

# Conceptual analysis of the UASB/Polishing Pond system regarding the removal of specific constituents and control of gaseous emissions

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**Abstract:** A conceptual and integrated analysis of the UASB/Polishing Pond system is presented in relation to the removal of specific constituents not normally covered in the pond's literature, namely surfactants (linear alkylbenzene sulphonate, LAS), micropollutants (phthalates and bisphenol A) and sulfide. Experimental studies carried out on a small full-scale UASB/PP system have shown that polishing ponds can be very effective in the removal and oxidation of sulfide, but limited in the complementary removal of some micropollutants and surfactants. Further research is needed to investigate these possible limitations.

**Keywords:** micropollutants, pathogens, polishing pond, sulfide, surfactants, UASB reactor

## INTRODUCTION

The anaerobic process presents several favourable characteristics, which include low cost, operational simplicity, low energy consumption and low production of solids. These advantages coupled with favourable environmental conditions in warm-climate regions, where high temperatures prevail throughout the year, make anaerobic treatment systems, in particular the UASB reactor, an attractive technology for wastewater treatment.

Despite their advantages and broad application, UASB reactors still have some operational limitations, which remain unresolved (Table 1). In addition to the known limitations regarding the pathogen, nitrogen and organic characteristics of anaerobic effluents, which in many cases require a post-treatment step to meet environmental discharge limits, there are other concerns in relation to the removal of surfactants, micropollutants and sulfides (Chernicharo and Stuetz, 2008).

Polishing ponds (PP) are basically maturation ponds that are conceived to polish the effluent from anaerobic reactors. In addition to their main role of pathogen removal, some improvement in terms of ammonia and organic matter may be expected. Polishing ponds are designed as maturation ponds, both as cells in series or baffled units, with depths ranging from 0.60 to 1.00 m. If properly designed, the system can lead to effluents complying with World Health Organisation (WHO) guidelines for unrestricted irrigation (von Sperling *et al.*, 2005).

Wastewater treatment plants using UASB reactors followed by polishing ponds have a very simplified process train (Figure 1). In addition to the preliminary treatment units (screen and grit chamber), the process is composed of an anaerobic treatment unit, a polishing pond (either a single baffled pond or ponds in series), and a dewatering unit for the waste sludge produced in the UASB reactor, which has already been thickened and stabilised inside the reactor.

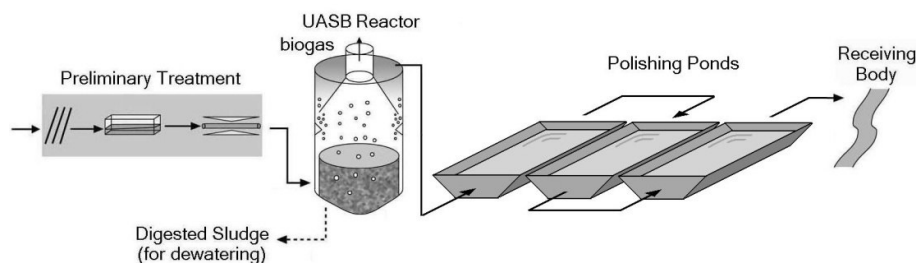


Figure 1 - Typical configuration of a UASB/Polishing Pond system  
Source: (von Sperling *et al.*, 2005)

**Table 1:** Summary of potential problems and possible improvements in the design, construction and operation of UASB treatment plants

