Determination of the sedimentation constants for total suspended solids and the algal component in a full-scale primary facultative pond operating at high wind velocities under tropical conditions


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Abstract This study evaluated the amount, distribution and sedimentation constant of solids in a full-scale primary facultative pond operating mostly under high wind conditions and the contribution made by the algal biomass. Solids deposition rates were measured using sedimentation traps placed in the inlet and outlet zones of the pond. Most sludge accumulation occurred, not surprisingly, in the inlet zone A1 with a sludge volume of 9072 m³ accumulating over an operating time of approximately 3 years. However, sludge deposition within this zone was uneven and affected by wind action. Mean proportionality constant ($K$) values for solids sedimentation were 3.02 and 5.70 for depths of 50 cm and 100 cm respectively for A1. In contrast in zone A3 (the outlet zone), reduced $K$ values of 1.38 and 3.22 were obtained for depths of 50 cm and 100 cm respectively. The algal sedimentation constant varied from 0.8 d$^{-1}$ in zone A1 to 0.02 d$^{-1}$ in A3. These data suggest that in this large facultative pond the wind, blowing predominantly from the direction of the outlets towards the pond inlets, had a greater influence on solids deposition than the bulk hydraulic flow and also kept the pond completely mixed for most of the time.

Keywords Algal biomass; facultative ponds; sedimentation constants; suspended solids

Introduction
The accumulation of organic solids in the bottom sediments of waste stabilization ponds represents a reservoir of organic substances that can either be anaerobically digested away with the release of methane from the pond surface and or solubilized and recycled into the water column to act as substrates and nutrients for further microbial activity.

According to Nelson (2002), to determine the amount of sediments, the solids in the influent wastewater, the mass of bacteria and the maximum algae mass per unit area occurring in the surface layers of the pond must all be considered.

The methods currently used to determine the amount and rate of sedimentation of suspended solids in ponds are based on the concept of sedimentation in an ideal tank or by using computational models of flow dynamics. However these do not properly evaluate the intervening factors that affect sedimentation at full-scale (Krishnappan and Marsalek, 2002).

The present study seeks to determine the quantity, distribution and rate of accumulation of solids and the sedimentation constants for both total suspended solids and that of the contributing algal biomass by using sedimentation traps in a full-scale, tropical primary facultative pond operating most of the time under high wind conditions.
Methods

The pond system (total area 11 ha) comprises a facultative pond (5.5 ha, depth 2.0 m) and 2 maturation ponds (2.8 ha each, with depths of 1.5 m) in series. It treats domestic sewage from the tourist resort of Ponta Negra, in the coastal city of Natal, Rio Grande Do Norte, Northeast Brazil. The climatic conditions are tropical, with incident mean annual solar radiation at the surface of 5900 W/h/m², a mean water temperature of 27°C but also with wind speeds reaching 3.3 m/s during daylight hours but greatly reducing at night, blowing in the direction 130° north i.e. in the case of the facultative pond (but not the maturation ponds), from the direction of the outlets towards the pond inlets.

For the purpose of this study the trapezoidal facultative lagoon was divided into three sections or zones along its length starting from the inlet end namely A1, A2, and A3 with areas of 14175, 17168 and 25831 m² respectively. The rate of deposition of particulate matter in the pond was determined every 15 days in the A1 and A3 zones (i.e. in the inlet and outlet zones) using sedimentation traps suspended vertically in the water column at depths of 50 cm and 100 cm at 12 m intervals across the complete width of the pond in the two zones. The depth of the sludge layer was determined using a portable echo sounder and by the empirical “White towel test” method (Mara and Pearson, 1998) at 30 points distributed across all three sections of the facultative pond (see Meneses et al., 2005), located using a Global Positioning System (GPS). Sludge core samples were also collected and subsequently sectioned in the laboratory for analysis for total, fixed and volatile solids (APHA, 1998).

Sedimentation rate was calculated from the suspended solids concentration in the traps in relation to trap area. As pond solids sedimentation is proportional to the inlet solids load, the proportionality constant called the sedimentation constant was calculated from the equations:

\[ \text{S}_a = K \cdot Q \cdot C_{SSTi} \]  \hspace{1cm} (1)

\( \text{S}_a \) is the solids sedimentation rate (kg.d⁻¹); \( Q \) is the inflow (m³.d⁻¹); \( C_{SSTi} \) is the total suspended solid concentration that enters the lagoon and \( K \) is the constant of proportionality.

