Polishing ponds for post-treatment of digested sewage part 1: flow-through ponds

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Abstract Polishing ponds are used to improve the quality of effluents from efficient anaerobic sewage treatment plants like UASB reactors, so that the final effluent quality becomes compatible with legal or desired standards. The residual organic material and suspended solids concentrations in the digested sewage are reduced, but often the main objective of polishing ponds is to improve the hygienic quality, measured by the concentration of two indicator organisms: helminth eggs and faecal coliforms (FC). The FC removal is normally the slowest process and for that reason becomes the main design criterion for a polishing pond. By contrast in conventional waste stabilisation pond (WSP) systems the organic material removal is the governing design parameter.

The feasibility of operating a single polishing pond for the post-treatment of UASB effluent is shown in this paper and the final effluent quality as a function of the retention time is discussed. Even under the most adverse weather conditions (several weeks of rain) the population of algae remained stable and produced enough oxygen to maintain a predominantly aerobic environment. The final effluent TSS and BOD concentrations were not very low for retention times of less than 1 week, but this could be attributed to the presence of algae in the final effluent. Filtered effluent BOD and TSS concentrations were very low. For retention times of more than 1 week algae were efficiently removed from the liquid phase by the action of predators and algae floculation and settling, so that a final effluent with a very low BOD and TSS concentrations was produced.

To maximise the FC removal efficiency the polishing pond was constructed with the objective of approaching a plug flow regime. However, the observed efficiency was well below the expected value for all retention times, which was attributable to imperfections of the flow regime. From tracer studies it was established that the dispersion number was in the range of 0.14 to 0.16, which means that moderate mixing occurred, even though the pond was designed to avoid mixing as much as possible. Also the dead volume fraction ranging from 0.12 to 0.15 was quite considerable. Due to these imperfections the required retention time for an effluent to be used in unrestricted irrigation was produced for a retention time of about 10 days, twice the value of the minimum retention time for a batch or true plug flow pond. Although the plug flow regime could not be approached in practice, the required retention time of 10 days is still very much shorter than the value used in conventional WSPs (20 to 30 days).

Keywords Polishing ponds; anaerobic pre-treatment; retention time; effluent quality; pathogen removal; design criteria

Introduction

Polishing ponds can be used to improve the quality of anaerobically pre-treated sewage. Even efficient anaerobic treatment plants, like UASB reactors, usually cannot produce an effluent that is compatible with strict effluent standards. Depending on the situation, polishing ponds may be applied to upgrade anaerobic effluent so as to attain legally required standards or the objective may be to obtain a final effluent that can be used for irrigation. After efficient anaerobic treatment, the removal of the residual organic load is much less problematic. Also, since the organic material concentration is low, there is no possibility of having an anaerobic pond and the other ponds may be united into one single polishing unit (Catunda and Van Haandel, 1996). In this paper it is shown that the required
retention time for reduction of the BOD and TSS concentrations to a virtually constant value is very short, only about 3 days. This is a factor 7 to 10 times shorter than the retention time in conventional stabilisation ponds. The absence of the anaerobic pond constitutes a very important practical advantage, since it is often a source of serious operational problems (bad odours, accumulation of solids).

Since the removal of residual BOD and TSS is rapidly achieved, in many cases the main design criterion for polishing ponds will be pathogen removal, especially if the wastewater is to be used for irrigation. The WHO standards for unrestricted irrigation are that the helminth concentration must be less than 1 per litre and the faecal coliform concentration less than $10^3$ per 100 ml (Helmer et al., 1991). While the retention time for removal of helminth eggs is relatively short (Saqqar and Pescod, 1990), the time for FC reduction may be long, especially if the contents of the pond are mixed. When the FC decay is considered a first order process (Marais, 1974), chemical engineering theory shows that the most efficient configuration is a plug flow reactor, i.e. a pond in which no mixing occurs. In such a plug flow pond the decay of FC is exponential (Levenspiel, 1972).

In this investigation the FC concentration in digested sewage was of the order of $10^7$ per 100 ml, so that the required removal efficiency for unrestricted irrigation ($FC < 10^3$) was 99.99% (4 log units). By using the value of the experimentally determined decay constant ($2 \text{ to } 2.3 \text{ d}^{-1}$) the minimum time for this removal efficiency was calculated at 4 to 5 d for exponential decay. However, the experimentally observed removal efficiency was much lower than expected on the basis of first-order kinetics (exponential decay). This was attributed to the fact that partial mixing could not be avoided, even though the polishing pond was specifically designed to approach the plug flow regime as closely as possible.