	Constituents of interest	Potential problems	Possible improvements
Biogas	H <sub>2</sub> S	Odour emission Corrosion Toxicity	Biogas flare Biogas treatment
	CH <sub>4</sub>	GHG emission Explosion risk	Energy recovery
Waste gas	H <sub>2</sub> S	Odour emission Corrosion Toxicity	Waste gas collection Waste gas treatment
	CH <sub>4</sub>	GHG emission	
Effluent	Carbon	DO depletion	Post-treatment
	Nutrient	Eutrophication Toxicity	Agricultural reuse Post-treatment
Scum	Surfactant	Toxicity Foam	Disinfection Sub-superficial irrigation Aquifer recharge
	Micropollutants	Toxicity Health risks	Aerobic post-treatment Reduce turbulences
Tri-phase separator	Dissolved H <sub>2</sub> S	Odour emission Corrosion Toxicity	Increase sludge age Post-treatment Effluent recycle
	Dissolved CH <sub>4</sub>	GHG emission	Aerobic post-treatment Gas stripping/treatment Micro-aeration using biogas
Cover	Organics Debris	Blockage Management	Gas stripping/treatment Micro-aeration using biogas Biological oxidation
	Organics Debris	Blockage Management	Improve pre-treatment Eliminate baffle <sup>(1)</sup> Maintain baffle <sup>(2)</sup>
Feeding system	Organics Debris	Blockage Management	Improve pre-treatment Removal/disposal Increase degradation <sup>(3)</sup>
	-	Gas leakage Structure failure Corrosion	Use of proper materials Use of proper linings Improve design
Sludge	-	Corrosion	Use of proper materials Use of proper linings
	-	Blockage Bad mixing	Improve pre-treatment Increase n° of distributors
Pre-treatment and pumping station	Nutrient Pathogen Sand Debris	Sludge build up Health risks Dewatering	Improve design Improve operation Improve pre-treatment Hygienization
	Dissolved H <sub>2</sub> S	Odour emission Passage of debris Passage of oil/grease Flowrate variation	Waste gas collection Waste gas treatment Use of sieves O&G removal Control cross-connections Minimum of two pumps Use of variable speed pump Overflow structure Use of holding tank

(1) Scum is released with the effluent at the same rate it is formed. Therefore, the impact in effluent quality is minimal, usually amounting to less than 1% increase in BOD and COD concentrations.

(2) Scum accumulation does not tend to increase after a certain period of time if the settler compartment is uncovered. Potential beneficial effects of the scum layer in odour abatement are still under investigation (Souza *et al.*, 2006).

(3) Possible ways to increase scum degradation inside the reactor are still under investigation (Pereira *et al.*, 2008)

GHG: green house gas

Source: (Chernicharo and Stuetz, 2008)

Considering the intrinsic and other present limitations associated with the UASB reactors (Table 1) and the favourable aspects of using polishing ponds to treat domestic sewage in developing countries, this paper aims to present a conceptual and integrated analysis of the UASB/PP system in order to improve the overall performance of the wastewater treatment plant, not only in terms of better effluent quality but also in relation to the control of gaseous emissions. The constituents of interest are shown in Table 1. Alternatives of management of gaseous and dissolved methane are covered in Chernicharo & Stuetz (2008) and, therefore, are outside the scope of this paper.

Previous studies have reported on the feasibility of PP for improving the microbiological quality of anaerobic effluents and also the quality in terms of organic matter and nutrients, as summarized in Table 2. However, very little is known in relation to other constituents of interest, such as surfactants, micropollutants (e.g. endocrine disrupters, pharmaceuticals etc.) and dissolved and gaseous sulfide.

**Table 2:** Summary of expected performance of UASB reactors alone and of systems comprised by UASB reactors and a series of polishing ponds (PP)

Constituent	Effluent concentration (mg/L)		Removal efficiency (%)	
	UASB reactor	Overall (UASB/PP)	UASB reactor	Overall (UASB/PP)
BOD	70 – 100	40 - 70	60 – 75	75 – 85
COD	180 – 270	100 - 180	55 – 70	70 – 83
Ammonia-N	30 – 50	10 - 20	(a)	50 – 65
N total	35 – 55	15 - 25	5 – 15	50 – 65
<i>E. coli</i>	10 <sup>6</sup> - 10 <sup>7</sup>	10 <sup>2</sup> - 10 <sup>4</sup>	1 – 2 log units	3 – 5 log units
Helminth eggs	> 1	< 1	70 - 90	~ 100

Source: (von Sperling *et al.*, 2005; von Sperling and Chernicharo, 2005 )

Although few studies have been published regarding the removal of LAS in pond systems treating domestic wastewater, there are indications that very high biodegradation can occur, depending on pond hydraulic retention time (HRT) and dissolved oxygen (DO) levels. Moreno *et al.* (1994) reported total LAS removal of 97% in ponds operating at very high HRT (20 to 60 days), while Mungray & Kumar (2008, in press) reported removal efficiencies varying from 47 to 88%. On the other hand, biodegradation of LAS under anaerobic conditions has historically been believed not to occur, as known mechanisms that precede the aerobic mineralization of LAS require molecular oxygen (Ying, 2006), although LAS has been reported to degrade anaerobically under certain conditions (Angelidaki *et al.*, 2000; Sanz *et al.*, 2003). In a recent study carried out by Mungray & Kumar (2008, in press), the removal efficiencies of LAS in five full-scale UASB reactors operating in India were very low, ranging from 2 to 18%.

