UASBs or anaerobic ponds in warm climates? A preliminary answer from Colombia

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Abstract An anaerobic pond and a UASB reactor treating the same domestic sewage under the same environmental conditions were monitored at the wastewater research and technology transfer station in Ginebra, Valle del Cauca region in Colombia. Preliminary results showed removal efficiencies in the UASB of around 66, 78 and 69% for COD, BOD and TSS, respectively. The removal efficiencies in the anaerobic pond for the same parameters were 68, 59 and 73%, respectively. A preliminary cost comparison has shown that construction and operation and maintenance costs of the anaerobic pond are 16 and 38% less than those for the UASB, respectively. Based upon this preliminary study, it would seem that technical features of these two systems (AP and UASBs) in terms of removal efficiencies are not key points to choose one over the other since they perform similarly when treating the same sewage. This is particularly true if both reactors work under optimal conditions. Therefore, a more rational and definite answer to the question – UASBs or anaerobic ponds in warm climates? – must be based on a more rigorous appraisal of social, economic and managerial factors linked to the local context.

Keywords Anaerobic treatment; anaerobic ponds; UASB reactors; performance

Introduction

Anaerobic ponds (AP) and UASB reactors are widely used for primary sewage treatment. According to data reported in the literature, these reactors can achieve up to 70-80 percent removal of BOD at temperatures of around 25 ºC. Since anaerobic ponds are low rate systems, they require retention times between 1-2 days to achieve such efficiencies, depending on the wastewater strength (Mara *et al.*, 1992). UASB reactors also achieve the same level of treatment but at shorter retention times of around 6-8 hours (van Haandel and Lettinga, 1994; Dean and Horan, 1995). These levels of treatment make the two technologies technically feasible for wastewater treatment in developing countries. However, there has been not a properly conducted experimental comparison of the two systems treating the same wastewater under the same environmental conditions.

Collazos (1986) carried out a comparative study of an AP and a UASB reactor at pilot scale treating the wastewater of Bucaramanga city in Colombia. Although this study found a better BOD removal efficiency in the UASB reactor, it did not report any operational conditions of the AP such as sludge accumulation, odour release and inlet and outlet arrangements. All these factors may act negatively due to poor design and construction, so causing a reduction in removal efficiency and thus making any comparison unfair.

There have always been debates over what technology is best to treat a given wastewater. Arguments are often polarised in favour or against any given technology, and they are mainly based on technical considerations alone. However, there are other factors to be taken into account, and these may change preconceived judgements. For example, it should be borne in mind that finance for wastewater treatment in developing countries is scarce and, given the fragility of their economies, there is a need for sustainable technologies. Having said this, the aim of this work is to carry out a preliminary technical comparison

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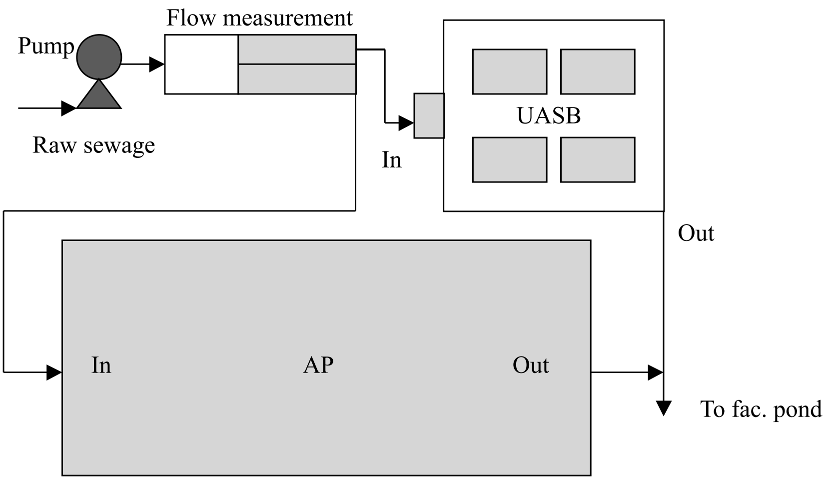

Figure 1 Reactor layout and sampling point location

between a UASB and an AP treating the same wastewater under the same environmental conditions. A preliminary cost comparison of the two systems is also presented.

Materials and methods

This study was carried out in the town of Ginebra (9000 p.e.) in Valle del Cauca region in southwest Colombia. The weather is tropical with an average temperature of 25ºC throughout the year. The main economic activities are agriculture followed by tourism. At the town's wastewater treatment plant (a 2-day anaerobic pond followed by a 5-day facultative pond) there is a wastewater research and technology transfer station for wastewater treatment and reuse in small and medium-sized towns. This belongs to Aquavalle, the regional water company, and it is being developed in partnership with Instituto Cinara at the Universidad del Valle in Cali.