Mixing in continuous reactors like polishing ponds can be quantified by determining the residence time distribution (RTD) of the liquid by applying a slug of a tracer in the influent and observing its concentration as a function of time in the effluent. The experimental data showed that even in the pond that was carefully designed and operated, the dispersion number was of the order of 0.1 to 0.2, which means that mixing intensity was moderate. When the results of the tracer studies were applied to evaluate the faecal coliform removal efficiency in the partially mixed pond by using the Wehner and Wilhelm equation, it was established that there was a good correlation between theory and experimental data.

The relatively long retention time could have led to nutrient removal, due to elevation of the pH by biological CO$_2$ consumption. A steady increase of the pH value from 6.9 in the digested sewage to 8.4 in the pond was indeed observed during a retention time of 1 week. However, at retention times longer than 1 week, a reduction of the photosynthetic activity occurred due to the removal of a large fraction of the algae. This led to a decrease of the DO concentration and the pH value. For that reason ammonia was present principally in the ionic NH$_4^+$ form and was only partially removed. The pH increase was too small to effect significant phosphorus removal. At the same time there was a dramatic improvement of the final effluent quality in terms of total BOD and TSS, whereas the turbidity also decreased very substantially.

Post treatment in polishing ponds
If efficient anaerobic pre-treatment is applied, for example in a UASB reactor, the concentrations of suspended solids and organic material are reduced substantially (Van Haandel and Lettinga, 1993), so that the demand for oxygen is much lower than in the case of raw sewage treatment. Thus the surface loading rate almost invariably will be less than the value for maturation ponds (150 kg BOD m$^{-2}$d$^{-1}$; Pearson and Mara, 1986), especially if the polishing pond is shallow. Hence the oxygen demand in a polishing pond is relatively low. In addition, anaerobic digestion improves the sewage transparency, because most of
the colloids (main source of turbidity in raw sewage) are removed. As a result sunlight can penetrate deeper into the pond, so that photosynthesis can develop in a larger part of the pond volume, producing more oxygen per unit pond area. The combination of a low oxygen demand and a high oxygen production potential will mean that the environment of a polishing pond resembles that of a maturation pond where the anaerobic environment is restricted to the bottom sludge layer. The prevalence of photosynthesis over bacterial degradation has important consequences: (1) if (bi)sulphide ions are present in the digested sewage, these will be oxidised, so that bad odours, which often emanate from anaerobic ponds, will be greatly reduced; and (2) the net consumption of CO₂ which accompanies the net O₂ production in the pond leads to a decrease in acidity and hence to an increase of the pH.

The prevalence of photosynthesis over bacterial oxidation and anaerobic digestion changes the objective of post-treatment in a polishing pond: its most important function is the removal of pathogens as indicated by the decrease of the FC concentration. The removal of FC is often described as a first-order process (Marais, 1974). In that case, chemical reactor engineering (Levenspiel, 1979) shows that removal efficiency is increased if a plug flow regime is approached. A plug flow regime is not possible in conventional stabilisation ponds, where the prime goal is organic material removal and a series configuration of mixed ponds is essential. In single ponds, the mixing intensity is influenced by the geometry factors that cannot or only partially be controlled, such as mechanical mixing by the wind or thermal convection, evolution of gas bubbles from the bottom sludge and movements of organisms that develop in the pond. The influence of mixing or dispersion in reactors in which a first-order process develops is expressed quantitatively by the Wehner and Wilhelm equation (Wehner and Wilhelm, 1956):

$$\frac{N_e}{N_i} = 4a \exp \left[ \frac{1}{(2D)} \right] / \left[ (1+a)^2 \exp \left[ \frac{a}{(2D)} \right] - (1-a)^2 \exp \left[ -\frac{a}{(2D)} \right] \right]$$

(1)

Where:

- \(a = (1+4k_dR_aD)^{1/2}\)
- \(N_i, N_e\) = Faecal Coliformes concentration in the influent and effluent resp.
- \(k_d\) = decay constant (d⁻¹)
- \(R_a\) = actual retention time (d)
- \(D\) = dispersion number

Equation (1) can be reduced to a simplified form for the plug flow (exponential decay: \(N_e/N_i = \exp(-k_dR_a)\)) and for complete mix reactors (hyperbolic decay, \(N_e/N_i = 1/(1+k_dR_a)\)).

