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STRIPPING AND DISSIPATION TECHNIQUES FOR THE REMOVAL OF DISSOLVED GASES FROM ANAEROBIC EFFLUENTS

R. M. Glória, T. M. Motta, P. V. O. Silva, P. da Costa, E. M. F. Brandt, C. L. Souza* and C. A. L. Chernicharo

Federal University of Minas Gerais, Belo Horizonte - MG, Brazil.
E-mail: claudio@desa.ufmg.br

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Abstract - UASB reactors are a common technology for wastewater treatment. However, certain disadvantages must be considered. One of the disadvantages relates to the presence of dissolved gases, hydrogen sulfide and methane, in the effluent, which can potentially be released into the atmosphere. This can cause malodours and contribute to the greenhouse effect. In this perspective, this work investigated alternative techniques to minimize these disadvantages: air stripping inside the settling compartment; and a dissipation chamber immediately after the reactor outlet. Results achieved with the air stripping technique showed low removal efficiencies for methane, around 30%, and in the range of 40 to 60% for hydrogen sulfide. On the other hand, the removal efficiencies obtained with the dissipation chamber technique were much higher, consistently reaching 60% or more for both gases, plus a relatively lower exhaust flow. For the best operational condition tested, median removal efficiencies of 73 and 97% were observed for dissolved methane and dissolved sulfide, respectively.
Keywords: Dissipation chamber; Stripping; Dissolved methane; Hydrogen sulphide; Gaseous emissions; UASB reactor.

INTRODUCTION

When anaerobic UASB-type reactors are employed for the treatment of domestic sewage, the generation of gaseous by-products, notably methane and hydrogen sulfide, is unavoidable. The former is a greenhouse gas and the latter causes bad odours and corrosion. In addition, methane losses mean less energy potential to be exploited. In this sense, a higher dissolved methane concentration in the reactor effluent leads to a decrease in the CH_4 recovery efficiency, which stands for the percentage of the total CH_4 produced (biogas + losses with the effluent) that is actually recovered with the biogas, inside the three-phase separator. This parameter is another important issue of concern when CH_4 is intended to be used as energy source (Giménez, 2012).

Some alternatives to reduce the concentrations of dissolved methane from the effluent of anaerobic reactors have been tested, such as micro-aeration (Hartley and Lant, 2006) and membranes (Cookney *et al.*, 2010); however, none of them proved to be truly feasible and effective. In a recent study using membranes to remove dissolved gas, Luo (2014) obtained high removal efficiencies for methane, around 86%; however, it is still an expensive technique. Other researchers are focusing on improving the post-treatment of the anaerobic effluent to promote a controlled biological oxidation of dissolved CH_4, for example, using a closed-type down-flow

*To whom correspondence should be addressed
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hanging sponge (DHS) reactor (Hatamoto *et al.*, 2010; Matsuura *et al.*, 2010; Hatamoto *et al.*, 2011).

In relation to dissolved sulfide, various techniques have been applied to attempt its removal from anaerobic reactor effluents, notably from UASB reactors. Some studies have been carried out in this direction, including: aeration of the effluent, with removal efficiency of approximately 86% (Khan *et al*., 2011); electrochemical technique, with removal efficiency of approximately 82% (Dutta *et al.,* 2010); micro aeration technique, with removal efficiency of around 16% (Krayzelova *et al.,* 2014) and biochemical technique (photosynthetic bacteria), with removal efficiencies ranging between 81 and 95% (Kobayashi, 1983).

