Prospectus of waste stabilization ponds in Ceará, Northeast Brazil

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Abstract WSP technology has been used in Ceará, Northeast Brazil, since middle 1970s. There are presently 96 ponds plants and most of them are comprised by single cells (40%) and series of 3 ponds (35%). They were under loaded due to incomplete house connections to the sewerage network and low *per caput* wastewater contributions. Highest removal rates of organic material, ammonia and faecal coliform were found in 3 pond series. Faecal coliform removal was in accordance with the literature and series of ponds reached numbers $\leq 10^5$ cells/100 ml. In series with 4 and 5 ponds FC was below 10^3 cells/100 ml. Ammonia removal varied from 30 to 80% and total phosphorus the removal was not significant. An increase in the number of maturation ponds enhances nutrient and coliform removal. Up-grading schemes should be investigated as well as effluent reuse potential.

Keywords Pond performance; wastewater characteristics; WSP in Ceará.

INTRODUCTION

Waste stabilization ponds (WSP) are considered the best option for the treatment of wastewater in small communities, mainly in developing countries and locations with warm climate (Arthur, 1983; Mara *et al*., 1992). However, there are pond plants all over the world according to a number of studies (Middlebrooks *et al*., 1982; Bucksteeg, 1987; Al-salem and Lumbers, 1987; Vuillot *et al*., 1987; Madera *et al*., 2002; Tsagarakis *et al*., 2003). Pond technology is expanding and evolving, presented as the most appropriate in many situations (Pearson, 1996; Mara, 2007).

The first reference to WSP in Brazil is dated from the 1970s and built in the Southeast region of the country (Azevedo Netto, 1975). These plants were comprised of single pond units and they reflected the engineering concepts of the period, based on Marais and Shaw (1961) and McGarry and Pescod (1970).

In Brazil, pond research began in the second half of the 1970s at the Federal University of Paraíba. Consistent results were reached through the studies conducted by Silva (1982) and co-workers (*e.g.* König, 1987; de Oliveira, 1990; Curtis *et al*., 1992; Oragui *et al*., 1993). This made possible the dissemination of simple innovative concepts such as the inclusion of anaerobic ponds and series arrangements. Thus, the designers were brought to a critical reflection with respect to the fact that technologies previously adopted frequently failure.

The following reasons made possible the adoption of waste stabilization ponds in the Brazilian Northeast: a) low cost of the available land; b) simplicity and low cost for operation and maintenance; c) necessary minimization of environmental and public health impacts of untreated wastewater; d) potential use of treated wastewater as a compensation of the climatic uncertainties, and e) indirect increment of water volumes for potable ends in areas with scarcity, since treated effluent may supply low quality water demands.

As a result from these local studies during the last two decades stabilization ponds have been firmed as the most effective technology for the treatment of domestic wastewaters in the state of Ceará (37°14' - 41°24' W; 2°46'-7°52' S) (Figure 1). The state has a warm climate with average rainfall of 750 mm/year associated to high evaporation rates (up to 7 mm/day). Average monthly temperature varies from 22^{o} to 33^{o} C. The state comprises an area of 148,016 km^2 (IPLANCE, 2002). Recent data from IBGE (2007) shows a population around 8.1 millions. About 77% live in urban and peri-urban areas requiring appropriate sanitation infra-structure. Within this context the present paper approaches WSP *prospectus* and trends in Ceará.

Figure 1. Location of Ceará state, Northeast Brazil.

METHODOLOGY

A documental investigation was conducted at the Environmental Agency of the Ceará State (Superintendência Estadual do Ceará - SEMACE) and the Company for Water and Wastewater of Ceará (Companhia de Água e Esgoto do Ceará - CAGECE). The searched information was relative to pond plant schemes, with focus on the treated effluent and operational performance. The investigation was conducted from February to September 2008.

RESULTS AND DISCUSSION

The domestic wastewater in Ceará

In Ceará the design assumptions for wastewater flow is conservative and considers a daily contribution of 150 litres *per caput*. However, measurements of the influent flow showed a *per caput* contribution of 93 litres (±32). According to Campos and von Sperling (1996) in developing countries flow rate variations are particularly relevant. Also, data information is often not readily available as well as accurate measurements. In addition to that, the authors highlight that water consumption and wastewater characteristics are dependent on average family income. The low water usage rate implies in low dilution of pollutants and this results in a stronger wastewater (Table 1).