Chlorophyll \( a \) and phaeophytin concentrations were determined for water and sludge column samples taken from six locations equidistant along the length of the pond (APHA, 1998). The algae sedimentation rate was calculated according to Nelson (2002):

\[ \text{S}_a = \chi AK \]  \hspace{1cm} (2)

\( \chi \) is the maximum concentration of chlorophyll \( a \) in the active band in mg/L, in this case in the water column of the lagoon assuming complete mixing; \( A \) is the area of influence in m²; \( K \) is the algal sedimentation constant in d⁻¹.

Results and discussion

Sludge distribution in the pond showed that sludge accumulation was, not surprisingly, greatest near the inlet region i.e. in the first 100 m of the pond (zone A₁) (Figure 1), with the thickness of the sludge layer varying from 0.01 to 1.10 m and with a mean sludge concentration of 94.63 g/L in zone A₁. However sludge accumulation was uneven with most accumulation occurring in the bottom right-hand quadrant of Figure 1, i.e. corresponding to the area of pond zone A₁ receiving the prevailing wind. Surface water movement (≥ 30 cm in depth) was estimated to occur at a velocity of 182 m/h from the outlets towards the inlets, that is in a counter flow direction compared to the main body of the water as determined in simple drogue experiments with oranges and coconuts which
accumulated in this region (see Meneses et al., 2005). This suggests that sludge accumulation was more affected by wind speed (1–4 m/s) and direction than by bulk water flow entering the pond through the equal and efficient splitting of the influent flow between the inlets discharging 50 cm above the pond base and extending some 20 m into the pond. The calculated sludge volume for zone A1 was of 9072 m³ which had accumulated over 36 months of operation.

The proportionality constant ($K$) for solids sedimentation was determined using the mean flow of 5000 m³/d with an influent mean total suspended solids concentration of 435 mg/L of which 362 mg/L were volatile suspended solids.

Using equation 1 the mean $K$ values for zone A1 i.e. in the first third of the pond were 3.02 for a depth of 50 cm and 5.70 for a depth of 1.0 m. Sedimentation measurements in zone A3 near the outlet zone gave lower mean values of $K$ of 1.38 and 3.22 for depths of 50 cm and 100 cm respectively. In the outlet section (A3) the value for total suspended solids in the water column was 272 mg L⁻¹ and for volatile suspended solids 242 mg L⁻¹.

The algal sedimentation constant was determined from the chlorophyll $a$ concentration using equation 2, and was 0.80 d⁻¹ in area A1 reducing to 0.03 d⁻¹ for A3. Figure 2 shows the distribution of the algal $K$ values along the pond.

The values for the proportionality constant ($K$) for the sedimentation of solids were similar at depths of 0.5 and 1.0 m since the values approximately doubled for a doubling of the depth. This tends to strengthen the theory that the hydraulic regime in the pond is one of complete mixing and suggests that in this large pond the speed and direction of the wind were important factors, possibly more so than geometry and inlet positions, in influencing the hydraulic regime. The lack of stratification was confirmed by the homogeneous nature of the data for chlorophyll $a$ concentration and oxygen with depth in the

Figure 1 Sludge layer distribution along the primary facultative pond. The inlets are marked on the right-hand side of the figure

Figure 2 Variation in the algal sedimentation constant with distance from the inlet, based on chlorophyll $a$ values for algal biomass
water column (Meneses et al., 2005). The higher algal sedimentation constant in the first section of the pond near the inlet zone (Figure 2) demonstrates that the wind has a direct influence on the accumulation and sedimentation of solids and algae in this pond.

Conclusions

The results presented here support the notion that relatively high wind velocities affect the hydraulic regime in a large pond causing complete mixing of the water body and affecting the efficiency of solids deposition and sludge accumulation. This large pond system is known to be functioning sub-optimally in terms of solids, BOD and faecal coliform removal despite a correct surface organic loading of approximately 350 kg BOD/ha/d on the primary facultative pond and a retention time of 22 days. In fact total suspended solids removal was only 37.5%. It would seem that there is a case for using smaller ponds in parallel rather than large single facultative ponds to reduce the adverse impact of the wind on treatment efficiency in such situations.

References