Other alternatives, such as stripping and dissipation techniques (this study), which present low cost and operational simplicity for the removal of dissolved gases, are based on aeration and gas transfer conditions. Since gas transfer occurs through the gas-liquid interface (according to the two-film theory), this operation has to be carried out as to maximize the opportunity of interfacial contact between the two phases. In order to have the bulk solution also take part in the transfer, continuous renewal of these interfaces is essential (Popel, 1979). In this sense, the dissipation chamber technique, by exhaustion of the confined atmosphere, promotes the gas phase renovation. In addition, the turbulence caused by the free drop height increases the mass transfer for the liquid phase. Thereby two conditions are optimized: i) the oxygen diffusion in the liquid effluent, due to its high concentration in the gas phase; and ii) the release of dissolved gases (like hydrogen sulfide and methane) into the confined atmosphere, which is under low partial pressure due to its constant renovation, enabling gas recuperation. For the stripping technique, the gas transfer occurs as the bubble emerges from the orifice of diffusers and rises through the liquid. Besides oxygen diffusion into the liquid phase, hydrogen sulfide and methane transferences from the liquid phase are expected to occur, through the formed bubbles.

Therefore, this study aimed to test the effectiveness of the stripping and dissipation techniques for the removal of methane and hydrogen sulfide dissolved in the effluent of anaerobic reactors.

MATERIAL AND METHODS

Two pilot-scale UASB reactors of identical configuration (V=360 L), both fed with real domestic wastewater and operated with a hydraulic detention time of 7 h were used in the experiments. Two alternatives to remove the gases dissolved in the anaerobic effluent were tested:

i. Stripping device, located inside the settling compartment of one of the UASB reactors;

ii. Dissipation unit, located outside the other reactor, with the purpose to create hydraulic energy dissipation through a controlled free-fall.

The stripping device, which consisted of 4 air injection points, located 15 cm below the liquid surface of the settling compartment of the reactor, was operated under 3 different rates of air injection (213, 160 and 107 $L.m^{-3}.min^{-1}$), comprising three operational phases. The volume used to calculate the rates of air injection was the volume of the settling compartment, above the stripping point (0.03 m^3).

The dissipation unit, which consisted of a 10 cm diameter cylindrical chamber, was operated at two different drop heights (0.5 and 1.0 m) and controlled air exhaustion rates, comprising 4 operational phases, as shown in Table 1.

The experiments with both techniques were carried out at ambient temperature (around 22 °C) and atmospheric pressure of around 91.9 kPa.

Analyses of sulfide in the liquid samples were performed according to the protocol adapted by Plas *et al*. (1992), whereas sampling and analysis of dissolved methane followed the protocol described in Souza *et al.* (2011). The quantification of methane and hydrogen sulfide in the waste gas were performed, respectively, via gas chromatography and a portable analyzer (Odalog®, range 1 to 2000 ppm).

Table 1: Operational phases of the experiments with the dissipation chamber.

Operational phases	Exhaustion rate ($L.min^{-1}$)	Exhaustion time (min)	Number of air renovations* ($renews.h^{-1}$)	Free drop height (m)	Chamber volume (L)	Hydraulic loading rate ($m^3.m^{-2}.min^{-1}$)
1	1.6	5	12	1.0	8	0.132
2	1.6	2.5	24	0.5	4	0.132
3	1.2	3.3	18	0.5	4	0.132
4	0.8	5	12	0.5	4	0.132

(*) refers to headspace inside the dissipation chamber unit

RESULTS

Stripping Device

Figures 1(a) and 1(b) present, respectively, the concentrations of dissolved methane (before and after the stripping device) and the respective removal efficiencies. For all three operational phases, statistically different concentrations were observed before and after the stripping device (Figure 1(a)), confirming the removal of dissolved methane, from around 15 to approximately 10 mg.L^{-1} (median values). In relation to the removal efficiencies (Figure 1(b)), the results showed an enormous dispersion, but the median removal was about the same for all phases (around 30%).These removal efficiencies are about three times lower than results obtained by Luo (2014) using membranes; however, other factors should be taken into account when comparing both techniques, in particular the costs. No statistical differences between phases were observed (non-parametric method, Kruskal-Wallis, independent samples, with significance level of 5%), meaning that the higher air injection rates tested during phases 1 and 2 (213 and 160 L.m^{-3}.min^{-1}, respectively) did not affect the dissolved methane removal efficiency. Indeed, some phenomena could be occurring and this should be better explained. New experiments have been planned, testing other operational parameters, aiming at the establishment of a proper relationship between air injection rate and methane removal.