Figure 1 shows the \(N_e/N_i\) ratios as a function of the dimensionless group \(k_dR_a\) for different values of the dispersion number: \(D = 0\) (true plug flow), \(D = 0.01\) (little mixing), \(D = 0.1\) (moderate mixing) \(D = 1\) (intense mixing) and \(D = \infty\) (complete mixing). It can clearly be seen that the increase of mixing intensity reduces the FC removal efficiency considerably, especially if the required efficiency is high. The World Health Organisation guidelines for the effluent quality for unrestricted irrigation (Helmer et al., 1991) specify a FC count of less than 10³ per 100 ml. In raw sewage the FC concentration is of the order of 10⁷ to 10⁸ which is reduced by about factor 10 to 10⁶ to 10⁷ in the anaerobic pre-treatment. Hence the required FC removal efficiency is of the range of 99.9 to 99.99 per cent, as indicated in Figure 1. The influence of the mixing intensity on the required retention time is exemplified in Figure 1: For a 99.99% removal efficiency (4-log) the required value of \(k_dR_a = 9.2\) for \(D = 0\) and 17 for \(D = 0.1\). It is concluded that even a moderate mixing intensity leads to almost doubling the required retention time, and hence the pond area.

The dispersion number \(D\) in Equation (1) is a measure of the mixing intensity. It is determined experimentally by adding a tracer to the influent flow and observing its
concentration in the effluent as a function of time, thus measuring the residence time distribution (Levenspiel, 1979). A second important parameter that can be determined from the residence time distribution is the actual retention time, ART = R_a, or the mean liquid retention time. This parameter is the ratio of the effective reactor volume and the flow rate and as such not necessarily equal to the hydraulic retention time, given as the ratio of the physical pond volume and the flow rate. The actual retention time of the liquid is determined experimentally as the time required to recover in the effluent 50% of a tracer slug applied to the influent. The difference between the physical pond volume and the effective pond volume is the volume of stagnant zones in the pond, the so-called dead volume. The dead volume fraction can be determined as:

\[ F_d = \frac{(V_t - V_r)}{V_t} = 1 - \frac{R_a}{R_h} \]  

(2)

where:

- \( V_t, r \) = total and real (effective) pond volume
- \( R_h \) = hydraulic retention time
- \( f_d \) = dead volume fraction

Once the values of the dead volume fraction, \( f_d \) and the dispersion number, \( D \), have been determined from a tracer study and the decay constant \( k_d \) has been determined from batch data, the theoretical removal efficiency of the bacteria can be calculated from Equation (1) and compared to the experimental value.

Several authors (Agunwamba et al., 1992; Yanez, 1993) have proposed models to calculate the dispersion number from the pond geometry and operational conditions. Even though these models give widely different values for the dispersion number when they are applied to a particular pond system, they do indicate that insofar as the pond geometry is concerned, a low dispersion number may be expected in ponds with a high length/width ratio and a small depth, i.e. little mixing ponds should be narrow and shallow. Von Sperling (1999) recommended that as a first estimate, the dispersion number can be equated to the width/length ratio of a pond, which is a simplification of Yanez’s empirical expression, where \( D \) is estimated as the width/length ratio: \( D = B/L \).
Experimental investigation

An experimental demonstration-scale investigation was carried out to demonstrate the feasibility of post-treatment of UASB effluent in a single, flow-through polishing pond and to determine the required retention time to obtain reliably a high quality effluent for use as irrigation water. As FC removal was the main goal, the pond was constructed with the objective to have as little mixing as possible. The pond with a total volume of 32.5 m³ had five parallel subdivisions (lanes) as shown in Figure 2a. Each subdivision had a liquid depth of 0.65 m, a length of 10 m and a width of 1 m, so that a total length/width ratio of 50/1 was achieved. For expected values of $k_d > 2.0 \text{ d}^{-1}$ for the decay constant (experimentally determined) and $D = 0.02$ (estimated from the dimension of the pond in the expression of Von Sperling (1999)), this pond would have an FC removal of more than 99.99% for a retention time of 5 d, which was considered sufficient. Hence initially the adopted retention time was 5d.

