Thermo-tolerant coliform bacteria decay rates in a full scale waste stabilization pond system in Northeast Brazil

S. L. Macedo, A. L. C. Araújo and H. W. Pearson

ABSTRACT

This paper presents the results for thermo-tolerant coliform (TTC) decay rates ($K_b$) in a full scale WSP system located in Natal-RN, northeast Brazil. The series comprises a primary facultative pond (2 m deep), followed by two maturation ponds (1.5 m deep) giving a total area of 11 ha. The influent sewage and the pond effluents were monitored weekly during a seven month period. The results showed that the $K_b$ values predicted by the Marais equation assuming a hydraulic regime of complete mixing overestimated TTC die-off rates. The $K_b$ value adopted in the project design was 6.20 d$^{-1}$ but the mean value found for the WSP system during the monitoring programme was only 0.85 d$^{-1}$. This value is low compared to the values cited in the literature for shallow ponds (< 1.25 m deep) but similar to values for deeper ponds. The sub optimal TTC removal rate in this WSP system may be caused by the adoption of too high a $K_b$ value at the design stage and the negative influence of high wind conditions on the mixing regime in the water columns of the ponds. Thus values for $K_b$ adopted at the design stage of WSP systems should be coherent with the hydraulic flow model, the type of pond, pond depth, and with the surface organic loading.

Key words | hydraulic retention time, thermo-tolerant coliforms decay rate ($K_b$), thermo-tolerant coliform removal, waste stabilization ponds

INTRODUCTION

Waste stabilization ponds (WSP) are efficient at removing pathogenic microorganisms, particularly in tropical regions as a result of the high ambient temperatures and light intensities, elevated pH values in the pond water column, coupled with their relatively long hydraulic retention times (HRT) when compared to other treatment technologies. Research in many countries has attested to the high efficiency of ponds in removing thermo-tolerant coliform bacteria (TTC) based on the measurement of bacterial decay rates ($K_b$). However, these $K_b$ values were generally determined in pilot-scale pond systems which may differ from those found in full scale systems.

Well designed, operated and maintained WSP series, produce effluents meeting the WHO guidelines for unrestricted irrigation and in the semi-arid of Northeast Brazil, treated wastewater may be the only available water resource for agriculture. However, WSP systems are often incorrectly designed, operated and maintained and consequently their final effluents still contain high concentrations of pathogenic microorganisms which put at risk the health of the workers and consumers.

The WSP system of Ponta Negra was commissioned in 2000 and is currently treating around 60% of its design flow. Previous results have shown that organic matter and TTC removal rates were below those projected at the design stage, probably due to the use of overestimated $K_b$ values for both BOD and TTC removal. Moreover, the adverse impact of strong winds during daylight hours throughout the year is considered to be at least partly implicated in their poor performance (Meneses et al. 2005; Pearson et al. 2005; Saraiva et al. 2005). This research studied TTC removal in the Ponta Negra WSP system in more detail and compared the empirical equations for $K_b$ with the actual values found by means of applying specific hydraulic models.

S. L. Macedo
Institute for Sustainable Development and the Environment of Rio Grande do Norte (IDEMA), Rua Parambu, 62 – Conjunto dos Bancários – Pitimbu, Natal-RN, CEP 59068-620, Brazil
E-mail: idema-sergiomacedo@rn.gov.br

A. L. C. Araújo
E-mail: acalado@cefetrn.br

H. W. Pearson (corresponding author)
Environmental Sanitation Group, Department of Chemistry, State University of Paraíba (UEPB) Avenida das Bananas, 351, Bodocongó, 58109-753 Campina Grande, PB, Brazil
E-mail: howard_william@uol.com.br

doi: 10.2166/wst.2011.110
MATERIAL AND METHODS

The Ponta Negra WSP system was designed to treat the sewage of 33,500 inhabitants (8,208 m³/day) and comprises a primary facultative pond (PFP) followed by two maturation ponds (MP-1; MP-2), (see Table 1 and Figure 1). Part of the final effluent is re-circulated to the PFP with the rest being discharged into infiltration channels over a 15 ha area of sandy soil.

