Table 1. Beds 1 and 3 were filled with sand 1, and beds 2 and 4 with sand 2. Each bed was fed with the pond system final effluent three times per day every 8 hours (30 mm d$^{-1}$ hydraulic loading rate), totaling 230 L d$^{-1}$.

**Physico-chemical characterisation of samples**

All physico-chemical parameters were analysed according to the *Standard Methods for the Examination of Water and Wastewater* (1995). The analytical parameters assessed in this study were: pH, Chemical Oxygen Demand (COD), Total Nitrogen (TN), Ammonium...
Nitrogen (NH$_4$-N), Nitrate Nitrogen (NO$_3$-N), Ortho-phosphate (PO$_4$-P) and Total Suspended Solids (TSS). Biochemical Oxygen Demand (BOD) was assessed only for the pond system.

Results and discussion

Pond system characterisation

The characterisation of the pond system is shown in Table 2. The results presented are the average of two years (2000/2001).

According to the values shown in Table 2, the first anaerobic pond (P$_1$) presents a volumetric loading rate around 2.5 times higher than that recommended by the Brazilian standard to treat sewage (from 0.1 to 0.3 kgBOD m$^{-3}$ d$^{-1}$) (Von Sperling, 1996). In spite of overloading, the COD removal efficiency after the anaerobic and facultative ponds is about 90%. Similar results were obtained by Zanotelli et al. (2000) achieving 94% COD removal when studying a sequence of two anaerobic ponds followed by a facultative one to treat manure.

The total nitrogen removal during the treatment was 72%, and the highest nitrogen removal observed was around 42% in the facultative pond. Probably this observed nitrogen removal would not occur by a regular nitrification/denitrification process, because of the high organic matter concentration remaining in these ponds, which would inhibit nitrifying bacteria growth. In addition, there was not enough dissolved oxygen (about zero) to sustain their growth. Thus, biomass assimilation, sedimentation and ammonia volatilisation are

**Table 1** Physico-chemical characteristics of sands 1 and 2. Values for $d_{10}$, $d_{60}$, uniformity coefficient ($d_{60}/d_{10}$), hydraulic conductivity ($K_s$), pH, iron (Fe), calcium (Ca), aluminium (Al) and magnesium (Mg)

<table>
<thead>
<tr>
<th>Sample</th>
<th>$d_{10}$ (mm)</th>
<th>$d_{60}$ (mm)</th>
<th>$d_{60}/d_{10}$</th>
<th>$K_s$ (m s$^{-1}$)</th>
<th>pH</th>
<th>Fe (mg kg$^{-1}$)</th>
<th>Ca (mg kg$^{-1}$)</th>
<th>Al (mg kg$^{-1}$)</th>
<th>Mg (mg kg$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand 1</td>
<td>0.21</td>
<td>0.45</td>
<td>2.14</td>
<td>4.4.10$^{-4}$</td>
<td>5.1</td>
<td>ND</td>
<td>20</td>
<td>ND</td>
<td>12.5</td>
</tr>
<tr>
<td>Sand 2</td>
<td>0.23</td>
<td>1.38</td>
<td>6.00</td>
<td>5.4.10$^{-4}$</td>
<td>5.0</td>
<td>ND</td>
<td>40</td>
<td>ND</td>
<td>12.5</td>
</tr>
</tbody>
</table>

ND – not detectable

Nitrogen (NH$_4$-N), Nitrate Nitrogen (NO$_3$-N), Ortho-phosphate (PO$_4$-P) and Total Suspended Solids (TSS). Biochemical Oxygen Demand (BOD) was assessed only for the pond system.
important mechanisms to be considered for nitrogen removal in these systems (Middlebrooks et al., 1983). High levels of ammonia in piggery ponds result in a significant degree of volatilisation, to the extent that ammonia can at times be smelt emitting from the ponds (Shilton, 1996). Considering the pH of the facultative and aerated pond (P₃ and P₄), higher than 8.0, most of the nitrogen was as free ammonia and could be readily removed by volatilisation and by stripping through aeration. Shilton (1996) reported that the rate of ammonia volatilisation ranged from 0.35 to 1.53 g m⁻² d⁻¹ in an aerobic pond, increasing with higher concentrations of ammonia and TKN.