Special care was taken with the transfer of the liquid from one lane to the next. Previous experience (Dixo et al., 1995) had shown that during the daytime dissolved oxygen tends to desorb, due to supersaturation. The rising oxygen bubbles tend to carry algae with them and a mat of floating algae may form, which is undesirable, since it hinders sunlight penetration. For that reason the transfer from one lane to the next was from top to bottom, as indicated in Figure 2b. This construction had the advantage that it was impossible that backmixing could occur. Another reason for the connection form was that it had been observed before that the traditional “round the bend” connection led to a very high dispersion number (0.4 to 0.6 for L/B of 5).

The influent of the polishing pond was the effluent of a pilot-scale UASB reactor treating raw sewage from the city of Campina Grande. The retention time in the digester was 3 h and no sludge was discharged intentionally, so that excess sludge was present in the UASB effluent. This operational procedure was adopted to create an unfavourable condition for the polishing pond: in practice the UASB effluent quality would normally be better because a longer retention time (4 to 6 h) would be applied and excess sludge would possibly be discharged from the UASB reactor, preventing it from being carried with the effluent.

The polishing pond was operated for a period of 10 months, during which retention times of 5 and 15 days were applied. The flow was kept constant with the aid of a dosing pump. The tests to characterise the pond performance were: DO (min/max) at mid-depth, BOD, COD, TKN, P, algae (as chlorophyll $a$), pH, alkalinity and the hygienic quality in terms of FC and helminth eggs concentrations. In order to account for the presence of algae the filtered BOD and COD values of the digested sewage and the effluents of the different lanes were also determined. Table 1 shows the average of the experimental results for the applied total retention time of 5 d. The experimental data of Table 1 show that the FC count of the effluent was too high for unrestricted irrigation (maximum 1000 per 100 ml). For that reason the retention time was increased to 15 days. The results are in Table 3.

The dispersion number and the dead volume ratio of the polishing pond were determined for each of the applied hydraulic retention times, by adding potassium chloride to the influent and determining the potassium concentration profile with time in the effluent of the pond. The same experiment was also used to determine the actual mean retention time of the liquid in the pond and hence the dead volume fraction.

Table 3 shows the experimental values of the decay constants obtained from batch data and of the dispersion number and the dead volume fraction obtained from tracer studies for each of the two values of the hydraulic retention time. With the aid of these data and Equation (1) the theoretical values of the remaining FC fractions for the different retention times were calculated and these values were compared with the experimental data. Both are indicated in Table 3. In the case of Table 2 the data of lane 4 (corresponding to a retention
Table 1. Pond performance of the polishing pond for a constant flow of 270 l/h (HRT = 5 d) treating effluent from a UASB reactor. February 1999 to June 1999. Sewage temperature 26 ± 1°C

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Raw sew.</th>
<th>Dig. sew.</th>
<th>Pond lane 1</th>
<th>Pond lane 2</th>
<th>Pond lane 3</th>
<th>Pond lane 4</th>
<th>Pond lane 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. DO(*)</td>
<td>mg/l</td>
<td>–</td>
<td>–</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Max. DO(*)</td>
<td>mg/l</td>
<td>–</td>
<td>–</td>
<td>1.5</td>
<td>2.5</td>
<td>&gt;20</td>
<td>&gt;20</td>
<td>&gt;20</td>
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<tr>
<td>TSS</td>
<td>mg/l</td>
<td>422</td>
<td>190</td>
<td>120</td>
<td>102</td>
<td>68</td>
<td>52</td>
<td>68</td>
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<tr>
<td>BOD</td>
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<td>169</td>
<td>87</td>
<td>71</td>
<td>55</td>
<td>54</td>
<td>59</td>
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<tr>
<td>BOD&lt;sub&gt;f&lt;/sub&gt;</td>
<td>mg/l</td>
<td>–</td>
<td>105</td>
<td>64</td>
<td>36</td>
<td>40</td>
<td>32</td>
<td>35</td>
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<tr>
<td>COD</td>
<td>mg/l</td>
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<td>254</td>
<td>187</td>
<td>223</td>
<td>256</td>
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<td>188</td>
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<tr>
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<td>87</td>
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<td>54</td>
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<td>45</td>
<td>43</td>
<td>43</td>
<td>39</td>
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<tr>
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<td>–</td>
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<td>6.9</td>
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<td>7.3</td>
<td>7.7</td>
<td>8.1</td>
<td>8.3</td>
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<tr>
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<td>432</td>
<td>436</td>
<td>413</td>
<td>397</td>
<td>391</td>
<td>379</td>
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<tr>
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<td>µg/l</td>
<td>–</td>
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<td>464</td>
<td>916</td>
<td>1466</td>
<td>1702</td>
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<tr>
<td>Helminth eggs</td>
<td>/l</td>
<td>–</td>
<td>214</td>
<td>82</td>
<td>8</td>
<td>5</td>
<td>0</td>
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<tr>
<td>F. coli forms</td>
<td>/100 ml</td>
<td>7.4E7</td>
<td>2.3E7</td>
<td>4.7E6</td>
<td>2.9E6</td>
<td>1.1E6</td>
<td>3.3E5</td>
<td>7.5E4</td>
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Table 2. Pond performance of the polishing pond for a constant flow of 90 l/h (HRT = 15 d), treating effluent from a UASB reactor. January to May 2000. Sewage temperature: 26 ± 1°C