The lower air injection rate practiced during phase 3 (107 L.m^{-3}.min^{-1}) resulted in a lower methane dilution measured in the headspace above the liquid surface of the settler compartment (Figure 2). In the headspace, the median methane concentrations were around 1% for phase 3, against 0.5% for phases 1 and 2 (Figure 2). However, no statistical differences between phases were observed (non-parametric method, Kruskal-Wallis, independent samples, with significance level of 5%).

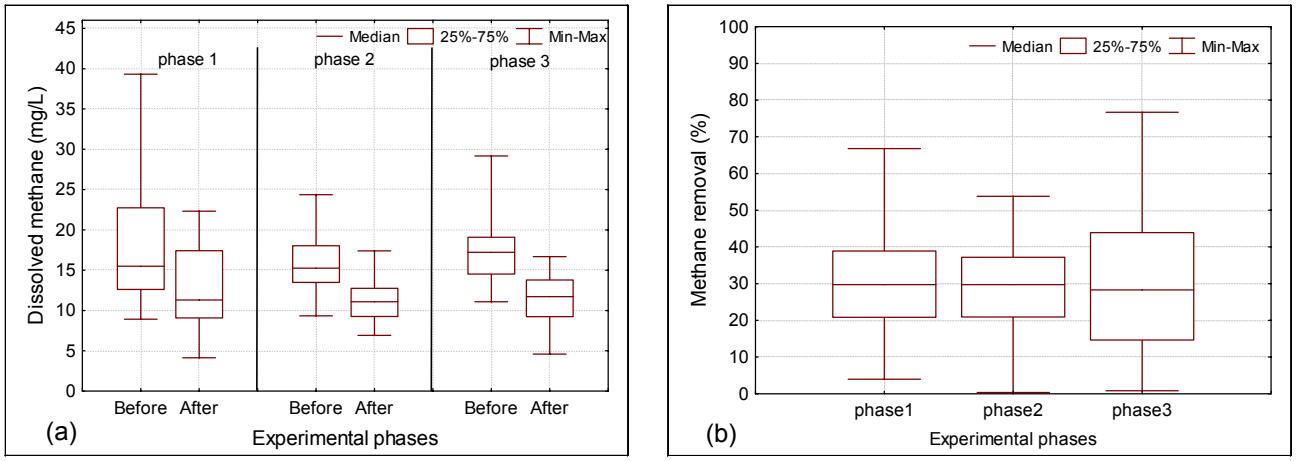

Figure 1: Results obtained with the stripping unit: (a) dissolved methane concentrations before and after the stripping device, (b) methane removal efficiencies.

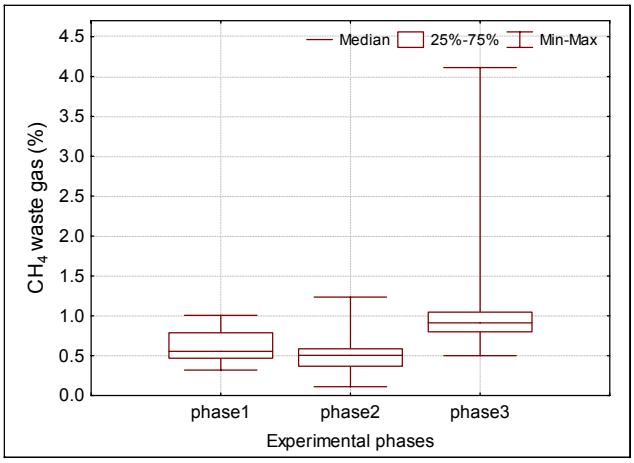

Figure 2: Results obtained with the stripping unit: methane concentrations in the waste gas.