The efficiency of the pond system to remove ortho-phosphate was around an 83% reduction, less than that found by Zanotelli et al. (2000) which was 98%. The main ortho-phosphate removal observed was around 67% between the anaerobic and the facultative ponds.

This insufficient nitrogen and phosphorus removal during the pond treatment produces a final effluent unacceptable for discharge with ammonium and phosphorus concentrations at levels that are toxic to aquatic organisms and promote eutrophication. Even though 96% TSS removal was obtained, its final concentration is still high for discharge.

**Table 2** Average values of 20 samples collected in the pond system during the period of 2000/2001

<table>
<thead>
<tr>
<th>Observed parameters</th>
<th>Sample points</th>
<th>Removal in relation to point P₁</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P₁</td>
<td>P₂</td>
</tr>
<tr>
<td>pH</td>
<td>7.14 (± 0.07)</td>
<td>7.60 (± 0.04)</td>
</tr>
<tr>
<td>COD (mg L⁻¹)</td>
<td>11578.66</td>
<td>6444.73 (± 1906)</td>
</tr>
<tr>
<td>BOD (mg L⁻¹)</td>
<td>5772.42</td>
<td>2959.44 (± 672)</td>
</tr>
<tr>
<td>TN (mg L⁻¹)</td>
<td>2045.16</td>
<td>1646.84 (± 373)</td>
</tr>
<tr>
<td>NH₄-N (mg L⁻¹)</td>
<td>1275.40</td>
<td>938.64 (± 382)</td>
</tr>
<tr>
<td>NO₃-N (mg L⁻¹)</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>PO₄-P (mg L⁻¹)</td>
<td>364.07 (± 36)</td>
<td>292.44 (± 90)</td>
</tr>
<tr>
<td>TSS (mg L⁻¹)</td>
<td>4237.31</td>
<td>5524.41 (± 412)</td>
</tr>
</tbody>
</table>

**Constructed wetland pilot plant**

The results of the constructed wetlands performance are shown in Figure 3. The values presented are the average between beds 1 and 3, using sand 1, and beds 2 and 4, using sand 2. These averages were taken after the verification that there is no significant difference between them (p>0.05) when the ANOVA variance analysis test was applied, in both cases.

The pilot plant operated for 280 days for beds 2 and 4 (sand 2). However, the experiments with beds 1 and 3 (sand 1) were stopped after 111 days of operation, when a serious reduction in the wastewater drainage was observed, indicating clogging of the beds.

As can be observed in Figure 3, COD loading rate ranged from 12.12 to 23.75 g m⁻² d⁻¹ and the removal performance ranged from 25% to 54% for beds with sand 1, and from 12% to 43% for beds with sand 2. After a period of organic loading rate increase, it stabilised at values around 23 g m⁻² d⁻¹ (112 to 280 operation days). During this period, the beds with sand 2 showed a 33% COD removal with a final effluent still high in COD (506.56 ± 40 mg L⁻¹). In a similar study Kantawanichkul et al. (1999) reached a COD removal of 79% to 90% when loading rates of 5.5 to 11.0 gCOD m⁻² d⁻¹ were applied, and COD concentration ranged from 314 to 601 mg L⁻¹.
The average temperature ranged from 26.7°C, during the summer and autumn (1 to 111 operation days) to 16.2°C, during the winter (112 to 248 operation days). After 112 operation days, COD and NH$_4$-N loading rates applied increased because the removal efficiency in the pond system was adversely affected owing to the temperature decrease.