As a consequence of insufficient removal during treatment of wastewater released from industry and households, different classes of organic micropollutants are nowadays detected in surface and drinking water. Among these micropollutants, bioactive substances, e.g., endocrine disrupting compounds and pharmaceuticals, have demonstrated adverse effects on living organisms in aquatic systems (Cirja *et al.*, 2008).

From the review on the factors affecting the removal of micropollutants in wastewater treatment systems, recently published by Cirja *et al.* (2008), it was concluded that sorption and biodegradation are the dominant removal processes in conventional wastewater treatment plants. According to Cirja *et al.* (2008) some general rules can be derived concerning the factors affecting the removal of micropollutants: i) hydrophobic compounds (nonylphenol, estradiol etc) can be removed from the influent via adsorption to the sludge particles present in the system; ii) compounds containing complex structure (e.g., alkyl chain branching) and toxic groups (e.g., halogens and nitro group) show higher resistance to biodegradation processes; iii) when the sludge age in the wastewater treatment system was sufficiently high (at least 8 d) the removal of organic compounds through biodegradation processes was enhanced; iv) treatment systems in countries with average temperature of 15 to 20 °C removed better micropollutants via biodegradation when compared to cold countries.

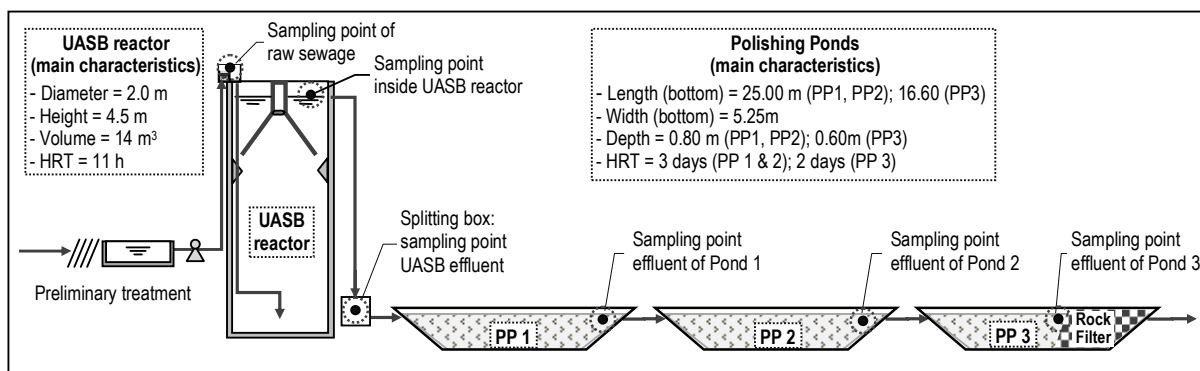
The hydraulic retention time and the organic load also have significant role in the removal of micropollutants. For instance, Svenson *et al.* (2003) showed that a treatment system with high hydraulic retention time which included a wetland unit, resulted in complete removal of estrogens present in the influent. Furthermore Koh *et al.* (2008) suggested that systems receiving low organic loads tend to better remove recalcitrant micropollutants. As far as the reactor configuration is concerned, Koh *et al.* (2008) suggested that trickling filters are normally less

effective than activated sludge systems in the removal of estrogens from sewage, and that little is known about the efficiency of ponds in the removal of such micropollutants. Another important conclusion of Koh *et al.* (2008) is that systems configured to remove nutrients (N and P) are more efficient in estrogens removal since the existence of aerobic, anoxic and anaerobic zones allow different metabolic pathways to occur. In addition, the occurrence of nitrification is normally associated with high sludge age which promotes the growth of a more diverse and specialized microbial community, including those microorganisms that have low growth rates and are adapted to degrade estrogens.