Figures 3(a) and 3(b) present, respectively, the concentrations of dissolved sulfide (before and after the stripping device) and the respective removal efficiencies. As for methane, statistically different concentrations were observed before and after the stripping device, for all three phases (Figure 3(a)), confirming the removal of dissolved sulfide. In relation to the removal efficiencies (Figure 3 (b)), the median values were 61, 37 and 44%, for phases 1, 2 and 3, respectively. These removal efficiencies fall below the ones reported by Khan *et al*. (2011), who applied similar techniques, like aeration of the effluent, and obtained a removal efficiency of approximately 86%. Non-parametric tests showed statistical differences between the removal efficiencies of phase 1 in relation to phases 2 and 3 (Kruskal-Wallis method, independent samples, with significance level of 5%).The higher efficiencies observed in phase 1 were related to the higher air injection rate applied (213 $L.m^{-3}.min^{-1}$), but it is possible that factors other than physical stripping took part in the sulfide removal process (such as chemical oxidation due to oxygen diffusion in the liquid), since the emission of hydrogen sulfide in the headspace above the liquid surface of the settler compartment was not proportional to the air injection rates.

The waste gas of the settler compartment presented the following median concentrations (Figure 4): 87 ppm (phase 1), 175 ppm (phase 2) and 190 ppm (phase 3). Such concentrations determined release rates higher for phase 2. Statistical differences were observed between all tested phases (by using non-parametric method, Kruskal-Wallis, independent samples, with significance level of 5%).

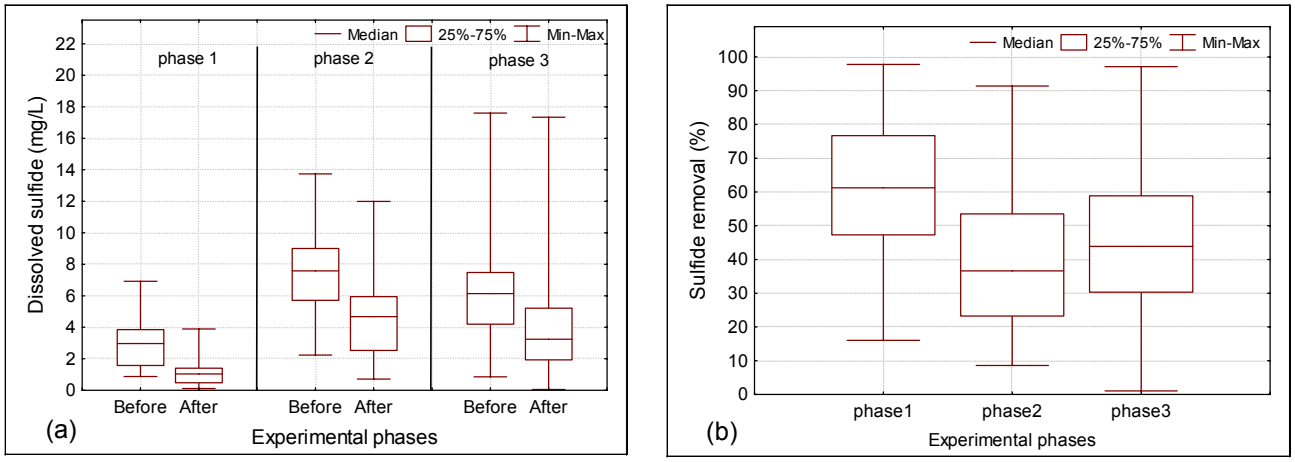

Figure 3: Results obtained with the stripping unit: (a) dissolved sulfide concentrations before and after the stripping device, (b) dissolved sulfide removal efficiencies.