Table 1. Characteristics of domestic wastewater in Ceará, Northeast Brazil

Parameter	*Mean*	*Range*	*Standard deviation*	*Number of samples*
BOD (mg/l)	431	116 – 1,168	160	168
COD (mg/l)	725	182 – 1,818	279	268
TSS (mg/l)	282	44 – 1,396	174	259
pH (units)	7.01	6.00 – 8.20	0.32	262
Total ammonia (mg N/l)	35.9	12.3 – 54.3	9.2	96
Total phosphorus (mg P/l)	7.94	5.05 – 10.31	1.19	94
Soluble phosphorus (mg P/l)	4.34	2.90 – 6.60	0.67	51
Faecal coliforms (MPN/100 ml)	2.7E+7	2.4E+6 – 2.4E+8	ND	86
Helminths (eggs/l)	910	262 – 1,580	282	54

On the existing WSP systems

The first pond plant was built at Fortaleza, the state capital, in 1974 to serve a housing state settlement. During the following decade most of the WSP systems were comprised by single primary facultative ponds. By the end of the 1980s there were 13 systems in the state. In the year 1999 there were 41 plants and five years later 84 systems. Presently, there are 96 WSP plants and other 17 are being designed or under construction. The population equivalent served by WSP in Ceará is about 1.46 millions inhabitants. Among the existing plants only one treats exclusively industrial wastewater (textile type). A profile of the 95 WSP plants in operation for the treatment of domestic wastewater, configuration and estimated flow rate are shown in Table 2.

Table 2. WSP systems treating domestic wastewater in Ceará, Northeast Brazil.

Plant configuration	*Number of plants*	*Flow rate (m^3/d)* [a]
Primary facultative pond (single cell)	38	24,161
Primary facultative followed by 2 maturation ponds	34	28,418
Primary facultative followed by 3 maturation ponds	8	8,965
Anaerobic followed by a secondary facultative and one maturation pond	2	14,425
Anaerobic followed by a secondary facultative and two maturation ponds	8	20,638
Anaerobic followed by a secondary facultative and three maturation ponds	3	36,410
Partially aerated facultative pond followed by three maturation ponds	1	452
UASB reactor followed by two maturation ponds	1	572
Total	95	101,272

[a] Based on a contribution of 93 litres/*per caput*.day.

Practically all pond plants were under loaded because either wastewater contribution was low or the connections of houses to the sewerage network were not complete. Thus, the pond systems had high hydraulic retention time (average of 61 days, ±29). They might have produced effluents free of parasites according to the removal model of Ayres *et al*. (1992).

An important fact is that 26% of the WSP systems in operation did not possess preliminary treatment (*i.e.* screening and grit removal). This caused excessive solids accumulation near the inlet structures and odour nuisance. Mal odour is also alleged to be the cause for the reduced number of anaerobic ponds. Actually, most of the complaints come from non-planned residential occupation, mainly slums, too close to the ponds plants (< 200 m).

Average results showed that all systems met the state standards for filtered BOD, filtered COD and total suspended solids, which limits are 60, 200 and 150 mg/l, respectively (SEMACE, 2002). Ammonia removal varied from 30 to 80% and increased with number of ponds in series. There was no total phosphorus removal in primary facultative ponds or even in series of 3 ponds. An increase in the number of maturation ponds provided some removal of total phosphorus and reached on average 15 and 29% in series with 4 and 5 ponds, respectively. For faecal coliforms pond series had average concentration numbers in accordance to the legislation (limit of $5x10^3$ cells/100 ml), but not the single cell plants. Dissolved oxygen and pH are also regulated parameters that complied with the norm. The limits are 10 units for pH and 3.0 mg/l for minimum dissolved oxygen. Table 3 shows the characteristics of treated effluent from WSP systems in Ceará.

Table 3. Characteristics of WSP effluents in Ceará, Northeast Brazil.

Parameter	*Plant configuration*			
	Single primary facultative pond	Series with 3 ponds	Series with 4 ponds	Series with 5 ponds
pH (units)	7.79 (±0.15) (n = 652)	8.43 (±0.39) (n = 434)	8.17 (±0.31) (n = 435)	8.72 (±0.21) (n = 341)
BOD (mg/l)	117 (±32) (n = 170)	81 (±21) (n = 57)	55 (±22) (n = 61)	33 (±13) (n = 92)
Filtered BOD (mg/l)	46 (±20) (n = 188)	26 (±12) (n = 68)	20 (±9) (n = 63)	15 (±7) (n = 89)
COD (mg/l)	357 (±151) (n = 267)	176 (±88) (n = 119)	120 (±69) (n = 121)	122 (±48) (n = 113)
Filtered COD (mg/l)	114 (±63) (n = 220)	65 (±38) (n = 61)	61 (±36) (n = 63)	47 (±21) (n = 67)
TSS (mg/l)	133 (±60) (n = 257)	115 (±52) (n = 122)	125 (±36) (n = 112)	114 (±28) (n = 114)
DO (mg/l)	3.8 (±2.1) (n = 65)	6.3 (±1.3) (n = 63)	7.6 (±2.6) (n = 61)	9.1 (±3.2) (n = 73)
Total ammonia (mg N/l)	25.0 (±2.9) (n = 53)	10.8 (±3.3) (n = 48)	8.2 (±1.7) (n = 42)	7.2 (±3.1) (n = 61)
Total phosphorus (mg P/l)	8.03 (±0.93) (n = 39)	7.54 (±1.16) (n = 37)	6.72 (±0.99) (n = 37)	5.62 (±1.12) (n = 41)
Soluble phosphorus (mg P/l)	1.22 (±0.63) (n = 31)	4.45 (±0.89) (n = 29)	4.77 (±1.23) (n = 30)	3.84 (±1.17) (n = 41)
Faecal coliforms (MPN/100 ml)	1.0E+6 [a] (n = 56)	3.7E+3 [a] (n = 36)	1.1E+2 [a] (n = 43)	9.4E+1 [a] (n = 78)

