Mitigation of dissolved methane and sulfide in the effluent of anaerobic reactors treating sewage: a management framework

Centeno Mora, E. *, Souza, C.L., Bressani-Ribeiro, T.**, Chernicharo, C.A.L. ****

* University of Costa Rica, Civil Engineering School and Centre of Research of Sustainable Development, San José, Costa Rica. erick.centenomora@ucr.ac.cr. ** Federal University of Minas Gerais, Sanitary and Environmental Department, Belo Horizonte, Brazil. claudio@desa.ufmg.br; thiagobressani@ufmg.br; calemos@desa.ufmg.br.

Highlights:

- A conceptual framework is proposed for effective management of dissolved methane and sulfide in anaerobic reactor effluents.
- The mitigation techniques were categorized based on literature review and empirical experimentation.
- An original decision flowchart to select suitable mitigation strategies based on treatment plant scale is proposed.

Keywords: dissolved gases; municipal wastewater; technology selection.

INTRODUCTION

Anaerobic sewage treatment in warm climate regions is a consolidated practice in many countries such as Brazil, Colombia, Egypt, Ghana, India, and others, in which upflow anaerobic sludge blanket (UASB) reactors are widely used (Chernicharo & Bressani, 2019). In addition, it is a current topic of research in subtropical regions with lower temperatures, in which anaerobic membrane bioreactors are preferred (van Lier et al., 2019). In this regard, mainstream anaerobic digestion of sewage can be considered as a mature technology, with many advantages over more traditional aerobic processes (e.g., activated sludge), such as lower sludge production, biogas generation, null energy consumption for the biological treatment and lower operating and maintenance costs, among others (Chernicharo & Bressani, 2019).

However, the anaerobic treatment of sewage still has constraints that hinder its more extensive application. Among them, dissolved methane and sulfide in the anaerobic effluent have been extensively studied in the last years (Centeno Mora et al., 2020). The presence of these gases in the anaerobic effluent has harmful consequences, particularly when they are emitted to the atmosphere. In the case of dissolved methane, it represents *i)* loss of energy (30-40% of the produced CH_4 is lost dissolved in the liquid phase, according to Souza et al. (2011)); *ii)* increase in the carbon footprint, considering that CH_4 has a global warming potential up to 25-28 times that of CO_2; and *iii)* a safety risk when this CH_4 is blended with atmospheric oxygen and its concentration is in the flammable range (e.g., between 5%v/v and 15%v/v). In the case of sulfide, its emission can produce corrosion in the wastewater treatment plant (WWTP) infrastructure and odour nuisance in the WWTP neighbourhood.

Different mitigation strategies and techniques have been tested and reported in the literature for the mitigation of dissolved gases (i.e., CH_4 and H_2S) contained in anaerobic reactor effluents (Centeno Mora et al., 2020): membrane contactors, simplified and packed chambers, vacuum chambers, downflow hanging sponge reactors, oxidation in the biological post-treatment unit, among others. These management strategies have different technology readiness levels (TRL), treatment objectives (e.g., destruction of these compounds, or its recovery for a further beneficial use), and applicability extend. Furthermore, there is a notable scarcity of decision-making tools available in the literature.

In this regard, this abstract proposes a conceptual framework for effectively managing dissolved gases such as CH_4 (D-CH_4) and H_2S (D-H_2S) in the effluent of anaerobic reactors treating sewage. The primary objective is to provide guidance in the decision-making process during the selection of the most suitable mitigation strategies to address dissolved gases mitigation.

METHODOLOGY

A literature review was performed to identify the main desorption and treatment techniques which have been experimentally tested for the mitigation or recovery of D-CH_4 and D-H_2S in the effluent of anaerobic reactors. These techniques were categorized depending on the mitigation strategies reported in the literature, as follows:

A. Desorption from the anaerobic effluent to a waste gas for its further oxidation.

B. Desorption from the anaerobic effluent to a CH_4-rich recovered gas which can be energetically used.

C. Direct oxidation/destruction of the dissolved gases in the liquid post-treatment unit.

D. Use of these dissolved gases (especially CH_4) for a biological process in the liquid post-treatment unit.

Later, a decision flowsheet to select the most appropriate mitigation strategy for an anaerobic-based municipal WWTP, depending on its scale, was proposed.

RESULTS AND CONCLUSIONS

Figure 1 shows the proposed classification for the different reported techniques for the D-CH_4 and D-H_2S mitigation in anaerobic-based municipal WWTPs, and **Table 1** presents complementary data for the considered techniques, according to the reported literature.