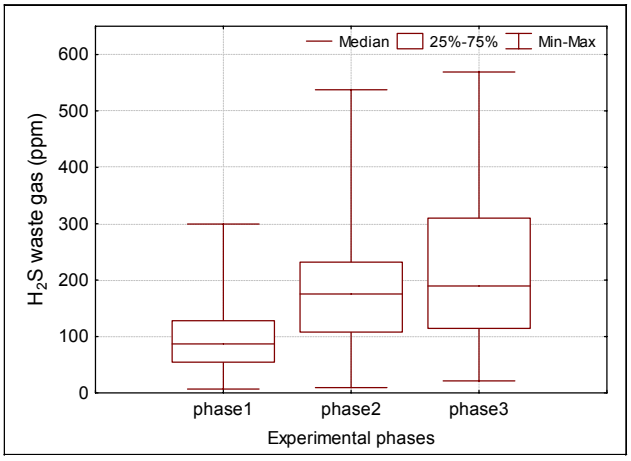

Figure 4: Results obtained with the stripping unit: hydrogen sulfide concentrations in the waste gas.

Dissipation Chamber (DC)

Figures 5(a) and 5(b) present, respectively, the concentrations of dissolved methane (before and after the DC) and the respective removal efficiencies. For this technique, high removals were noted in all operational phases, in general from 17-19 mg.L^{-1} to around 6 mg.L^{-1}, as confirmed by statistical analyses. From Figure 5(b), it can be noted that the highest methane removal efficiency was achieved in phase 1 (median of 73%), against 62-63% observed in the other phases, therefore indicating that the physical and operational conditions adopted in phase 1 (higher free drop height) favoured a greater release of dissolved methane. It can also be noticed that, for the specific free drop height adopted in phases 2, 3 and 4 (0.5 m), the different exhaustion rates applied did not affect the methane removal efficiencies, indicating that the turbulence caused by the drop inside the chamber was the governing factor. However, no statistical differences between all tested phases were found, with respect to methane removal efficiencies (non-parametric method, Kruskal-Wallis, independent samples, with significance level of 5%).

In previous studies carried out by Souza and Chernicharo (2011), also using the dissipation chamber technique, lower methane removal efficiencies were reported, in the range of 33 to 39%, but the authors tested lower hydraulic loading rates (0.048 to 0.060 m^3.m^{-2}.min^{-1}) and also a lower air renovation rate (11 h^{-1}). The free drop height was basically the same used in phases 2, 3 and 4 of the present study (0.45 m). These efficiencies are lower than the ones obtained in the present study, which were consistently above 60%, possibly due to the higher hydraulic loading rates (0.132 m^3.m^{-2}.min^{-1}) and number of air renovation rates (12 to 24 h^{-1}) applied.

As expected, the concentrations of methane in the waste gas (headspace of the DC) were higher in phases with lower exhaustion rates, phases 1 and 4 (Figure 6). However, no statistical differences between the tested phases were found with respect to the methane in the waste gas (non-parametric method, Kruskal-Wallis, independent samples, with significance level of 5%).