Hydrogen sulfide (H<sub>2</sub>S), resulting from the reduction of sulfate or thiosulfate under anaerobic conditions, is the most common odorant associated with sewage odours, although other compounds such as dimethyl sulfide and dimethyl oligosulfides can also significantly contribute to sewage odours (van Langenhove and de Heyder, 2001). The H<sub>2</sub>S generated in UASB reactors can be dissolved in the liquid phase or released to the gas phase. The amount of H<sub>2</sub>S that will be present in the gas and liquid phases will depend on factors such as pH, temperature and gas partial pressure inside the reactor. H<sub>2</sub>S that remains dissolved in the liquid phase will be released with the treated effluent, whilst the H<sub>2</sub>S that diffuses from the liquid phase in the reactor can be present either in the biogas collected inside the tri-phase separator or in the waste gas released from the surface of the settler compartment (Chernicharo and Stuetz, 2008). The removal of H<sub>2</sub>S from the waste gas aims to reduce the corrosive impact of emissions as well as the olfactory annoyance, since its collection and treatment is not usually considered in most UASB treatment plants. To avoid public complain, many plants are now spending significant O&M funds via chemicals dosing in order to minimize the dispersion of H<sub>2</sub>S emissions to nearby local receptors (Chernicharo and Stuetz, 2008).

## METHODOLOGY

The conceptual analysis of the UASB/PP system regarding the removal of specific constituents and control of gaseous emissions was based on literature review and on preliminary measurements of some constituents of interest (detergents, micropollutants and sulfide) in a small full-scale UASB/PP system. The treatment system (flow sheet, sampling points and main characteristics are presented in Figure 2) was composed by an UASB reactor and three shallow polishing ponds operating in series. The system was installed at the UFMG/COPASA Centre for Research and Training on Sanitation (CePTS), Belo Horizonte – Brazil (coordinates 19°53'42" S and 43°52'42" W, altitude 800 m). The feed was raw sewage taken from the Arrudas WWTP, representing typical urban wastewater (mean liquid temperature = 23°C).



**Figure 2:** Flow sheet, sampling points and main characteristics of the small full-scale UASB/PP system

The homologues of the anionic surfactant commonly known as LAS – linear alkyl benzene sulphonate were quantified by high performance liquid chromatography (HPLC) using UV/Vis detector set at 220 nm after their separation in a Lichrosorb 10 RP8 column (Chrompack) kept at 35 °C. The mobile phase delivered through the column was a combination of two phases in isocratic mode: a) 80% methanol in water (1.5 mL/min); and b) 1% NaClO<sub>4</sub> in water (0.2

mL/min). Before injection the samples were filtered through 1.2  $\mu\text{m}$  membranes for solid removal and then 100 mL was filtered through C-18 cartridges (Strata, 500 mg) for the extraction of LAS from the aqueous samples (raw sewage and effluents from the UASB reactor and from all polishing ponds). The C-18 cartridges were then eluted with 3 mL methanol allowing for a concentration factor of 33.3 times. Three 24-hour composite samples were taken for the raw wastewater and for the effluent of UASB reactor, while depth-composite samples were taken for the effluents of all ponds.