The research station comprises six wastewater treatment technologies. The UASB and the pond complex are full-scale systems. The other alternatives are pilot-scale units such as RBC, duckweed ponds, a Japanese package plant and an integrated system with a septic tank, anaerobic filter and hydroponic gravel beds. The influent wastewater, after conventional preliminary treatment, is pumped to a flow splitting chamber from which all the systems are fed.

The results presented here were obtained from the anaerobic pond (AP) and the UASB reactor treating purely domestic sewage. Figure 1 shows the reactor layout together with the location of the sampling points.

With the UASB, flow readings were taken every hour during each 24-hour sampling period from a calibrated V-notch, and 24-hour composite samples (aliquots taken every hour) were taken from the influent and effluent twice per week. With the AP, flow readings were taken hourly every sampling day from 0600 to 2000 h also by a calibrated V-notch;

Table 1 Operational parameters of the reactors.

Reactor	Operational parameters					
	Q_{ay} (l/s)	HRT (h)	H (m)	V_t (m^3)	COV (kg COD/m^3d)	Solids load (kg TSS/m^3d)
UASB	10.0	7.0	4.3	277.8	1.80	0.75
Anaerobic pond	10.0	48.0	4.0	3437	0.26	0.11

Table 2 Raw sewage characteristics at Ginebra research station.

Parameter	*n*	Mean value	Standard deviation
Temperature ((C)	30	25	0.30
pH	50	6.92	0.25
COD (mg/l)	28	523	61
BOD_5 (mg/l)	12	343	43
TSS (mg/l)	25	219	40
Settleable solids (1 h) (ml/l)	25	2.4	1.1
Total N (mg/l)	4	42.3	17.1
Total P (mg/l)	4	5.1	2.6
Faecal coliforms /100ml	3	3.7×10^5 [a]	2.0×10^5 [a]

[a]Geometric mean.

Table 3 Characteristics of the inoculum material.

Parameter	Beginning of the study	End of the study
TSS (g/l)	88.0	26.7
VSS (g/l)	39.5	10.2
Biogas production (l/m^3)	12.9	60.0
Methanogenic activity (g COD/g VSS-d)	0.19	0.26

14-hour composite samples (aliquots taken every hour) were taken from the influent and effluent four times per week.

The composite samples in both cases were analysed for pH, temperature, COD, BOD_5, TSS and settleable solids. Temperature and pH were monitored daily while BOD_5 tests were carried out twice per month. All laboratory analyses were carried out according to *Standard Methods* (APHA, 1992). Table 1 presents the operational parameters of both reactors.

Experimental results

Raw wastewater characteristics. Table 2 details the typical composition of the raw wastewater at the Ginebra research station.

Inoculum source to the UASB. The material used to inoculate the UASB reactor was taken from the AP in August 1998. The AP has been accumulating sludge for five years (since commissioning). Table 3 shows the inoculum sludge characteristics, which correspond also to the sludge settled in the AP.

Reactor performance data. Figures 2-9 show the performance of the reactors during the study periods: for the UASB this was October 1998 – January 1999, and for the AP June 1998 – December 1998. Additional records for the AP were taken from the water company's database.

The two reactors achieved similar removal efficiencies for all the parameters considered with the exception of BOD, for which the UASB had a better removal efficiency than the AP. However, the AP had a slightly better performance for TSS and settleable solids removal.

Discussion

Based on Table 2, the raw wastewater at Ginebra can be classified as medium strength (Metcalf and Eddy, 1991). However, for the Colombian context this wastewater is quite

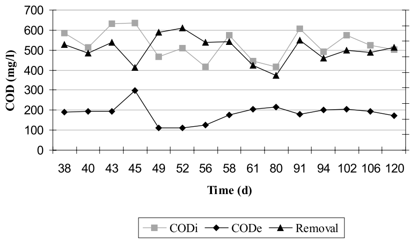

Figure 2 COD influent and effluent variations and removal efficiency in the UASB

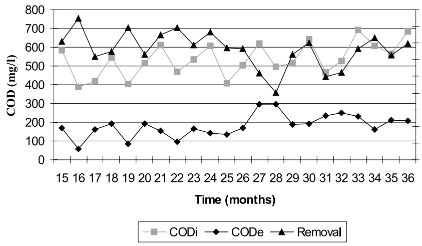

Figure 3 COD influent and effluent variations and removal efficiency in the AP

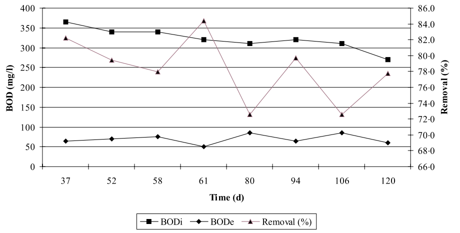

Figure 4 BOD influent and effluent variations and removal efficiencies in the UASB