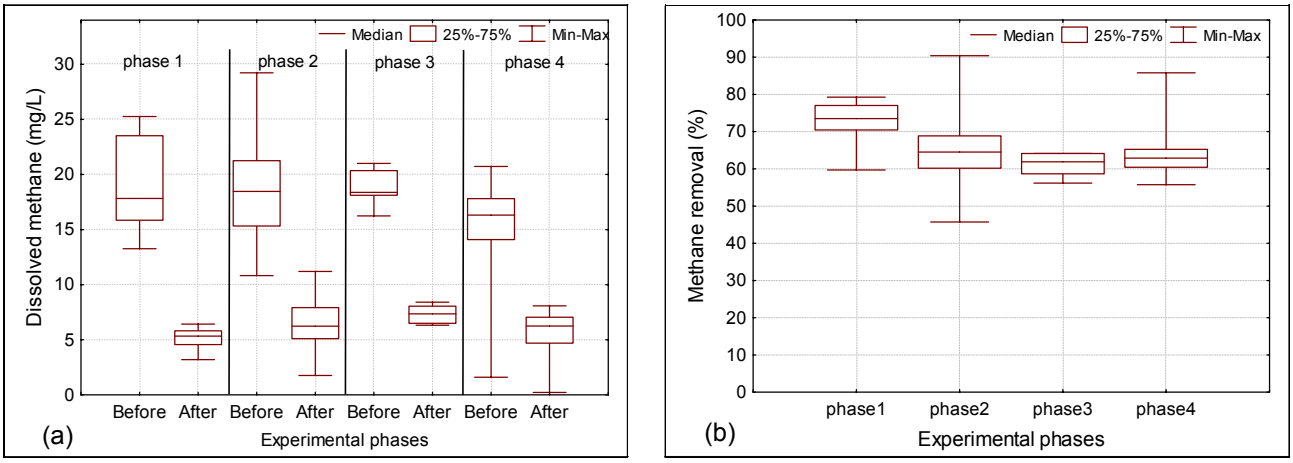

Figure 5: Results obtained with the dissipation chamber technique: (a) dissolved methane concentrations before and after the dissipation chamber, (b) methane removal efficiencies.

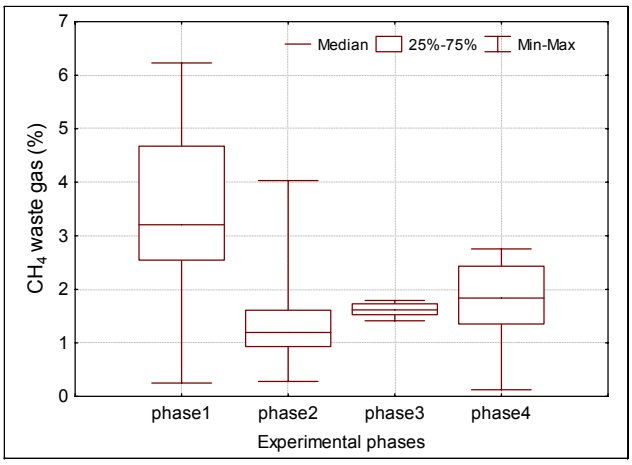

Figure 6: Results obtained with dissipation chamber technique: methane concentrations in the waste gas.

Figures 7(a) and 7(b) present, respectively, the concentrations of dissolved sulfide (before and after the DC) and the respective removal efficiencies. The median concentrations after the DC were lower than 5 $mg.L^{-1}$, however with well-scattered results, notably in phase 4, possibly associated with the big variations also detected before the DC. In relation to the removal efficiencies (Figure 7(b)), it can be noted that the highest sulfide removal efficiency was achieved in phase 1 (median of 97%), again indicating that the higher free drop height adopted in phase 1 (1.10 m) favoured the H_2S release and sulfide oxidation processes. Very high efficiencies were also observed in phases 2 and 3 (median values of 77 and 80%, respectively), while the lowest efficiency was detected in phase 4 (median value of 57%). In this last phase, the lower drop height (0.5 m), associated with lowest exhaustion rate (12 $renews.h^{-1}$), minimized the effects of release and oxidation of sulfides. Statistical analyses support the efficiency differences detected between phases 1 and 2 and phases 1 and 4 (non-parametric method, Kruskal-Wallis, independent samples, with significance level of 5%). The higher efficiencies obtained with the DC technique in the present research (around 80%) are comparable to the ones reported by Kobayashi (1983), which ranged between 81 and 95%, using however the biochemical technique (photosynthetic bacteria) for dissolved sulfide removal. The efficiencies of the present study are also much higher than the ones obtained by Krayzelova *et al.* (2014), with the micro aeration technique, of around 16%, and by Souza (2010), with the dissipation chamber technique, of around 40%, using however different operational conditions: free drop height = 0.45 m; number of renovations = 11 h^{-1}; and hydraulic loading rates varying between 0.048-0.060 $m^3.m^{-2}.min^{-1}$.