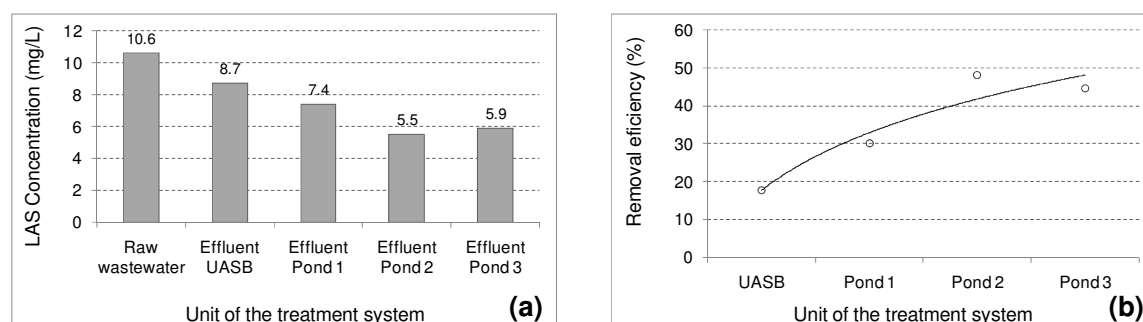
For analysis of micropollutants, 300 mL of aqueous samples (raw sewage and effluents from the UASB reactor and from the first polishing pond) free of solids were first filtered through C-18 cartridges (Strata, 500 mg) by using a manifold system connected to a vacuum pump under a flow rate of 5 mL/min. The hydrophobic micropollutants were then eluted from the C-18 cartridges by using two different solutions: 3 mL of a mixture of hexane and dichloromethane (1:4) and 5 mL of a mixture of hexane and dichloromethane (9:1). The organic extract was dried under nitrogen and then re-dissolved in 1 mL of methanol allowing for a theoretical concentration factor of 300 times. The organic extracts were then analyzed by gas chromatography coupled to mass spectrometry (GC-MS) in a Shimadzu QP 2010 equipment. The sample (2  $\mu\text{L}$ ) was injected in the mode splitless at 250 kPa and 280  $^{\circ}\text{C}$  in a 30 m column (Rtx-5MS, 95% dimethyl polysiloxane) which had 0.25 mm of inner diameter and 0.25  $\mu\text{m}$  of **particle** diameter. The oven temperature started at 80  $^{\circ}\text{C}$  and was increased to 130  $^{\circ}\text{C}$  at the rate of 18  $^{\circ}\text{C}/\text{min}$  and then to 270  $^{\circ}\text{C}$  at 5  $^{\circ}\text{C}/\text{min}$  before being ramped up to 300  $^{\circ}\text{C}$  (at 18  $^{\circ}\text{C}/\text{min}$ ) where it was held for 7 min. The mobile phase was He (3.26 mL/min) and the ionization temperature at the mass spectrometer was 250  $^{\circ}\text{C}$ .

Sulfides were determined using the methylene blue method, according to Plas *et al.* (1992). Triplicate grab samples were collected in four different days, being immediately mixed with a solution of zinc acetate (0.01 M) in order to promote the precipitation of dissolved sulfide.

## RESULTS

### Removal of surfactants

The average results obtained from the three samples analysed are shown in Figure 3. It was observed that the removal of LAS continued along the treatment system, but that the overall efficiency was limited to around 50%. The UASB reactor was responsible for a minor reduction (around 18% removal), whereas the set of three ponds was responsible for a further 35% removal efficiency. As a result, a reasonable amount of LAS is released in the final effluent (average concentration of 5.9 mg/L). This value does not meet the Brazilian standard for this parameter which is set at 2 mg/L.



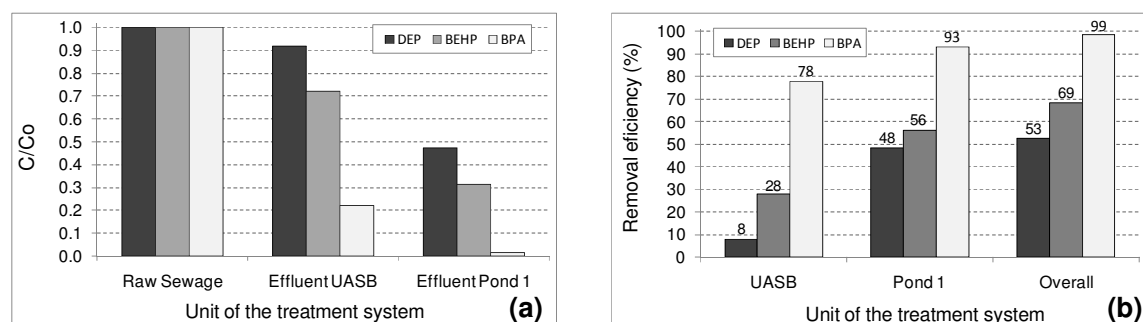
**Figure 3:** Average concentration (a) and cumulative removal efficiency (b) of LAS along the system

The results of the present study indicate lower removal efficiencies than those found by Moreno *et al.* (1994) and Mungray & Kumar (2008), who reported pond systems with removal efficiencies varying from 47 to 97%. These differences are most likely due to the different operating conditions employed in the pond systems. In the studied system, the reduced HRT in the train of three polishing ponds (around 10 days, in total) probably leads to a lower

heterotrophic biomass mass compared to those in the systems investigated by Moreno *et al.* (1994) and Mungray & Kumar (2008). Another possible reason for the assumed lower heterotrophic biomass quantity in the polishing ponds could be the lower substrate availability resulting from the previous removal of organic matter in the UASB reactor and therefore also the removal of LAS in these systems could be limited.

