FAECAL COLIFORM DECAY RATE IN WSPs OF PONTA NEGRA, NORTHEAST OF BRAZIL

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INTRODUCTION

- High efficiency on FC removal (1000 cfu/100 ml)
- Real x Pilot scale
- In semi-arid regions of Northeast Brazil, the effluents may be the only available water resource for irrigation
- WSPs are often not properly designed, operated and maintained (low quality effluents)
- The WSPs of Ponta Negra (11 ha) was commissioned in 2000 (60% capacity)
- Performance in terms of organic matter and faecal coliforms removal is below expected (overestimated decay rates for both BOD and coliforms on design stage)

**OBJECTIVE:** study the removal of faecal coliforms and compares the empirical equations for $K_b$ with the real values found by means of a specific hydraulic model
MATERIAL AND METHODS

- 33,500 habitants (8,208 m³/day)
- Primary facultative pond (PFP) followed by two maturation ponds (MP-1, MP-2)
- The final effluent is discharged in channels for infiltration (15 ha of sandy soil)
- Weekly collection of grab samples of raw sewage and pond effluents during a seven month period
- Samples analysed for faecal coliforms, pH, temperature, suspended solids, dissolved oxygen, total and filtered DBO₅ and COD, Chlorophyll a
- Flow rate was measured daily with an automatic flow meter
Ponta Negra WSPs

**Characteristics**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>PFP</th>
<th>MP-1</th>
<th>MP-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (m)</td>
<td>445</td>
<td>196*</td>
<td>234*</td>
</tr>
<tr>
<td>Width (m)</td>
<td>118*</td>
<td>143</td>
<td>122</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>2.0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>52,570</td>
<td>28,040</td>
<td>28,600</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>105,138</td>
<td>42,057</td>
<td>42,899</td>
</tr>
</tbody>
</table>
Ponta Negra WSPs
Ponta Negra WSPs: final effluent
RESULTS: operational

- Flow rate = 4742 m$^3$/day (58% of the maximum design flow)
- SE winds (85%), mean velocity of 4.1 m/s. From 10 to 14 h (7.21 – 9.40 m/s) and from 18 to 8 (0 m/s)
- Scum layer near the inlet of the PFP (morning), which disappears as wind velocities increased

- HDT (17.2 – 6.8 – 7.0 = 31 d)
- Organic loadings were 296, 262, and 248 kgDBO$_5$/ha.day
- PFP (OK!), MP (overloaded)
- MP - High levels of chlorophyll a, suspended solids and DBO e COD
- Influence of wind
RESULTS: winds

- Predominantly SE (variations: NE)
- Velocities: mean – 1 to 4 m/s; max – 10 m/s (10 e 14:00 h); min – 0 m/s (18 e 6:30 h)
RESULTS: RS and effluents

- 73% and 55% of BOD and COD removal
- Filtered fraction of DBO and COD varied in the ranges of 20 to 27% and 29 to 33%
- Major part of the organic contents in pond effluents were associated with algae (high values of chlorophyll a, SS)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>RS</th>
<th>PFP</th>
<th>MP-1</th>
<th>MP-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (° C)</td>
<td>28.9</td>
<td>27.8</td>
<td>28.1</td>
<td>28.0</td>
</tr>
<tr>
<td>pH</td>
<td>7.0</td>
<td>7.3</td>
<td>7.4</td>
<td>7.3</td>
</tr>
<tr>
<td>DO (mg/L)</td>
<td>-</td>
<td>4.2</td>
<td>4.8</td>
<td>4.0</td>
</tr>
<tr>
<td>BOD₅ (mg/L)</td>
<td>305</td>
<td>120</td>
<td>116</td>
<td>82</td>
</tr>
<tr>
<td>BOD₇ (mg/L)</td>
<td>-</td>
<td>32</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>577</td>
<td>338</td>
<td>319</td>
<td>259</td>
</tr>
<tr>
<td>COD₇ (mg/L)</td>
<td>-</td>
<td>97</td>
<td>104</td>
<td>84</td>
</tr>
<tr>
<td>Suspended solids (mg/L)</td>
<td>364</td>
<td>421</td>
<td>324</td>
<td>241</td>
</tr>
<tr>
<td>Chlorophyll a (µg/L)</td>
<td>-</td>
<td>1825</td>
<td>1592</td>
<td>1104</td>
</tr>
<tr>
<td>Faecal coliform (FC/100ml)</td>
<td>5.53 x 10⁷</td>
<td>3.03 x 10⁶</td>
<td>4.84 x 10⁵</td>
<td>5.99 x 10⁴</td>
</tr>
</tbody>
</table>
RESULTS: FC removal

- 92.94% (PFP), 84.03% (MP-1) and 87.62% (MP-2) = WSPS – 99.86%
- Methodology and variables used by the designer of the WSPs:
  - complete mixing
  - Kb of 6.2 d⁻¹
  - 398,551 FC (PFP), 9,234 FC (MP-1), and 208 FC (MP-2)

- Ponta Negra present a disperse flow (Meneses, 2006).
- Coliform decay rate was estimated using models for complete mixing, disperse flow, and plug flow, and compared with values of empirical equation
RESULTS: Dispersion number

