Baffled primary facultative ponds with inlets and outlets set at different levels treating domestic wastewater in northeast Brazil

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Abstract This study evaluates the performance of four 2.3m-deep pilot-scale, independently loaded, primary facultative ponds treating predominantly domestic sewage in northeast Brazil. The ponds contained longitudinal baffles giving different length to width ratios from 3.55 to 32.4. The ponds had mean hydraulic retention times of ~15 days, and mean surface organic loadings of 330kg BOD_5.ha.d^{-1} during the first experimental phase and 375kgBOD_5.ha.d^{-1}, in the second. The vertical inlets and outlets pipes were positioned at 1.8m and 5cm respectively below the pond surface in the first phase and. at 50cm and 1.8m respectively in the second. All the ponds functioned as efficient primary facultative ponds but statistical analysis demonstrated no differences in effluent quality for most of the parameters measured for the various configurations of baffles and inlet and outlet depths All behaved similarly to the unbaffled pond. The only exceptions were suspended solids and chlorophyll a concentrations which tended to be lower for all combinations of baffles with the outlets set 1.8m below the surface. This study suggested that the longitudinal baffling of primary facultative ponds did not significantly improve pond performance. However, baffling maturation ponds might prove to be a different proposition.
Keywords inlets and outlets; baffles; primary facultative ponds; waste stabilization ponds.

INTRODUCTION

The process design procedure for primary facultative waste stabilization ponds receiving raw sewage and secondary facultative ponds normally receiving the effluent from anaerobic pretreatment ponds is identical and well established usually being based simply on permissible surface organic loading for given mean ambient temperatures during the coldest period of the year (Gloyna, 1976; Mara, 1975; Mara and Pearson, 1998; Mara et al., 1992). Some attempts have been made to refine this process by including a factor for pond dispersion into the design equations but the problem has always been how to predict the dispersion number for yet to be built pond (Nameche and Vasel, 1998). An approach based on uncertainty analysis has been suggested by von Sperling (1996), for facultative ponds adopting a range of values for parameters such as flow, BOD and thermotolerant coliforms to achieve the required effluent quality via a multi-trial Monte Carlo simulation programme.

Whist pond geometry has been shown to effect pond performance (Pearson, et al., 1995), aspects of physical design in terms of pond hydraulics and the positioning and design of the inlet and outlet structures are less secure and have been reviewed recently by Shilton and Sweeney (2005). It is known that hydraulic short circuiting can be caused by wind effects (Fares and Lloyd, 1995; Menezes, et al., 2005) and thermal stratification (Pedahzur, et al., 1993) amongst others and this can reduce pond performance. In this context the use of longitudinal, transverse and vertical baffles have been studied in an attempt to create in-pond conditions as close to plug flow as possible (Watters, et al., 1973; Shilton and Harrison, 2003).

The positioning, orientation and depths of the inlet and outlet structures have been considered by Shilton and Harrison (2003), who suggested that the positioning of the outlets is critical in terms of hydraulic efficiency because the wastewater tends to circulate around the pond rather than simply move steadily from the inlet to the outlet.

In this study the effect of various configurations of longitudinal baffles and the impact of the vertical depth of the inlet and outlet structures were evaluated in experimental, tropical, primary facultative ponds.

MATERIALS AND METHODS

The pilot-scale pond system, illustrated in Figure 1, was constructed at the Experimental Station for the Biological Treatment of Sewage (EXTRABES) of the Federal University of Campina Grande (UFCG), and the State University of Paraíba (UEPB). The system comprised four independently loaded primary facultative ponds (F1, F2, F3 and F4), with a water depth of 2.3m, each 25.4m in length and between 7.10 and 7.15m wide. Three of the ponds were baffled and the fourth, without baffles, acted as the control. Ponds F1 and F2 contained three and five parallel longitudinal baffles respectively each 22.9m long representing about 90% of the pond length. Thus pond F1 functioned as a set of four channels 1.7m in width and pond F2 as a set of six channels each 1.1m wide. A round-the-corner system (chicane) was built in Pond F3 forming a channel 2.3m wide and 75m in length. The length to width ratios were 3.55 for the un-baffled pond F4, 14.85 for pond F1, 23.52 for pond F2 and 32.4 for pond F3. The ponds and baffles were constructed in brick with vertical sides on a concrete base and rendered with a 25mm layer of cement mortar to ensure they were water tight.