In addition, analyses of H_2S in the waste gas indicated concentrations varying from 100 to 500 ppm (Figure 8), confirming the release of part of the dissolved sulfide to the headspace of the DC. Regarding statistical analysis for hydrogen sulfide concentration in the waste gas, differences were detected only for phase 1 in relation to the other phases (non-parametric method, Kruskal-Wallis, independent samples, with significance level of 5%).

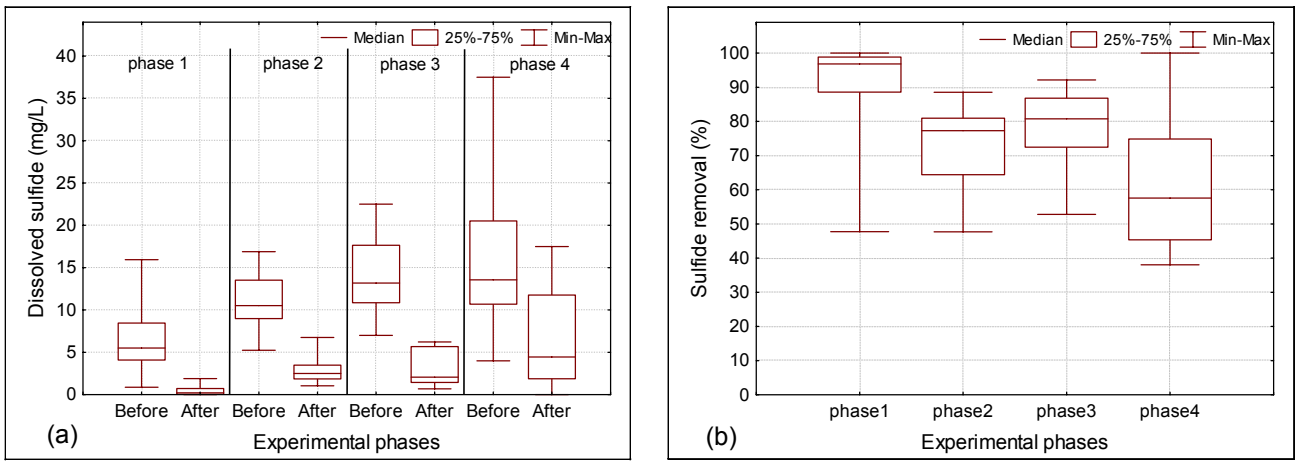

Figure 7: Results obtained with the dissipation chamber technique: (a) sulfide concentrations before and after the dissipation chamber, (b) sulfide removal efficiencies.

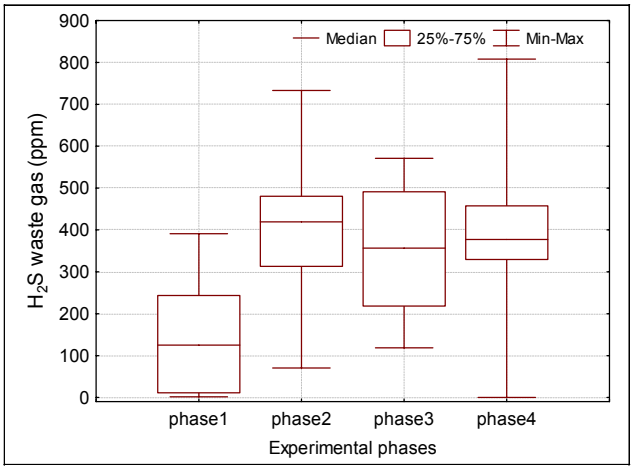

Figure 8: Results obtained with the dissipation chamber technique: hydrogen sulfide concentrations in the waste gas.