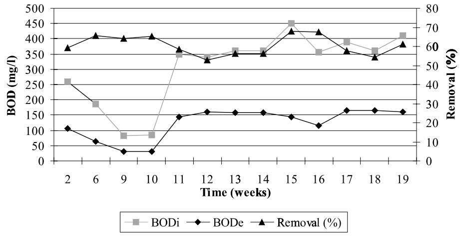

Figure 5 BOD influent and effluent variations and removal efficiency in the AP

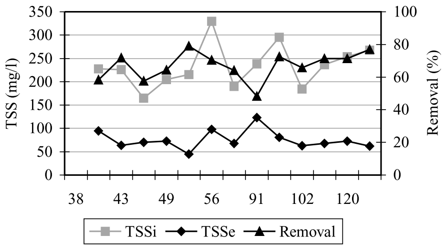

Figure 6 TSS influent and effluent variations and removal efficiency in the UASB

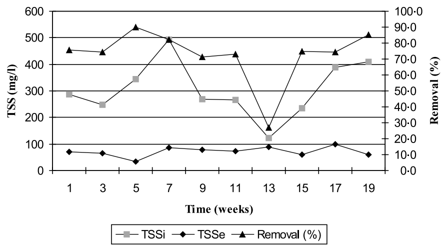

Figure 7 TSS influent and effluent variations and removal efficiency in the AP

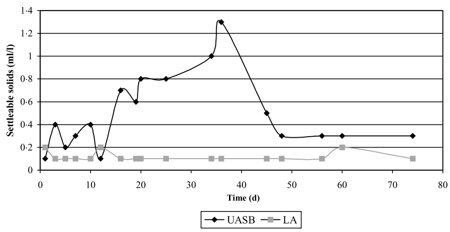

Figure 8 Settleable solids 1 h effluent variations in the UASB

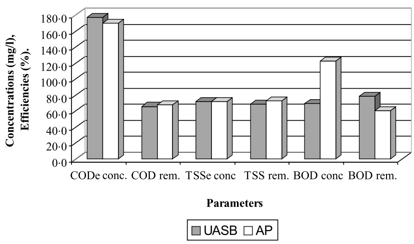

Figure 9 Average effluent concentrations and removal efficiencies of UASB and AP

strong as typical domestic wastewaters have COD and BOD values in the ranges 350–400 mg/l and 180–200 mg/l, respectively. The high strength of the Ginebra wastewater may be attributable to the discharge of raw wastes from a slaughterhouse and several restaurants.

The inoculum taken from the AP rapidly adapted to conditions in the UASB and performed well despite its low methanogenic activity (Table 3). However, the level of biogas production reached at the end of the study confirms the good biological quality of the AP sludge.

The variation of UASB performance shown in Figure 2 is not attributable to any instability of the biological process since the reactor quickly recovers its normal operation conditions. Rather it is due to the natural changes in the quality and quantity of the raw wastewater. Even though UASB reactors are in general less able to cope with high variations in raw wastewater composition due to their short hydraulic retention times, the performance of the UASB at Ginebra was very good.

The effluent average COD concentration in the UASB was 177 mg/l, corresponding to an average COD removal efficiency of 66%. These figures are in agreement with most of the results reported in the literature for UASBs treating domestic sewage (Peña *et al*., 1998; Rodríguez, 1996; van Haandel and Lettinga, 1994; Vieira, 1988; Pathe *et al*., 1988).

The effluent quality of the AP varied less than that of the raw wastewater, although the absolute variation pattern of effluent quality did not show any definite steady state. Figure 3 shows how the effluent COD concentration tended to increase slightly with time. A likely explanation for this is the continuous sludge settling and accumulation, which caused a reduction in retention time in the pond, so affecting its removal efficiency. The average effluent COD concentration in the AP was 170 mg/l, yielding an average removal efficiency of 68%. These figures are in agreement with results reported elsewhere (Mara *et al.*, 1992; Oldham and Nemeth, 1973) and indicate satisfactory performance of the unit.