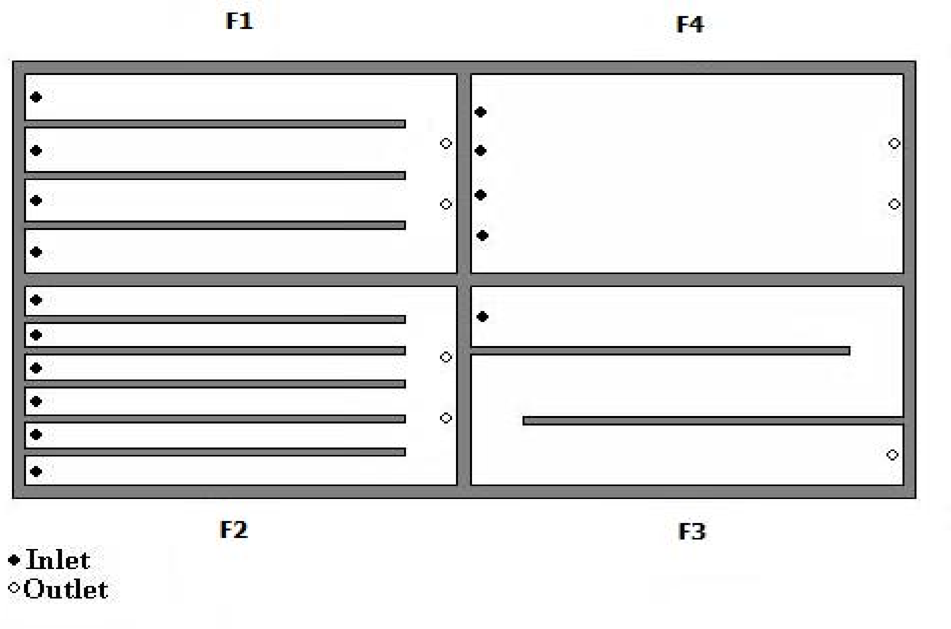

Figure 1. Schematic representation of the baffled primary facultative ponds at EXTRABES

All four ponds were operated during two different one-year periods at a flow-rate of $28m^3.d^{-1}$ giving a mean hydraulic retention time of ~ 15 days. The surface organic loadings were $330kgBOD_5.ha.d^{-1}$ during the first experimental period and $375kgBOD_5.ha.d^{-1}$, during the second as a result of a slight increase in sewage strength. The ponds received sewage, predominantly domestic in nature, taken from the 900mm diameter East Interceptor of the sewerage system of Campina Grande City (7º 13' 11" South, 35º 52' 31" West, 550m above m.s.l.), Paraiba, Brazil. Four PVC inlet pipes of 50mm diameter fed each of Ponds F1 and F4, six similar inlet pipes fed Pond F2 and one PVC inlet pipe of 75mm diameter fed Pond F3. The sewage was pumped from a wet well constructed adjacent to the interceptor to a constant level tank (CLT) with the excess sewage flowing back to the wet well via an overflow pipe. The sewage was pumped from the CLT to each pond using variable flow-rate horizontal axis pumps (model NETZSCH NE30A, Santa Catarina, Brazil) at the required rate to V-notch flow splitting boxes made of PVC. Thus the flow splitting boxes to ponds F1 and F4 contained four discharging V-notches evenly distributing the sewage to the four inlets of each pond. The flow splitting box of F2 contained six discharging V-notches equally dividing the sewage between the six pond inlets and in the case of pond F3 the sewage was pumped to the single inlet. Therefore each channel of Pond F1 received one fourth of the hydraulic loading applied to the pond, each channel of Pond F2 received one sixth, the whole loading was discharged at the beginning of the long channel of Pond F3 and the hydraulic flow was uniformly distributed throughout the breadth of Pond F4. Flow-rates were checked biweekly and corrected as necessary. The two outlet structures of Ponds F1, F2 and F4 were made of 75mm diameter PVC pipes positioned equidistant along the width of the end wall of each pond, while in Pond F3 only one 75mm diameter outlet PVC pipe was used for discharging the effluent (Figure 1). All the outlets were protected by a 200mm diameter PVC scum guard.

During the first experimental period the vertical inlet pipes were positioned at depths of 1.8m below the water surface of the pond and the vertical outlets 5cm below the surface. During the second monitoring period the pond inlets were set at 50cm below the pond surface and the outlets at 1.8m.

Grab samples of raw sewage and pond effluents were collected every ten days at 8 a.m. and analyzed for pH, temperature (T), dissolved oxygen, BOD_5, COD, suspended solids (SS), thermotolerant coliforms (TC), (*Standard Methods*, 1998) and chlorophyll *a* (Chl *a*), using the 90% methanol extraction technique (Jones, 1979).

RESULTS AND DISCUSSION

Mean temperatures of raw wastewater were respectively 27.0 and 26.7 ºC in the first and the second monitoring periods and varied in the narrow ranges 24.5-25.0 and 23.2-23.6 ºC in the pond effluents between both periods. Dissolved oxygen concentrations in the pond effluents varied between 0.6 and 1.65mg.L^{-1} during both experimental periods. The pH varied between 7.58 and 7.70 in the pond effluents with no difference between experimental periods one and two. Table 1 shows the results for both monitoring periods for the parameters BOD_5, COD, SS and TC measured in samples of raw sewage (RS) and pond effluents (F1, F2, F3 and F4) and also Chl *a* determined only in the pond effluents. In the first period data sample sizes varied between 40 and 50 except for SS which varied between 30 and 40 while in the second period the size was between 30 and 40 for all parameters.

