A full-scale anaerobic pond treating an alkaline mix of industrial and domestic wastewaters

F. J. A. da Silva*, R. O. de Souza* and A. L. C. Araújo**

*Department of Hydraulic and Environmental Engineering, Federal University of Ceará, *Campus* do Pici, Bloco 713, Fortaleza, CE, Brazil (E-mail: *fjas@cariri.ufc.br; rsouza@ufc.br*)

** Department of Natural Resources, Technological Education Federal Centre of Rio Grande do Norte. Avenida Senador Salgado Filho, 1559, Tirol, 59000-015, Natal-RN, Brazil. Post-Graduation Program of Sanitary Engineering, Federal University of Rio Grande do Norte (E-mail: *acalado@cefetrn.br*)

Abstract A full-scale anaerobic pond was investigated during 13 months. The study showed that textile effluent can be properly treated in anaerobic ponds if combined with domestic wastewater. Removal of organic material, as BOD and COD, was around 60% and 77% for filtered effluent. Influent pH contributed to the alkaline conditions in the pond effluent. There was an increase in ammonia effluent due to ammonification. Bacterial sulphate reduction caused an increase in sulphide concentrations in the effluent. Metal removal was satisfactory and varied from 61 to 87%. Removal mechanism was the formation of sulphide complexes followed by precipitation and immobilization in the sediment.

Keywords Anaerobic ponds; metal removal; treatment of mixed industrial and domestic wastewaters.

INTRODUCTION

Industrial wastewaters may contain several different toxic compounds which interfere adversely with the microbial community involved in waste degradation. Thus, physical-chemical treatment (nutrient addition, pH correction, sedimentation and coagulation-precipitation) might be required before the industrial effluent is discharged into a biological treatment plant (Eckenfelder, 1991; Arundel, 1995). A reasonable approach is to combine the industrial effluent with domestic wastewater to favor the biological treatment.

In the context above anaerobic ponds are important because they provide effluent equalization through solids settling and removal of toxic pollutants. Hydraulic retention time offers significant buffering capacity to attenuate impacts in the subsequent units of the treatment plant. Anaerobic ponds are especially advantageous in the treatment of strong wastes (BOD and TSS > 300 mg/L) (Mara and Pearson, 1986). Although many organic chemicals may not be properly degraded under anaerobic conditions, they are able to transform via combination of biotical and abiotical reactions into less toxic pollutants (Stanley and Smith, 1993; Terzis, 1994; Narayanan *et al.*, 1995).

The nature and chemical composition of the materials dictate the degradation sub-processes and the microbial groups involved in the conversion of substrates in anaerobic digestion (Pavlostathis and Giraldo-gomez, 1991). Methane fermentation is the rate-limiting step and methanogenic bacteria are sensitive to pH and alkalinity changes (Speece, 1996). Therefore, pH control is important for an adequate completion of anaerobic digestion and extreme values cause malfunction with increasing of sludge accumulation and decreasing of organic material removal (Pescod, 1996).

A waste stabilisation pond series (an anaerobic followed by a secondary facultative and three maturation ponds) was commissioned in 1992 to treat the effluent from 56 industries and 7 housing estates in Maracanaú, Northeast Brazil. The textile sector was the dominant industrial activity with

27 enterprises. A previous study by Carvalho *et al.* (1999) found a high influent pH (average 8.5 and values as high as 10.4). These authors remarked the risk of this causing some impact on the anaerobic pond performance. The present investigation has focus on the treatment of an alkaline wastewater by a full-scale anaerobic pond.

METHODOLOGY

The anaerobic pond of the Maracanaú treatment plant (3°52'57" S, 38°37'35" W, 45 m above mean sea level) has a volume of 126,600 m^3 (depth = 4 m). Its influent and effluent were monitored during 13 months (from June 1997 to June 1998) in a weekly basis.