Routine monitoring was based on the weekly collection of grab samples of raw sewage and pond effluents during a seven month period. Samples were taken between 07:00 and 08:00 hours and analysed, according to APHA (1998), for TTC, pH, temperature, total suspended solids (TSS), dissolved oxygen (DO), total and soluble BOD₅, total and soluble COD.

Chlorophyll a concentrations (Chl a) were determined using the method described by Jones (1979). Flow rate was measured daily with an automatic flow meter comprising a Prosonic transmitter and ultrasonic level sensor, models FMU 86-R1B1A1 and FDU 80 RG1A, respectively, installed on the Parshall flume at the inlet works.

RESULTS AND DISCUSSION

Operational characteristics

The mean flow rate during the monitoring period was 4742 m³/day, corresponding to only 58% of the maximum design flow of 8,208 m³/day. The mean temperature was 27°C and the mean monthly precipitation was 297 mm. The predominant winds were from the southeast (85%), with a mean velocity of 4.1 m/s, but higher velocities were observed between 10.00 and 14.00 hours (7.21–9.40 m/s), while through the night values were close to zero. This behaviour generally caused a scum layer to develop at the inlet region of the PFP by morning, which subsequently disappeared as wind velocities increased and mixed the water column.

The HRT and organic loadings were based on the measured influent flow rate plus the recirculation flow rate from the final effluent to the primary facultative pond (57 m³/h) resulting in a mean value of 6110 m³/day. The HRT values of 17.2, 6.8, and 7.0 days were estimated for the facultative (PFP) and the maturation ponds (MP-1, MP-2), respectively,
and the surface organic loadings (ls) were 296, 262, and 248 kgBOD5/ha.day, respectively. Whilst the primary facultative pond surface loading was within the range generally used in pond design at these temperatures, the maturation ponds could be considered to be overloaded, and this is supported by the high values for Chl a, TSS, BOD and COD and relatively low pH values in their effluents (Table 2). Although the projected maximum influent sewage flow had not been reached the results attested to the fact that the design criteria for the WSP system were inadequate and the impact of high wind velocities had not been considered.

**Raw sewage and effluents characteristics**

Table 2 shows the means of variables monitored in the raw sewage and the pond effluents. After performing Shapiro-Wilk’s normality tests for all variables (Statsoft 2006), the geometric mean was chosen as the central tendency for TTC values. The pond series removed 73% and 55% of BOD and COD, respectively. Soluble fractions of BOD and COD varied in the ranges of 20 to 27% and 29 to 33%, respectively, indicating that the major part of the organic contents in the pond effluents was associated with the algae as attested to by the high values of chlorophyll a and suspended solids.

**Thermo-tolerant coliform removal efficiency**

Pond efficiencies for TTC removal were 92.94% (PFP), 84.03% (MP-1) and 87.62% (MP-2), resulting in an overall removal efficiency for the pond series of 99.86%. Surface organic overloading on the maturation ponds due to the poor organic removal in the primary facultative pond (PFP) may be one of the causes for the poor TTC removal (<1 log unit reduction per pond). Adopting the same methodology and variables used by the designers of the WSP system, i.e. assuming complete mixing in the ponds, a $K_0$ of 6.2 d$^{-1}$ and the actual operational conditions, the effluent concentrations should be 398,551 TTC/100 ml (PFP), 9,234 TTC/100 ml (MP-1), and 208 TTC/100 ml (MP-2). These values are very different from those found during the monitoring period (Table 2), particularly for the final effluent ($5.99 \times 10^4$ TTC/100 ml) which is around 300 times higher than the predicted value of 208 FC/100 ml.

Anova analysis followed by the Tukey Test for comparisons among means at a level of 0.05 showed that mean TTC concentrations in the raw sewage was significantly different from the values in the pond effluents ($p < 0.05$). However, the means for the pond effluents did not differ from each other confirming that the maturation ponds were not efficient at TTC removal (Figure 2).