Table 1. Mean values and standard deviations for analytical parameters determined in raw sewage and pond effluents in both monitoring periods.

Sample	BOD_5 (mg.L^{-1})	COD (mg.L^{-1})	SS (mg.L^{-1})	Chl *a* (µg.L^{-1})	TC (cfu.100mL^{-1})
1st monitoring period					
RS	214±66	492±130	226±41	n.d.	(1.20±1.60).10^{8}
F1	55±16	245±92	104±49	737±628	(7.60±12.0).10^{6}
F2	55±14	225±66	90±25	635±414	(7.10±9.90).10^{6}
F3	57±23	225±65	92±32	580±464	(6.40±9.50).10^{6}
F4	62±21	262±64	106±26	606±294	(6,90±8.70).10^{6}
2nd monitoring period					
RS	241±74	503±179	286±98	n.d.	(3.84±2.94).10^{7}
F1	61±13	221±71	82±30	191±96	(8.05±3.88).10^{5}
F2	58±15	217±73	87±35	327±158	(1.21±1.52).10^{6}
F3	60±16	217±39	85±29	337±158	(7.43±5.34).10^{5}
F4	62±13	252±47	108±32	298±125	(1.05±0.37).10^{6}

n.d. – not determined

All the ponds performed as efficient primary facultative ponds treating domestic wastewater in tropical regions and the percentage removals are shown in Table 2. The BOD removals in the ponds varied between 71 and 75.9 percent and COD removal between 46.7 and 56.8 percent during the two monitoring periods. In terms of SS, in first period the efficiencies varied between 53.1 percent (F4) and 60.2 percent (F2) while in the second period performances were between 62.2 percent (F4) and 71.3 percent (F1).

Table 2. Mean percent removals in facultative ponds in both monitoring periods.

Pond	BOD_5	COD	SS	TC
1st monitoring period				
F1	74.3	50.2	54.0	93.667
F2	74.3	54.3	60.2	94.083
F3	73.4	54.3	59.3	94.667
F4	71.0	46.7	53.1	94.333
2nd monitoring period				
F1	74.7	56.1	71.3	97.904
F2	75.9	56.8	69.6	96.849
F3	75.1	56.8	70.3	98.065
F4	74.3	49.9	62.2	97.266

One factor-analysis of variance at a level of significance of 0.05 applied to sets of data of each of these parameters did not demonstrate any significant difference among the means obtained for the parameters measured in the various pond effluents, except for suspended solids in the second monitoring period in which mean the concentration of SS in the effluent of the unbaffled pond F4 was significantly greater than the means for the others. In terms of percentage improvement it is questionable if the increased cost of baffling is warranted in primary facultative ponds to marginally decrease suspended solids, given that it is the first pond in a series.

Mean chlorophyll a values varied between 580 and 737$\mu g.L^{-1}$ in the ponds during the first period but the differences were not significant at $p = 0.05$. However the reduction in mean chlorophyll *a* concentration in the effluents of the ponds in the second monitoring period (191 and 337$\mu g.L^{-1}$) compared to the first was significant. This difference could be related the deeper position of the outlets at 1.8m below the surface compared to 5cm in the first period since the algae occupy the upper photic region of the pond water column.

Although the mean concentrations of thermotolerant coliforms in the influent wastewater varied between monitoring periods one and two (Table 1), one factor-analysis of variance did not demonstrate any significant differences between pond effluent thermotolerant coliform concentrations between the monitoring periods or between the ponds.

According to Shilton and Harrison (2003), traditional thinking that in a long narrow pond the influent simply flows slowly from one end to the other, leading to a plug flow and consequently to a better performance, is not necessarily correct except at very high length to width ratios. Based on one-factor ANOVA baffling, even a length to breadth ratio of 32.4, did not influence significantly primary facultative pond performance which is in accordance with earlier conclusions made by Silva, et al. (2000), studying the behavior of fatty acids, and Oliveira, et al. (2000), investigating sulfur cycling in a primary facultative pond with a round-the-corner baffle. They attributed this to the high organic loadings and concluded that baffling the maturation ponds in the series rather than the primary facultative would give better results.

CONCLUSIONS

From the results of this study it can be concluded that:

1. The installation of longitudinal baffles in primary facultative ponds until a length to breadth ratio of 32.4 did not significantly improve pond performance.
2. The combinations of inlet and outlet depths used in this study also had little impact on effluent quality.
3. In terms of overall construction, the installation of longitudinal baffles in primary facultative ponds is an unnecessary additional cost.
4. This study only considered primary facultative ponds but the installation of such baffles in maturation ponds where thermotolerant coliform and nutrient removals are important is worthy of investigation.

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