The following parameters were analyzed during the study: BOD (unfiltered and filtered), COD (unfiltered and filtered), nutrients (total phosphorus - TP, total ammonia – TAN and nitrate- NO_3^-), total and suspended solids (TSS), sulphate (SO_4^{2-}), sulphide (S^{2-}), pH, and temperature. Also, once a month the following metals were analyzed in their total concentrations: iron (Fe), cooper (Cu), zinc (Zn), nickel (Ni), chromium (Cr), lead (Pb) and cadmium (Cd). The investigation was based on grab samples collected at 10:00 am, following recommendations of Pearson *et al.* (1987) and the analytical procedures by APHA (1992).

Flow rate measurements were monthly and performed in the two pumping stations (PS1 and PS2) that fed the pond system. The combined influent was discharged in a collecting tank prior to the discharge into the pond.

RESULTS AND DISCUSSION

Most of the flow (about 2/3) entering the pond came from PS2 which had mainly industrial wastewater, with a mean flow rate around 7,000 m^3/day (Figure 1). The average hydraulic retention time (HRT) of the anaerobic pond was 12.6 days (flow rate = 116 litres/s ± 14).

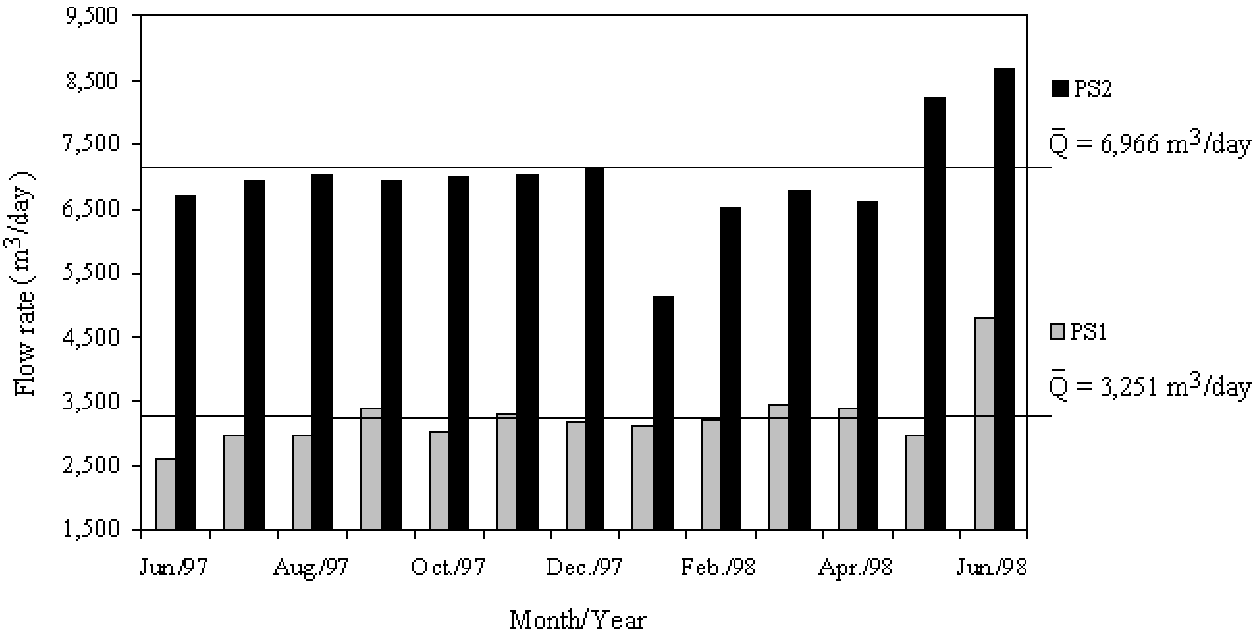

Figure 1. Flow rate entering the Maracanaú pond system (monthly values).

At least 30% of the samples had pH values higher than 9.0, corresponding to the contribution of the PS2 pumping station. Cotton dyeing and finishing textiles require large amounts of alkali salts (Na^+, K^+, Mg^{2+} and Ca^{2+}) for bleaching and washing. These processes produce a typically alkaline effluent with high pH (Altinbas *et al.*, 1995).