NH$_4$-N loading rate varied from 9.36 to 14.36 g m$^{-2}$ d$^{-1}$ and the removal performance ranged from 7% to 67% for beds with sand 1 and from 2% to 68% for beds with sand 2. Nitrification was observed after 112 operation days, when the nitrate nitrogen concentration increased significantly in the effluent from beds with sand 2. There was an average concentration of 52.11 ± 19 mg NO$_3$-N L$^{-1}$ in its influent, and 132.58 ± 44 mg NO$_3$-N L$^{-1}$ on average in the effluent. Considering the high NH$_4$-N loading rate applied (around 14 g NH$_4$-N m$^{-2}$ d$^{-1}$), the high COD concentration (626.45 ± 42 mg COD L$^{-1}$) and that most of the time the temperature stayed around 19°C, the nitrification achieved by the constructed wetlands pilot plant was considerable. The average NH$_4$-N removal in the beds with sand 2 was 58%, where 49% of this removal occurred by ammonia biotransformation to nitrate. Kantawanichkul et al. (1999) reported high nitrification for diluted piggery wastewater treated in a subsurface vertical-flow laboratory scale wetland. In another study, Kantawanichkul et al. (2001) reported 98% NH$_3$-N removal in a vertical vegetated bed over a horizontal flow sand bed (with 9.0 g TKN m$^{-2}$ d$^{-1}$ loading rate). It can be calculated from this study that 64% nitrification was obtained with a loading rate of 9.52 g NH$_3$-N m$^{-2}$ d$^{-1}$.

Due to high NH$_4$-N concentration the macrophytes (Typha spp) became yellowish during most of the experiment and many of them did not survive. The ones that did not survive were repeatedly replaced by new ones.

Sorption of phosphorus to the bed sand media is a major removal mechanism. Phosphorus may also be bound to the media of the constructed wetlands mainly as a consequence of adsorption and precipitation reactions with Ca, Al and Fe in the sand (Arias et al., 2001). However, for long-term phosphorus removal by subsurface flow wetlands no well founded design proposal could be found in the literature (Rustige and Platzer, 2001).

According to Table 1, only Ca and Mg were detectable in the sands. Due to the fact that the sands were chosen at random, the quantity of these minerals did not change or modify. The quantities of Ca and Mg were quite insignificant when compared to the materials used by Rustige and Platzer (2001) and Arias et al. (2001). Even so, a high PO$_4$-P loading rate was applied. The PO$_4$-P loading rate ranged from 1.09 to 2.05 g m$^{-2}$ d$^{-1}$ and the removal performance ranged from 62% to 95% for beds with sand 1 and from 26% to 91% for beds with sand 2.

Arias et al. (2001) reported that the phosphorus removal efficiency is often initially high and then decreases after some time. But after 112 operation days the average PO$_4$-P removal was 45% with a PO$_4$-P loading rate of about 1.36 g m$^{-2}$ d$^{-1}$. Kantawanichkul et al. (1999) reported phosphorus removal ranges from 32% to 52% for a loading rate of 0.4 to 0.7 g PO$_4$-P m$^{-2}$ d$^{-1}$. In the same way, significant rainfall can promote nutrient leaching increasing their concentration in the effluent. The rainfall on average ranged from 0.1 mm d$^{-1}$ (0.1 L m$^{-2}$ d$^{-1}$) to 9.5 mm d$^{-1}$ (9.5 L m$^{-2}$ d$^{-1}$). The maximum rainfall observed was around 30% of the hydraulic loading rate.

Conclusions
Piggery wastewater nutrient removal by applying economical and natural technologies such as pond systems and constructed wetlands, must be improved and more research is needed in order to understand the removal mechanisms.

In spite of the high carbon content in the wetland influent a nitrification process could be satisfactorily implemented. It was possible to work with higher nitrogen loading rates in
vertical flow constructed wetlands than previously described in the literature, but an increase in carbon removal in the pond system could improve the observed nitrification efficiency. Phosphorus removal data were similar to those observed in the literature. For long-term phosphorus removal it is necessary to test media with higher Ca, Fe and Al content.

**Acknowledgement**
The authors would like to thank CNPq – Brazil, BMBF – Germany and SADIA S/A – Brazil, for the financial support for this research.

**References**


Water Pollution Control Federation (1983). *Nutrient Control*, Manual of Practice FD-7, Water Pollution Control Federation, Alexandria, VA.