[a] Standard deviation not calculated.

Surface removal rates of organic material, ammonia and faecal coliform removal (in log units) of the WSP systems in Ceará are shown in Table 4. The highest performance for organic material and ammonia removal was achieved in series of 3 ponds.

Effluent from series with 4 and 5 ponds had faecal coliform numbers, broadly equivalent to *E. coli*, bellow 10^3 cells/100 ml, adequate for unrestricted irrigation in accordance to SEMACE (2002) standards and guidelines of WHO (2006). Despite of the high hydraulic retention time single pond systems showed similar faecal coliform numbers in the effluent. It seems that high hydraulic retention time in primary facultative ponds does not necessarily provide increase in coliform removal. Also, it should be remembered that mechanisms for bacterial removal in ponds are complexes (Curtis *et al.*, 1992).

Table 4. Surface removal rates and FC log removal in WSP systems, at Ceará, Northeast Brazil.

Parameter	*Plant configuration*			
	Single primary facultative pond	Series with 3 ponds	Series with 4 ponds	Series with 5 ponds
BOD (kg/ha.d)	92 (±43)	122 (±28)	118 (±35)	73 (±22)
Filtered BOD (kg/ha.d)	101 (±49)	138 (±32)	125 (±38)	78 (±29)
COD (kg/ha.d)	156 (±73)	202 (±46)	188 (±44)	125 (±38)
Filtered COD (kg/ha.d)	179 (±81)	251(±47)	227 (±68)	135 (±49)
Total ammonia (kg N/ha.d)	3.3 (±2.0)	10.2 (±4.1)	9.5 (±3.6)	7.5 (±3.1)
Faecal coliforms (log units)	1.418 (±0.386)	3.364 (±0.674)	5.473 (±0.717)	5.458 (±0.423)

Perspectives of WSP in Ceará

The WSP systems have been designed on a conservative basis, in such way that the economical sense appears to be neglected. The raw wastewater characteristics for design ends should be more realistic and reflect local conditions. In parallel, a more detailed study should provide the real capacity of the plants to receive new contributions.

Pond arrangements and models employed for design should be reviewed in order to minimize land requirement and increase performance. Anaerobic ponds, UASB reactors and even septic tanks followed by anaerobic filters should be included. For the case of single cells plants the possibility of up grading must be addressed.

The increase in the number of WSP plants in Ceará is accompanied by water scarcity as a growing challenge. Thus, effluent reuse is the obvious following step as suggested by Caixeta (2008). The real subject is the lack of a sanitation master plan in the state, which would include reuse as a policy with a clear economical approach, since existing reuse is unplanned. As Mara (2007) highlights "wastewater is too valuable to waste" and WSP is a reliable way to ensure the safety for food production.

CONCLUSION

The WSP systems in Ceará were under loaded because hydraulic and organic loadings were below those assumed in the original designs. Incomplete connections of house to the sewerage network and low *per caput* wastewater contributions were the cause. There is a need for more realistic design parameters and plant schemes should be reviewed.

The average hydraulic retention time of the pond plants was high (61 days, ±29) and this favors a treated effluent free of parasites. All systems met the standards for organic material removal. Ammonia removal varied from 30 to 80% and was higher in pond series. Total phosphorus removal varied from null in single cells and series of 3 ponds to 15 and 29% in series with 4 and 5 ponds, respectively. Series of ponds met the standard limit for faecal coliforms in the effluent (10^5 cells/100 ml). These numbers were below 10^3 cells/100 ml in 4 and 5 pond series.

The future of WSP in Ceará requires an investigation on the potential to up-grade systems with low performance, especially for coliform removal, and the quantification of the real capacity of plants and effluent reuse.

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