The pH of the anaerobic pond effluent was one unit above the neutral. Despite this, organic material removal (as BOD and COD) was about 60%. This was a little less than findings of Silva *et al.* (1996) when treating domestic wastewater, in which BOD removal ranged from 68 to 80% in a temperature of 26.0° C, and HRT varying from 0.8 to 6.8 days. The predominance of an alkaline industrial effluent with pH near 9.0 did not affect significantly pond performance.

The results of the pond monitoring are shown in Table 1. It should be pointed out that grab samples may bring apparent inconsistent numbers compared to composite samples. For instance, in a few cases influent concentrations were smaller than effluent. However, the total number of samples and the descriptive statistics showed adequate confidence (at 95% level). The present study is driven on the functionality and performance of the pond and subsidizes forthcoming studies.

Table 1. Characteristics of the influent and effluent of the Maracanaú pond system.

Parameter	*Raw wastewater*		*Anaerobic pond effluent*	
	Mean (Min-Max)	σ (n)	Mean (Min-Max)	σ (n)
Temperature (° C)	31.7 (27.2 – 34.0)	1.6 (41)	29.3 (26.4 - 32.6)	1.4 (41)
pH (units)	8.75 (7.03 - 11.11)	1.05 (41)	7.99 (7.57 - 8.45)	0.19 (41)
BOD (mg/l)	373 (150 – 997)	167 (40)	147 (67-272)	54 (40)
COD (mg/l)	1,112 (371 – 3,572)	700 (40)	452 (18-177)	152 (40)
BODf (mg/l)	163 (42 – 301)	64 (40)	87 (166-762)	41 (40)
CODf (mg/l)	348 (30 – 826)	183 (40)	266 (75-542)	112 (41)
TAN (mg N/l)	32.41 (12.00 - 68.00)	14.23 (41)	51.84 (22.50 - 88.80)	11.97 (41)
NO_3^- (mg N/l)	0.41 (0.02 – 3.94)	0.66 (41)	0.37 (0.01 - 1.48)	0.32 (41)
TP (mg P/l)	6.40 (1.93 - 11.12)	2.21 (40)	6.15 (3.87 - 9.45)	1.52 (40)
TSS (mg/l)	305 (24 – 777)	189 (40)	55 (17 – 91)	17 (40)
SO_4^{2-} (mg SO_4^{2-}/l)	134.53 (26.08 - 329.79)	72.15 (41)	85.3 (16.1 - 231.6)	43.93 (41)
S^{2-} (mg S/l)	2.19 (0.06 - 13.05)	2.58 (40)	9.20 (1.35 - 22.10)	4.49 (40)

For the case of filtered samples of BOD and COD in the effluent compared to unfiltered samples in the influent, the performance of the anaerobic pond was about 77%. A relevant aspect of the removal of organic material in the anaerobic pond was observed by comparing the correlation between unfiltered and the respective filtered samples. In the raw wastewater influent BOD *versus* BODf, the correlation coefficient (r) was 0.625 (at 0.05 level of significance), while in the COD *versus* CODf the coefficient was 0.280. In pond effluent the correlations were higher (Figures 2 and 3) suggesting a stable process. Solids removal was high (82%) and corresponded to the settling function of anaerobic ponds. Despite the good results a more critical evaluation will be addressed with respect to the sludge accumulation and in pond data.