BOD removal efficiency in the UASB indicates a steady state, varying according to the influent BOD concentration. Figure 4 shows that the effluent BOD remained at around 69 mg/l, equivalent to an average BOD removal efficiency of 78%. Figure 9 shows that BOD removal in the AP was lower than that in the UASB reactor with an average value of 59%.

Average TSS removal in the UASB reactor was 69%, with an effluent concentration of around 72 mg/l (Figures 6 and 9). This parameter exhibits a pattern of variation attributable to massive and localised releases of biogas bubbles from the sludge layer. These bubbles buoy up solids, which are then carried out in the effluent stream. This phenomenon was observed throughout the period of study. Another factor that may help explain the variation of TSS in the effluent is the uncontrolled growth of the sludge blanket. Hence, the likely combined effect of both these factors induces a solids dragging effect which deteriorates effluent quality in terms of both BOD and TSS.

Average TSS removal in the AP was 73%, with an effluent TSS concentration of also around 72 mg/l. Figure 7 shows the stability of TSS removal in this unit, which may be attributed to good in-pond settling. However, the removal efficiency eventually drops to quite low values due to resuspension of the solids occurring as a result of biogas bubbles being released from the pond base. Excessive sludge accumulation (52.5% of the total volume) after five years of continuous operation also contributed to the reduction in TSS removal efficiency.

In the UASB the concentration of reactor biomass increases with time due to the anaerobic conversion of organic matter into new cells. The settleable solids flux in the UASB

Table 4 Capital and operation and maintenance costs of the UASB and the AP at Ginebra research station in 1998 US dollars.

Item	UASB	AP
Initial investment.	83,300	70,300
Annual operation and maintenance	4,200	2,600
Operation and maintenance costs per m^3 of treated wastewater	0.013	0.008
Total cost per m^3 of treated wastewater	0.28	0.23
Operation and maintenance costs per inhabitant (4.500 p.e)	9.40	5.80
Total cost per inhabitant (4.500 p.e)	19.50	16.20

Note: All costs were calculated on annual basis according to Acuavalle's internal cost reports. Running costs for the AP were calculated from records of four years of operation; only six months of data were available for the UASB.

effluent therefore increases with time as shown in Figure 8. However, by controlling the height of the sludge blanket by wasting some of the solids, it is possible to reduce the effluent settleable solids flux. This effect can be observed in Figure 8 at around day 37 when sludge wastage was carried out.

In the case of the AP, the effluent settleable solids flux remained very low and constant. This is further evidence for the optimal performance of settling processes within the pond. However, excessive in-pond solids accumulation may lead to the wash-out of resuspended solids in the final effluent, so steadily reducing the efficiency of the pond in terms of both COD and BOD removal. This is certainly the case with the Ginebra AP after five years of operation without desludging, as can be seen in Figures 3 and 5.

Preliminary cost comparison. Table 4 gives construction costs (excluding land costs and engineering design) and operation and maintenance costs (updated to December 1998) for each treatment unit. The operation and maintenance costs given include only engineering staff, plant operators, laboratory materials and analyses.

From this cost comparison, the construction cost of the AP was 16% less than that of the UASB. Furthermore, the AP O&M costs were 38% less than those of the UASB. These figures demonstrate the advantage of AP for treating domestic wastewater compared with UASBs. However, this advantage may not hold when land prices are high. Thus it will often be necessary to consider this additional criterion in order to make an appropriate technology choice.

The minimum monthly legal salary (MMLS) in Colombia is US $147. Hence, the total cost per m^3 of wastewater treated in one month corresponds to 0.90% and 0.75% of the MMLS for the UASB and the AP respectively. Both technologies can therefore be considered as low-cost and suitable for low-income communities.

It would seem that technically speaking an AP and a UASB are equivalent treatment units in terms of removal efficiencies, thus achieving similar effluent qualities when treating the same sewage. Hence, the answer to the question as to what reactor may be best for a given situation should consider not only technical criteria but social, economic and management aspects linked to each system.

Conclusions

Based upon this preliminary study, the technical aspects of AP and UASBs in terms of removal efficiencies are not key points to choose between the two since they perform similarly when treating the same wastewater. Taking into consideration that the capital and O&M costs of AP are less than those of UASBs, it is always better to choose AP provided that sufficient topographically suitable land is available at low cost. A further point in favour of AP is that they do not require specialised staff for their operation and maintenance, which makes them especially convenient for small towns which do not have the resources to operate a UASB reactor properly.

Given that these two systems are essentially equal in terms of their technical performance, a rational answer to the question – *UASBs or anaerobic ponds in warm climates?* – must be based on rigorous social and economic criteria and management capability within the local context.

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