<table>
<thead>
<tr>
<th>References</th>
<th>Dispersion numbers - d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PFP</td>
</tr>
<tr>
<td>Polprasert and Bhattarai (1985) – a</td>
<td>0.127*</td>
</tr>
<tr>
<td>Agunwamba et al. (1992) – b</td>
<td>0.810*</td>
</tr>
<tr>
<td>Yanez (1993) – c</td>
<td>0.387*</td>
</tr>
</tbody>
</table>

\[
d = \frac{0.184 \times [t \times \nu (B + 2 \times H)]^{0.489} \times B^{1.511}}{(L \times H)^{1.489}}
\]

\[
d = 0.102 \times \left( \frac{3 \times (B + 2 \times H) \times t \times \nu}{4 \times L \times B \times H} \right)^{-0.410} \times \left( \frac{H}{L} \right) \times \left( \frac{H}{B} \right)^{-(0.981 + 1.385 \times H/B)}
\]

\[
d = \frac{L/B}{-0.26118 + 0.25392 \times (L/B) + 1.01368 \times (L/B)^2}
\]
RESULTS: actual Kb values

<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>0.20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.34&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>MP-1</td>
<td>0.77</td>
<td>0.44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.52&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>MP-2</td>
<td>1.01</td>
<td>0.45&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.58&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

- Kb values in shallow **pilot scale** WSPS (8 d<sup>-1</sup> and 3 d<sup>-1</sup> for PFP with λs < 350 kg/ha.day and 1.25 deep, and 1.0 deep maturation ponds, respectively) (Silva et al., 1996)

- Project: **complete mixing and Kb of 6.2 d<sup>-1</sup>**

\[
N_e = \frac{N_i}{1 + K_b \times t}
\]

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

\[
Ne = Ni \times e^{-K_b \times t}
\]

\[
a = \sqrt{1 + 4K_b \times t \times d}
\]
## RESULTS: empirical $K_b$ values

<table>
<thead>
<tr>
<th>Pond</th>
<th>$K_b$ (d$^{-1}$)</th>
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<tr>
<td></td>
<td>Complete Mixing</td>
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<tr>
<td></td>
<td>Marais (1974)</td>
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<tr>
<td>PFP</td>
<td>5.89</td>
<td>1.51</td>
<td>0.67</td>
<td>1.08</td>
<td>6.46</td>
</tr>
<tr>
<td>MP-1</td>
<td>6.20</td>
<td>1.54</td>
<td>0.86</td>
<td>1.53</td>
<td>2.15</td>
</tr>
<tr>
<td>MP-2</td>
<td>5.40</td>
<td>1.46</td>
<td>0.81</td>
<td>1.36</td>
<td>2.15</td>
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<tr>
<td></td>
<td>Polprasert et al. (1983)</td>
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<td></td>
<td>Xu et al. (2002)</td>
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<tr>
<td></td>
<td>Eq. 16</td>
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<td>Eq. 17</td>
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<tr>
<td></td>
<td>Dispersion flow</td>
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<tr>
<td></td>
<td>Sperling (1999)</td>
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<tr>
<td>PFP</td>
<td>0.36</td>
<td>0.29</td>
<td>-</td>
<td>0.91</td>
<td>0.36</td>
</tr>
<tr>
<td>MP-1</td>
<td>0.48</td>
<td>0.17</td>
<td>0.07</td>
<td>0.96</td>
<td>0.45</td>
</tr>
<tr>
<td>MP-2</td>
<td>0.45</td>
<td>0.13</td>
<td>0.14</td>
<td>0.93</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>Plug flow</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td>Saqqar &amp; Pescod (1992)</td>
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<td></td>
<td>Mayo (1995)</td>
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<td></td>
<td>Eq. 16</td>
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<td>Eq. 17</td>
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**RESULTS: Kb – pilot scale**

- $K_b$ values found in pilot scale WSPs in northeast Brazil as a function of depth, hydraulic detention time and organic loading (assuming complete mixing) (Farias 1989; Oragui et al 1995; Silva et al 1996)

<table>
<thead>
<tr>
<th>POND</th>
<th>Shallow ponds</th>
<th>Deep ponds</th>
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<tbody>
<tr>
<td></td>
<td>$H = 1.75$</td>
<td>$H = 1.25$</td>
</tr>
<tr>
<td></td>
<td>TDH $\geq 2$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$H = 1.75$</td>
<td>TDH $\geq 12$</td>
</tr>
<tr>
<td></td>
<td>$\lambda_s &lt; 350$</td>
<td>$\lambda_s &gt; 350$</td>
</tr>
<tr>
<td>AP</td>
<td>5.0</td>
<td>-</td>
</tr>
<tr>
<td>PFP</td>
<td>-</td>
<td>8.0</td>
</tr>
<tr>
<td>SFP</td>
<td>-</td>
<td>1.0</td>
</tr>
<tr>
<td>MP</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
CONCLUSIONS

- FC removal « predicted on design (flow model, a high $K_b$ value, low organic loadings estimated on MP)
- The $K_b$ value of 6.20 d$^{-1}$ adopted in project design for all ponds in the series, assuming complete mixing, is higher than the observed mean values of 0.77 – 1.01 d$^{-1}$
- Assuming completely mixed or dispersed flow conditions, $K_b$ values predicted by Von Sperling (1999) gives more realistic results (PN WPS).
- The Mayo (1995) equation was better for a plug flow regime.
- The value for $K_b$ should be coherent with the hydraulic flow model, the type of pond, and pond depth, and with the surface organic loading.