**Dispersion numbers (d)**

Dispersion numbers for the ponds (Table 3) were estimated by Equations (1) (Polprasert & Bhattarai 1985), 2 (Agunwamba et al. 1992, simplified by Von Sperling 1996) and

![Figure 2](https://iwaponline.com/wst/article-pdf/63/6/1321/445682/1321.pdf)}
Table 3 | Theoretical dispersion numbers for the three ponds

<table>
<thead>
<tr>
<th>References</th>
<th>Dispersion numbers (d)</th>
<th>PFP</th>
<th>MP-1</th>
<th>MP-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polprasert &amp; Bhattarai (1985)</td>
<td>0.127⁷ 0.566 0.322</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agunwamba et al. (1992)</td>
<td>0.810⁷ 1.121 0.859</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yanez (1993)</td>
<td>0.387⁷ 0.688 0.485</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Mean values for the four sections in the PFP.

Values presented in Table 4 are inferior, but closer to \( K_b \) values obtained in the deeper pilot scale ponds of Silva et al. (1996).

\[
N_e = \frac{N_i}{1 + K_b \times t} \quad (4)
\]

\[
N_e = N_i \times \frac{4 \times a \times e^{1/(2 \times d)}}{(1 + a)^2 \times e^{a/(2 \times d)} \times (1 - a)^2 \times e^{-a/(2 \times d)}}; \quad (5)
\]

\[
N_e = N_i \times e^{-K_b \times t} \quad (6)
\]

where: \( N_e \) = TTC in the effluent; \( N_i \) = TTC in the influent; \( K_b \) = TTC decay rate (d⁻¹).

\( K_b \) values estimated by empirical equations

The empirical equations below were used to determine \( K \) values (for completely mixed conditions) and the results are presented on Table 5.

\[
K_b(T) = 2.6 \times (1.19)^{T - 20} \quad (Marais 1974) \quad (7)
\]

\[
K_b(T) = 1.1 \times (1.07)^{T - 20} \quad (Yanez 1993) \quad (8)
\]

\[
K_b(T) = 1.608 \times H^{-0.877} \times t^{-0.329} + [7.656 \times 10^{-4} \times H^{-3.674} \times t^{1.811} \times \left(\frac{L}{B}\right)^{1.509}] \times 1.07^{T - 20} \quad (Von Sperling 1999) \quad (9)
\]

\[
K_b = 0.712 \times (1.166)^{T - 20} \quad (Mills et al. 1992) \quad (10)
\]

where: \( T \) = liquid temperature (°C); \( T_{air} \) = air temperature (°C); \( K_{20} = 20 \text{ °C decay rate (d}^{-1});

The results show that \( K_b \) values predicted by the Marais (1974) equation were an overestimation when compared to actual values presented in Table 4. On the other hand values

Table 4 | Actual \( K_b \) values according to the hydraulic flow model

<table>
<thead>
<tr>
<th>Pond</th>
<th>Complete Mixing</th>
<th>Dispersed flow</th>
<th>Plug flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFP</td>
<td>0.77</td>
<td>0.20⁷</td>
<td>0.34⁷ 0.27⁷ 0.15</td>
</tr>
<tr>
<td>MP-1</td>
<td>0.77</td>
<td>0.44⁷</td>
<td>0.52⁷ 0.47⁷ 0.27</td>
</tr>
<tr>
<td>MP-2</td>
<td>1.01</td>
<td>0.45⁷</td>
<td>0.58⁷ 0.50⁷ 0.30</td>
</tr>
</tbody>
</table>

a, b, c – the estimated values according to Polprasert & Bhattarai (1985), Agunwamba et al. (1992) and Yanez (1993), respectively.

Table 5 | Empirical decay rate values for completely mixed conditions

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PFP</td>
<td>5.89</td>
<td>1.51</td>
<td>0.67</td>
<td>1.08</td>
</tr>
<tr>
<td>MP-1</td>
<td>6.20</td>
<td>1.54</td>
<td>0.86</td>
<td>1.53</td>
</tr>
<tr>
<td>MP-2</td>
<td>5.40</td>
<td>1.46</td>
<td>0.81</td>
<td>1.36</td>
</tr>
</tbody>
</table>
predicted by the Von Sperling (1999) equation were closer to the actual values assuming complete mixing.

\[ K_b(T) = 0.917 \times H^{0.877} \times t^{-0.329} \times (1.07)^{T-20} \] (Von Sperling 1999) \hspace{1cm} (12)

\[ K_b = \ln[1.1274 \times (0.6351) \times (1.0281)^T \times (1.0016)^{Cs} \times (0.9994)^{I_s}] \] (Polprasert et al. 1985) \hspace{1cm} (13)

\[ K_b = 0.019 \times 0.915(T-20)e^{0.170I_m} \] (Xu et al. 2002) \hspace{1cm} (14)

where: \( Cs \) = algal concentration (mg/L dry weight); \( \lambda_s \) = surface organic loading (kgCOD/ha.day); \( I_m \) = mean light intensity (J/cm².day).