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Raw sew.</th>
<th>Dig. sew.</th>
<th>Pond lane 1</th>
<th>Pond lane 2</th>
<th>Pond lane 3</th>
<th>Pond lane 4</th>
<th>Pond lane 5</th>
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<td>–</td>
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<td>3.1</td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Max. DO(*)</td>
<td>mg/l</td>
<td>–</td>
<td>–</td>
<td>8.1</td>
<td>9.5</td>
<td>3.4</td>
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<tr>
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<td>mg/l</td>
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<tr>
<td>P</td>
<td>mg/l</td>
<td>–</td>
<td>–</td>
<td>8.3</td>
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<td>939</td>
<td>291</td>
<td>238</td>
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<tr>
<td>Helminth eggs</td>
<td>/l</td>
<td>–</td>
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<td>&lt;1</td>
<td>–</td>
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<td>F. coli forms</td>
<td>/100 ml</td>
<td>3.1E7</td>
<td>2.4E7</td>
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<td>8.0E4</td>
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Discussion

The most important point borne out by the experimental data in Table 1 show that it is perfectly feasible to operate a single pond system as a post-treatment option for anaerobically digested sewage. In terms of the final effluent BOD and TSS concentrations, an effluent with a quality equivalent to that of a conventional WSP system with three to five units in series and a retention time of 20 to 30 d was obtained in a single polishing pond with a retention time of less than 3 d. It is important to note that no sludge was discharged from the UASB reactor used for pre-treatment and this reactor operated at a short retention time, so that the UASB effluent had relatively high COD, BOD and TSS concentrations, as can be seen in Tables 1 and 2. If an effluent quality for unrestricted irrigation is to be obtained, the required retention time is longer: about 10 d but this value is still very much smaller than the retention time in conventional WSP systems (20 to 30 d).

When polishing ponds are compared to conventional WSP systems, the former have two important advantages: The very much shorter retention time allows a considerable reduction of the area, which is the principal weakness of conventional systems. Another important problem is the odour release in conventional ponds, which is not observed in polishing ponds. The absence of odour and the relatively small area make the polishing pond much more applicable than the conventional WSP near or even within urban areas.

Insofar as suspended solids are concerned, a practically constant value was obtained after a retention time of only 3 d, as can be seen in Tables 1 and 2, although its final value (about 65–70 mg TSS/l) is high by most standards. The organic material removal as indicated by the BOD concentration in the pond was similar, reaching a constant value of 55–70 mg/l after about 3 d, again higher than the maximum in most standards. The filtered BOD tended to a constant value in the range of 30–35 mg/l, so that it is concluded that half the BOD in the final effluent could be attributed to algae, the predominant suspended material. Algae are also responsible for more than half of the residual COD concentration, when the retention time was 5 d. The data in Table 2 show a remarkable decrease in the total TSS and BOD concentrations after a retention time of one week, causing their values to approach those of filtered samples. At the same time there was a visible decrease of the intense green colour in the second and third lanes to a much lower colour intensity in the last two lanes.