### Removal of micropollutants

Figure 4 shows preliminary results on the removal of diethylphthalate (DEP), bis(2ethylhexyl)phthalate (BEHP) and bisphenol A (BPA) in the combined UASB/PP system. The results refer to the average values of four sampling campaigns and are expressed in relation to the concentration present in the raw sewage. The contaminants chosen in this study have known endocrine disrupting properties to aquatic fauna (Damstra, 2002), are normally present in relatively high concentration in surface waters and derive from plastic ware such as PVC (in the case of the phthalates) and polycarbonate (in the case of bisphenol).



**Figure 4:** Relative concentration (a) and removal efficiencies (b) of Diethylphthalate (DEP), bis(2ethylhexyl)phthalate (BEHP) and bisphenol A (BPA) in the UASB-PP system.

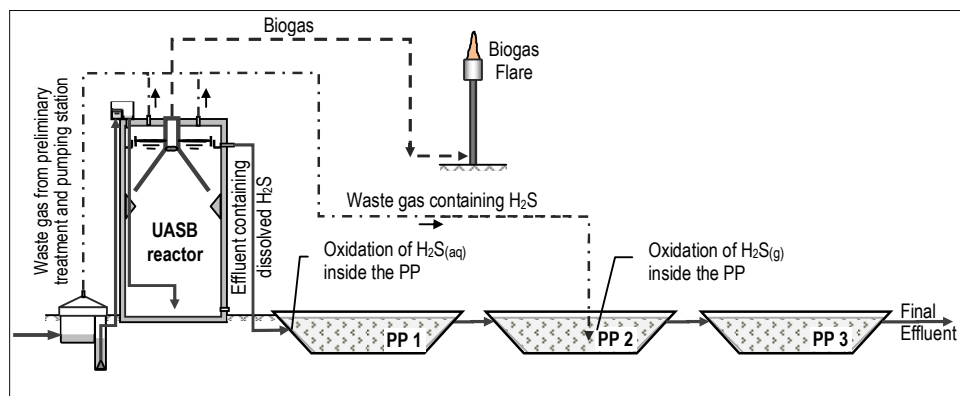
Figure 4 shows that the anaerobic step has little impact on the biodegradation of phthalates (8 to 28%) whereas bisphenol A is removed by 78%, which most likely occurs due to adsorption of the compound to the sludge due to the high hydrophobicity of such alkyl phenol. The polishing pond significantly reduced the concentration of phthalates from the UASB effluent leading to an overall efficiency of phthalates removal from 53 to approximately 70% in the UASB/PP system. As far as the bisphenol is concerned, the results show that the polishing pond was very efficient in removing this alkyl phenol from the UASB effluent, and this might have occurred due to a combination of the high hydraulic retention time and adsorption to algae mass.

### Conceptual analysis of H<sub>2</sub>S removal in aerobic liquid-based systems

The concept of waste-gas pollutants treatment in aerobic liquid-based systems was originally developed for activated sludge processes – AS, being later expanded for other systems, such as rotating biological contactors - RBC (von Rohr and Ruediger, 2001) and submerged aerated biofilters - SAB (Matos *et al.*, 2001). In liquid-based systems, the odorous contaminants are transferred from the gas into the oxygen-containing bulk liquid where they are degraded by a suspension of bacteria. The gas is generally introduced into the bottom part of the reactor in the form of dispersed bubbles. The waste-gas pollutants are co-degraded with the contaminants dissolved in the influent wastewater. Since most volatile organic contaminants have a much higher affinity for the liquid when compared to oxygen (as evidenced by lower Henry's coefficients), the liquid-based system is generally oversized for mass transfer of the odorous contaminants (Bielefeldt, 2001).