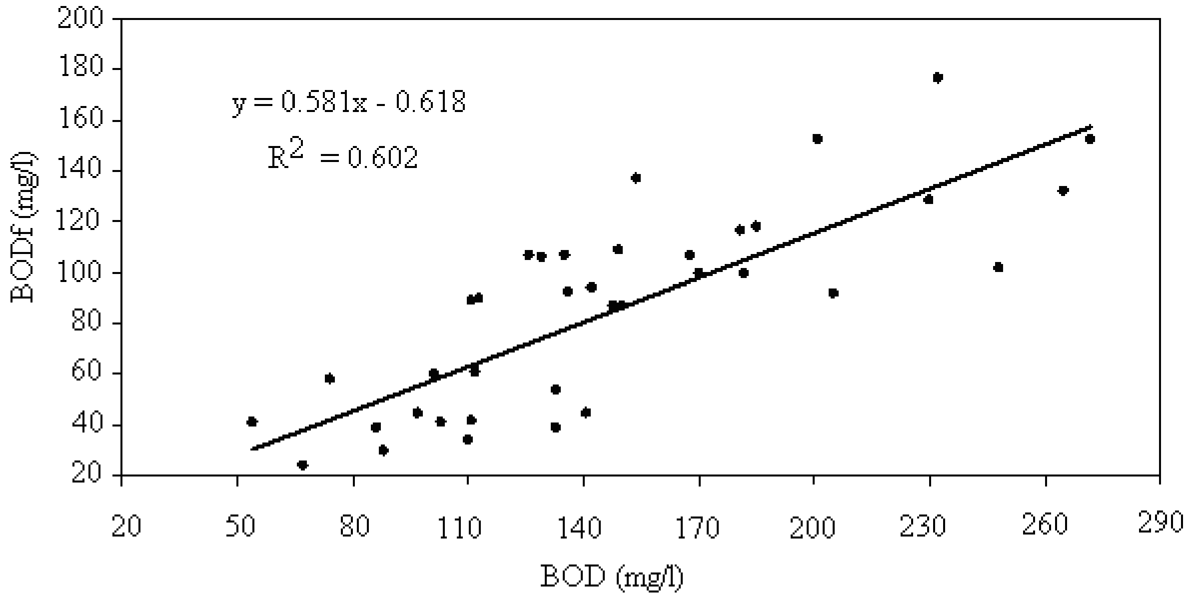

Figure 2. Unfiltered *versus* filtered BOD in the anaerobic pond effluent of the Maracanaú system.

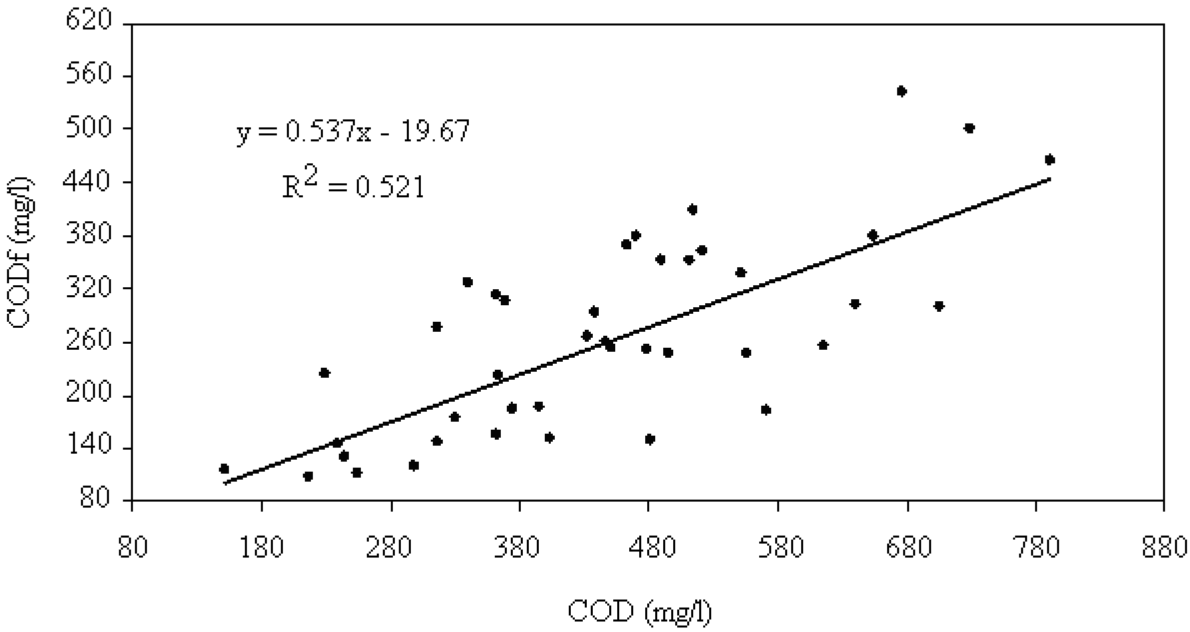

Figure 3. Unfiltered *versus* filtered COD in the anaerobic pond effluent of the Maracanaú system.