Management of the Waste Gases

In both tested techniques, the management of the waste gases is necessary after their generation. From the point of view of odour control, the physical, chemical and biological treatment methods have been extensively used for H_2S removal from waste gases emitted in wastewater treatment plants (Allen and Yang, 1992; Yang and Allen, 1994; Kohl and Nielsen, 1997; Kennes and Veiga, 2001; WEF, 2004). Notably, biological techniques such as biofilters and biotrickling filters have been shown to be very appropriate alternatives for the reduction of odorous compounds from waste gases generated in anaerobic reactors treating domestic wastewater, since the main odorant compound of concern, H_2S, is usually present in low concentrations (0-500 ppm), which is the ideal range for good biofiltration performance (Chernicharo, 2010).

Nevertheless, since the supersaturation of methane in the effluent of anaerobic reactors is an emerging issue, techniques for the proper management and control of waste gases containing methane are still under development. The studies so far have basically focused on improving the post-treatment of the anaerobic effluents, aiming to promote the biological oxidation of dissolved methane (Hatamoto *et al*., 2010; Matsuura *et al*., 2010; Hatamoto *et al*., 2011). Flaring, incineration and energy recovery could be considered, but only if the waste gases are concentrated, for example, by membrane separation processes (Bandara *et al*., 2011), dissipation chamber (this article) or by mixing gas streams rich in CH_4 (eg: biogas). However, these treatment techniques can only be economically viable when the amount of gas stream to be treated exceeds 10–15 $m^3\ h^{-1}$, and if the stream CH_4 concentration remains greater than $20\%_{v/v}$ (Nikiema *et al*., 2007). If data obtained in this study (including biogas production - data not shown) are used, the mixture of biogas with the residual gas flow obtained with the dissipation technique would result in a dilution of 10 to 20-fold. Thus, while the content of hydrogen sulfide would have an important reduction, to around 500 ppm, the methane content would drop to values as low as 6% in the mixture of biogas and waste gas, posing serious difficulties and technical problems, including risks of an explosive atmosphere within the range of 5 to 15% CH_4 (Noyola *et al.* 2006). On the other hand, in research related to landfills, coal mining and piggery, there are many studies on biofiltration of CH_4 at low concentrations (250-50,000 ppm_v), since in these fields problems related to greenhouse gas emissions are well known (Sly *et al*., 1993; Melse and Vander Werf, 2005; Gebert and Gröngröft, 2006; Nikiema *et al*., 2007; Park *et al*., 2009). However, we did not find in the literature any study regarding the removal of CH_4 from waste gases generated in anaerobic reactors used for the treatment of domestic wastewater, possibly because of the different requirements for the biofiltration of CH_4 in relation to odorant compound biofiltration and because of CH_4 mass-transfer limitatios in biofilms, which often reduce the abatement potential or lead to an empty bed residence time (EBRT) extremely high. In this sense, a deeper knowledge on biofiltration of CH_4 at low concentrations is required, in order to identify the conditions that allow the combined biofiltration with H_2S.

CONCLUSIONS

- Only low or intermediate removal efficiencies of dissolved methane and sulfide were accomplished with the stripping technique: around 30% for methane and in the range of 40 to 60% for hydrogen sulfide, depending on the air injection rate applied.
- Very promising results were obtained with the dissipation chamber technique, with removal efficiencies consistently above 60% being observed for dissolved methane and dissolved sulfide, even at low exhaustion rates. For the best operation condition (free drop height of 1.0 m and 12 $renews.h^{-1}$), median removal efficiencies of 73 and 97% were observed for dissolved methane and dissolved sulfide, respectively.
- Based on the characteristics of the waste gas produced by the dissipation technique, mixing with the biogas stream could result in a high dilution, not allowing flaring, incineration and energy recovery from the mixture of biogas and waste gas, unless a very low exhaustion rate is applied in the dissipation chamber. If a waste gas with low methane concentration (below $20\%_{v/v}$) is produced, its treatment using biofilters or biotrickling filters should be considered.

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