The expansion of the liquid-based system concept for H<sub>2</sub>S treatment in PP systems seems to be feasible options, once H<sub>2</sub>S also has a higher affinity for the liquid phase than oxygen (Henry's coefficient of 0.94 for H<sub>2</sub>S and 0.034 for O<sub>2</sub>) and therefore mass transfer limitation should not be a problem. Besides, the biodegradability of H<sub>2</sub>S is considered high (Kennes and Veiga, 2001). There are, however, major differences between PP and AS, RBC and SAB systems, such as: i) suspended and attached growth biomass are present in much higher concentrations in AS, RBC

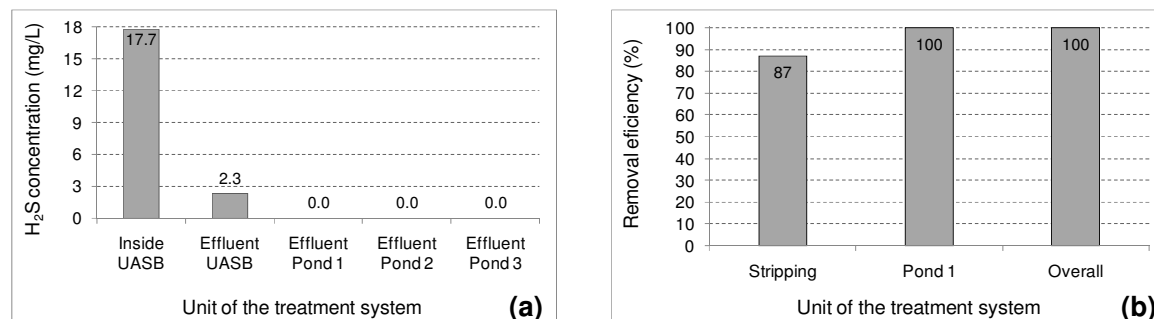
and SAB systems; ii) mixing/aeration is provided in AS, RBC and SAB systems; iii) AS and SAB systems have much higher water depths; and iv) RBC and SAB are usually enclosed systems. On the other hand, polishing ponds have much larger areas, which allow a scattered distribution of the gaseous emissions into the liquid phase. In addition, polishing ponds present much higher pH (usually between 8 and 9), meaning that nearly 100% of the  $H_2S$  will dissociate into the non-odorous  $HS^-$  form. Figure 5 gives an illustration of a possible process flowsheet for treating gaseous and dissolved sulfide in UASB/PP systems.



**Figure 5:** Schematic representation of combined management of gaseous and liquid emissions in small treatment plants with anaerobic reactors: Biogas flaring, liquid and waste gas treatment in Polishing Ponds

### Removal of dissolved $H_2S$ in the small full-scale system

Apart from the possibility of oxidising both the dissolved and the  $H_2S$  contained in the waste gas, currently only the effluent containing  $H_2S$  is directed to the polishing ponds. From the results presented in Figure 6, which refer to the average values of four sampling campaigns, most of the  $H_2S$  is removed even before entering the pond system, being stripped from the liquid phase due to the presence of a splitting box located 3.5 meters lower than the effluent level (see Figure 2). The remaining sulfide concentration is completely removed already in the first pond, with no trace concentrations being detected in ponds 2 and 3.



**Figure 6:** Average concentrations (a) and removal efficiencies (b) of  $H_2S$  along the UASB/PP system

## CONCLUSIONS

Polishing ponds are well known for their ability to improve the microbiological quality of anaerobic effluents as well as the removal of organic matter and nitrogen. These preliminary observations have shown that UASB/PP systems can also provide for the removal of surfactants, micropollutants and dissolved and gaseous sulfides. Results indicated that Polishing Ponds can contribute to the removal of dissolved and gaseous  $H_2S$ , although the degree of bio-chemical oxidation was not measured and this should be more investigated. The removal of selected micropollutants and surfactants was limited and is most likely linked to the characteristics and operating conditions of the treatment system. There are also concerns in relation to

micropollutants being adsorbed onto algae and released with the pond effluent. The removal of these constituents in UASB/PP systems requires further investigation, in order to evaluate these limitations and to identify means to improve its performance.

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