The performance of the pond is also attributed to the appropriate content of nutrient in the blended raw wastewater. The literature suggest ratios of COD:N:P of 250:5:1 for anaerobic treatment (e.g. MetCalf & Eddy, 1991; Henze *et al.* 1997). Considering only ammonia as N source the ratio of the influent was 174:5:1, therefore sufficiently balanced. According to Ammary (2004) the literature number is a guide and nutrient requirement may vary considerable with environmental and nutritional factors.

The total ammonia concentration was higher in the effluent than in the influent with an increase around 60%. In anaerobic ponds, organic nitrogen, mainly amine structures, undergoes microbial degradation with consequent ammonia release to the bulk liquid. This ammonification process is present in stable anaerobic reactors (Bitton, 1994; Speece, 1996). Nitrate concentrations were low and effluent values were in the same magnitude. Total phosphorus leaving the pond was virtually the same in the influent. The main role of anaerobic reactors is to remove organic material, not nutrient.

Sulphur compounds showed conversed results (as SO_4^{2-} decreased 37%, S^{2-} increased 320%). According to Lens *et al.* (1998), when the COD/sulphate-sulphur ratio exceeds 2.7, acetotrophic methanogenic bacteria (AMB) predominate over sulphate-reducing bacteria (SRB) in competition for acetate. Thus, anaerobic digestion can be successfully completed. In the upper layer of the water column of the pond the COD/sulphate ratio was 5.3, which supported the removal of organic matter. The balance between AMB and SBR is favored by sulphate reduction. On the other hand the increase in sulphide concentrations cannot be attributed only to sulphate reduction but possibly due to organic sulphur compounds.

Metal removal in the anaerobic pond is shown in Table 3. Influent concentrations were not too high for a wastewater with high industrial content. Dilution effect and industrial contributions with low metal content caused the results. Metal removal can be attributed mainly to the formation of sulphide insoluble complexes which precipitate and take part in the sediment (Cowling *et al.*, 1992; Artola *et al.*, 1997). Also, high pH may contribute to complex formation and precipitation (Tünay and Kabdasli, 1994).

Table 3. Metal concentration and removal in the anaerobic pond effluent of the Maracanaú system.

Parameter	*Metal concentration (µg/L)*						
	Fe	Cu	Zn	Ni	Cr	Pb	Cd
Mean	2,794	33	745	19	13	29	7
Median	1,996	32	150	17	12	21	6
Min - Max	1,326 - 6,270	20 -67	71 – 5,583	1 - 59	1 - 31	13 – 83	1 - 17
σ	1,633	12	1,624	16	10	20	5
Removal (%)	79.0	60.8	95.3	64.1	71.9	87.3	67.5

CONCLUSIONS

The anaerobic pond of Maracanaú treated a flow rate of 116 l/s (± 14) of a mixture of industrial and domestic wastewater with characteristics similar to textile effluent. Removal of organic material, as BOD and COD, was around 60%. For filtered samples, the removal reached 77%. Removal of total suspended solids was high (82%), due to settling. The pond performance was close to that observed in those treating only domestic wastewaters.

The alkaline influent contributed to a high pH (8.0) in the bulk liquid of the pond. However, this did not affect pond performance but may have impact on sludge digestion and accumulation. Textile effluent can be properly treated in anaerobic ponds if blended with domestic wastewater, since it provides the necessary balance of nutrients for the biological treatment.

The ammonification process caused an increase in the total ammonia concentration in the pond effluent. There was also increase in sulphide concentrations due to bacterial sulphate reduction and organic sulphur compounds. Total phosphorus and nitrate concentrations were about the same observed in the influent.

Metal concentration in the influent was low compared to usual industrial wastewaters. Apart from that, removal in the anaerobic pond varied from 61 to 87% for the selected metals in the study. The removal was probably due to the formation of sulphide complexes followed by precipitation and immobilization in the sediment.