The equations used to determine \( K_b \) for plug flow conditions are given below and the predicted values obtained are presented in Table 6.

\[ K_b = 0.50 \times (1.02)^{T-20} \times (1.15)^{2pH-6} \times (0.9784)_{DBO_5-100} \times (Saqqar and Pescod 1992) \] (15)

\[ K_b = 5.67 \times 10^{-4}(S_o/H) + 0.0135 \times pH \] (Mayo 1995) \hspace{1cm} (16)

\[ K_b = 0.014 \times (1.034^{T-20}) + 5.7 \times 10^{-4}(S_o/H) - 0.0063 \times pH \] (Mayo 1995) \hspace{1cm} (17)

Design criteria for northeast Brazil

Table 7 presents the \( K_b \) values obtained in pilot scale ponds in northeast Brazil (Farias 1989; Oragui et al. 1995; Silva et al. 1996).

CONCLUSIONS

The removal efficiency of thermo-tolerant coliform bacteria was less than the value predicted from design calculations.

Table 7 | Actual \( K_b \) values found in pilot scale WSP in Northeast Brazil as a function of depth (D), hydraulic detention time (HRT) and organic surface loading (\( \lambda_s \)), assuming complete mixing

<table>
<thead>
<tr>
<th>Pond</th>
<th>Shallow ponds</th>
<th></th>
<th>Deep ponds</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D = 1.75 TDH ≥ 2</td>
<td>D = 1.25</td>
<td>D = 1.0</td>
<td>D = 2.0</td>
</tr>
<tr>
<td></td>
<td>TDH ≥ 12</td>
<td>TDH ≥ 7</td>
<td>TDH ≥ 5</td>
<td>TDH ≥ 6</td>
</tr>
<tr>
<td>Anaerobic</td>
<td>5.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Primary facultative</td>
<td>–</td>
<td>8.0</td>
<td>3.0</td>
<td>–</td>
</tr>
<tr>
<td>Secondary facultative</td>
<td>–</td>
<td>1.0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Maturation</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Depth (D) in metres; TDH in days; \( \lambda_s \) in KgBOD5/ha.day
and this could be associated with the use of the wrong hydraulic flow model, the application of too high a $K_b$ value, and higher organic loadings on the maturation ponds than predicted.

The $K_b$ value of 6.20 d$^{-1}$ adopted for the design of all the ponds in the series, assuming complete mixing, is higher than the observed mean value of 0.85 d$^{-1}$. A $K_b$ of 6.20 d$^{-1}$ is more acceptable for use with shallow maturation ponds (depth $<$ 1.25 m) and with organic loadings less than 350 kgBOD$_{5}$/ha.day on the primary facultative pond (Silva et al. 1996).

Assuming completely mixed conditions in the Ponta Negra WSP system, $K_b$ values predicted by the Marais (1974) equation were an overestimation whilst the equation of Von Sperling (1999) gave more realistic results. Assuming dispersed flow conditions, the Von Sperling (1999) equation, also gave predicted results closer to the real values obtained for the WSP. The Mayo (1995) equation was better for plug flow conditions. Caution is therefore advised when applying the Marais equation (1974) for estimating $K_b$ values in large, deeper ponds particularly where windy conditions may prevail.

The $K_b$ values adopted at the WSP design stage should therefore be coherent with the hydraulic flow model, the type of pond, pond depth, and with the surface organic loading.

REFERENCES


Von Sperling, M. 1996 Lagoas de Estabilização. Belo Horizonte, Departamento de Engenharia Sanitária e Ambiental; UFMG.