It is interesting to note in Table 1 that a stable but small algae population (chlorophyll concentration of 123 µg/l) was observed in the first lane of the pond, even though the retention time was only 1 d, showing that the biological processes of photosynthesis and oxida-

<table>
<thead>
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<th>Parameter</th>
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<th>HRT = 12 d(*)</th>
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<tbody>
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<td>Experimental decay constant (d⁻¹)</td>
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</tr>
<tr>
<td>Dispersion number</td>
<td>0.14</td>
<td>0.16</td>
</tr>
<tr>
<td>Dead volume fraction</td>
<td>0.12</td>
<td>0.15</td>
</tr>
<tr>
<td>Actual retention time (d)</td>
<td>4.4</td>
<td>10.2</td>
</tr>
<tr>
<td>Remaining fraction (experimental)</td>
<td>3.3 × 10⁻³</td>
<td>2.1 × 10⁻⁴</td>
</tr>
<tr>
<td>Remaining fraction (theory - Wehner-Wilhelm)</td>
<td>3.4 × 10⁻³</td>
<td>1.2 × 10⁻⁴</td>
</tr>
</tbody>
</table>

(*) HRT in four lanes
tion developed in this lane. While the algae concentration, expressed by the chlorophyll a concentration, steadily rose as the water passed through the lanes for retention times up to 5 d (Table 1), there was a significant decline after retention times of more than 6 days as can be seen in Table 2. The strong reduction could also be perceived in other parameters: not only was there a strong reduction of the TSS, COD and BOD concentrations, but also the DO concentration and the pH value were reduced, indicating that there was a reduction of the photosynthetic activity at a retention time of 7 to 15 d. The reason for the lower rate of photosynthesis and the strong reduction of the algae concentration can be attributed to algae flocculation and consumption by predators. Algae flocculation was observed when samples of lanes 3, 4 and 5 at HRT = 15 d were placed in the sun: in less than 1 hour a green sediment developed. As for predators, varying concentrations of Daphnia and macroscopic organisms were observed in lanes 3, 4 and 5. Due to the efficient removal of the algae the effluent concentration for retention times of more than 10 days was less than 30 mg/l both for TSS and BOD, which makes the effluent quality compatible with very strict standards.

With respect to pathogens, the removal of helminth eggs was similar to that of suspended solids in general and after three days retention time helminths eggs were no longer observed. By contrast the removal of faecal coliforms was incomplete and much lower than originally expected The limit for unrestricted irrigation was only obtained at a retention time of 9–12 d (Table 2), which is more than double the theoretical value calculated for exponential decay. The relatively low FC removal efficiency must be attributed to imperfections in the flow regime in the pond.

The tracer studies showed that the flow pattern in the pond was indeed very far from the ideal plug flow behaviour. Even though the pond was narrow and shallow, the dispersion number was quite considerable. It may be concluded that uncontrollable factors like wind and rising of gas bubbles induce so much mixing that plug flow behaviour cannot be approached in practice: a dispersion number of at least 0.1 is almost unavoidable and this means that the retention time for FC removal in a flow-through polishing pond must be at least twice the theoretical minimum value. For this reason it can be argued that the pond should be operated in batch mode, since in that case the required retention time is equal to the theoretical minimum. Hence the retention time in a batch pond could be half the retention time in a flow-through pond. This aspect will be dealt with in detail in a separate paper.

Also the value of dead volume fraction in the polishing pond was almost surprisingly large and contributed to a low value of the FC removal efficiency. A possible explanation for this unsatisfactory behaviour is that a warmer and lighter upper layer is formed on top of the cooler bottom layer. Since the effluent of the different lanes was collected at the surface, it could have been possible that the lighter top layer would glide over the denser bottom layer, thus forming a stagnant zone at the bottom.

Conclusions

Single flow-through ponds can be used to improve the quality of UASB effluents: the residual concentrations of TSS, BOD and COD as well as pathogens (helminth eggs and faecal coliforms) can be removed in polishing ponds with a very much shorter retention time than that necessary in conventional waste stabilisation ponds.

In a shallow (0.65 m) polishing pond, treating UASB effluent, the concentrations of BOD and TSS reached values of 55 to 70 after only 3 days, whereas the filtered BOD concentration was 35 mg/l.

The removal of helminth eggs was complete after a retention time of only 3 d, even though the concentration in the digested sewage was high (82 units/l).

Tracer studies showed significant mixing in the pond with a large L/B ratio (dispersion numbers of 0.14 to 0.16), and a considerable dead volume fraction was (0.12 to 0.15).
The FC removal efficiency was closely predicted by the Wehner and Wilhelm equation for partially mixed ponds. Effluent quality compatible with the WHO guideline for unrestricted irrigation was attained for a retention time of 10 d, as against less than 5 d in a batch pond.

During the first 5 d in the pond the algae concentration increased rapidly and photosynthesis occurred at a high rate. Subsequently the algae concentration and photosynthesis rate decreased very significantly.

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References