REFERENCES

Altinbas, U., Dökmeci, S. and Baristiran, A. (1995).Treatability study of wastewater from textile industry. *Enviromental Technology*, **16**(3), 389-394.

Ammary, B. (2004). Nutrient requirements in biological industrial wastewater treatment. *African Journal of Biotechnology*, **3**(4), 236-238.

APHA. *Standard Methods for the Examination of Water and Wastewater.* 18th edition. Washington, DC: American Public Health Association. 1992.

Artola, A., Balaguer, M. D. and Rigola, M. (1997). Heavy metal binding to anaerobic sludge. *Water Research*, **31**(5), 997-1004.

Arundel, J. (1994). *Sewage and Industrial Effluent Treatment*. Blackwell Science. Oxford.

Bitton, G. (1994). *Wastewater Microbiology*. John Wiley & Sons, Inc. New York.

Carvalho, M. E., Mota, S., da Silva, F. J. A., Mara, D. D, Silva, S. A. and Pearson, H. W. (1999). From pilot to full-scale: comparing the performance of a pilot pond system with the full-scale version treating domestic and industrial wastewater in the state of Ceará, Brazil. In: *4th International IWA Specialist Group Conference on Waste Stabilisation Ponds*. Marrakesh, Morroco.

Cowling, S. J., Gardner, M. J. and Hunt, D. T. E. (1992). Removal of heavy metals from sewage by sulphide precipitation: thermodynamic calculations and tests on a pilot-scale anaerobic reactor. *Environmental Technology*, **13**(3), 281-291.

Eckenfelder, W. W. (1991). Strategies for toxicity reduction in industrial wastewaters. *Water Science and Technology*, **24**(7), 185-193.

Henze M, Harremoes P, Jansen J, Arvin E (1997). Wastewater Treatment, second edition, Springer.

Lens, P. N. L., Visser, A., Janssen, A. J. H., Hulshoff Pol, L. W. And Letinga, G. (19998). Biotechnological treatment of sulphate-rich wastewaters. *Critical Reviews in Environmental Science and Technology*, **28**(1), 41-88.

Mara, D. D. and Pearson, H. W. (1986). Artificial freshwater environment: waste stabilization ponds. In: *Biotechnology - comprehensive treatise*, 177-205.Volume 8, Chapter 4. Edited by H. J. Renm and G. Reed. Weinheim: Verlagsgesellschaft.

Metcalf & Eddy, Inc. (1991). Wastewatet Engineering, Treatment, Disposal, and Reuse. Third edition. McGraw-Hill, Inc., New York.

Narayanan, B., Suidan, M. T., Gelderloos, A. B. and Brenner, R. C. (1995). Anaerobic treatment of volatile and semi-volatile organic compounds in municipal wastewasters. *Water Environment Research*, **67**(1), 46-56.

Pavlostathis, S. G. and Giraldo-gomez. (1991) P. Kinetics of anaerobic digestion. *Water Science and Technology*, **17**(11), 97-123.

Pearson, H. W., Mara, D. D. and Bartone, C. R. (1987). Guidelines for the minimum evaluation of the performance of full-scale waste stabilisation pond systems. *Water Research*, **21**(9), 1067-1075.

Pescod, M. B. (1996). The role and limitations of anaerobic pond systems. *Water Science and Technology*, **33**(7), 11-21.

Silva, S. A., de Oliveira, R. and Mara, D. D. (1996). *Performance of Waste Stabilization Ponds in Northeast Brazil*. Research Monograph No 9. University of Leeds. Leeds. UK.

Speece, R. E. (1996). *Anaerobic Biotechnology for Industrial Wastewaters*. Nashville: Archea Press.

Stanley, S. J. and Smith, D. W. (1993). Lagoons and ponds. *Water Environment Research*, **65**(4), 344-349.

Terzis, E. (1994). Anaerobic treatment of industrial wastewater containing organic solvents. *Water Science and Technology*, **29**(9), 321-329.

Tünay, O. and Kabdasli, N. I. (1994) Hydroxide precipitation of complexed metals. *Water Research*, **28**(10), 2117-2124.