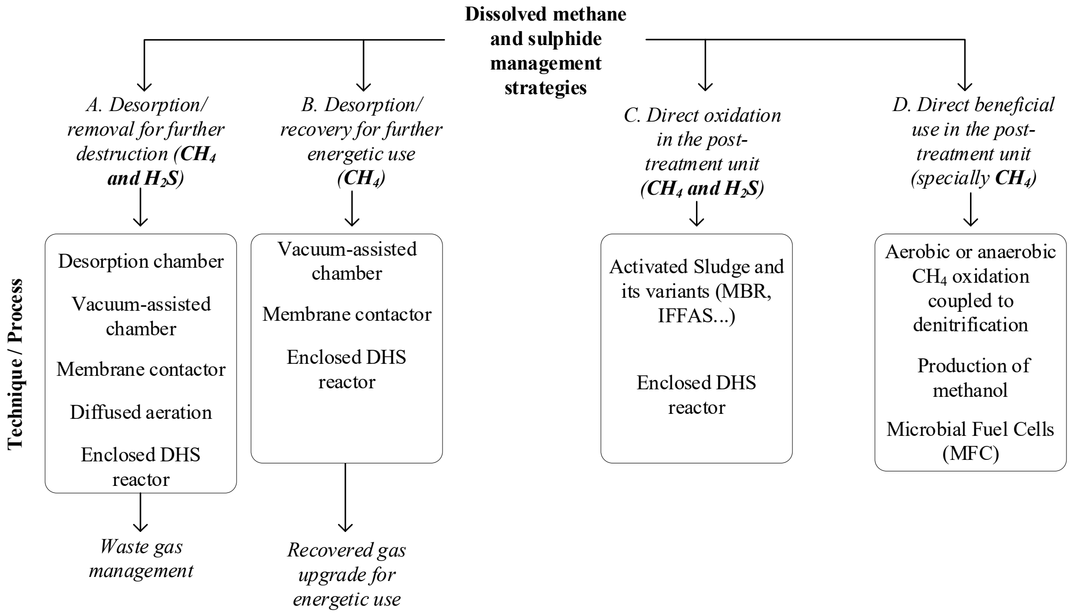


Figure 1. Strategies to deal with dissolved methane and sulfide in anaerobic reactors treating sewage.

Table 1. Main characteristics of the available strategies to deal with dissolved methane and sulfide.

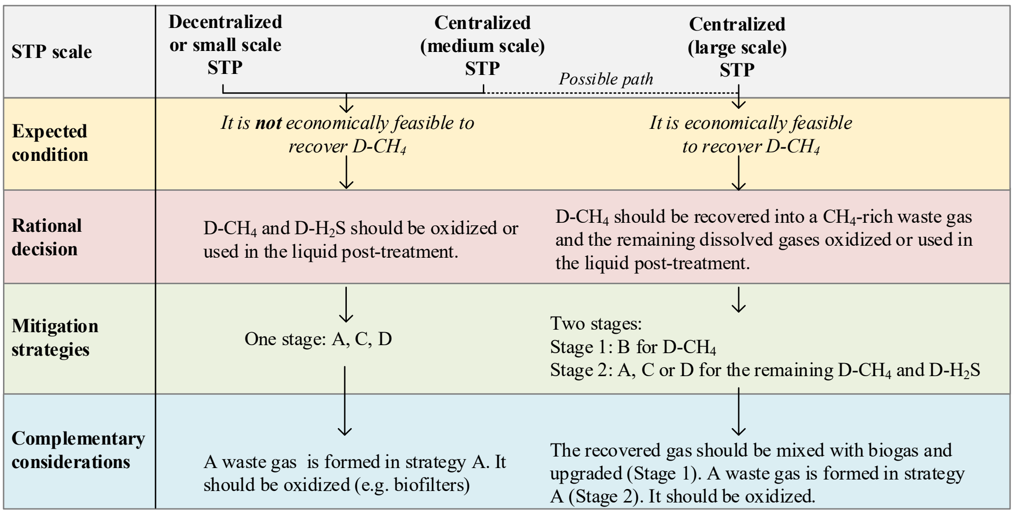
Technique	Compatible strategies [1]	D-CH_4 removal efficiency	H_2S removal efficiency	Observations
Desorption chamber	A	Up to 85%	Up to 80-90%	Full-scale. Simplified or packed media. A waste gas is generated.
Vacuum-assisted chamber	A, B	Up to 80% and 94% in one stage and three stages, respectively.	Approx. 50% in one stage, and 88% in three stages and pH adjustment.	Commercial prototype available. A CH_4-rich gas can be recovered.
Membrane contactor	A, B	Up to 99%	Up to 100% when air is used as sweeping gas.	Pilot scale. A CH_4-rich gas can be recovered.
Diffused aeration in an independent tank	A	Not reported	71-77%	Lab-scale.
Downflow hanging sponge (DHS) enclosed reactor	A, B, C	Up to 99%	Up to 100%	Pilot scale. Biological system. Two units-in-series.
Activated sludge reactor and its variants	C	Up to 85%	Up to 100%	Conventional activated sludge (full-scale), MBR (pilot-scale), IFAS (pilot-scale).
Aerobic or anaerobic CH_4 oxidation coupled to denitrification	D	Up to 95%	Up to 100% for the aerobic pathway.	Lab-scale. CH_4 or the residues from its oxidation are used as substrate / electron donors.
Microbial Fuel Cell (MFC)	D	Up to 85%	Not reported	Lab-scale. Electricity can be generated.

[1]: Strategies definition: A. Desorption from the anaerobic effluent to a waste gas for its further oxidation; B. Desorption from the anaerobic effluent to a CH_4-rich recovered gas which can be energetically used; C: Direct oxidation/destruction of the dissolved gases in the liquid post-treatment unit; D: Use of these dissolved gases (especially CH_4) for a biological process in the liquid post-treatment unit.

Adapted from Centeno Mora et al. (2020) and Centeno Mora et al. (2024)

As shown in **Figure 1** and **Table 1**, the considered mitigation techniques have been experimentally tested at multiple scales (from laboratory to full-scale), and they can be used in different mitigation strategies. For example, membrane contactors can be used for the desorption of dissolved gas (transfer to a waste gas) when they are operated at high gas-to-liquid (G/L) ratios (i.e., Strategy A), or for the recovery of CH_4 in a concentrated gas (Strategy B) when they are operated with vacuum or at very low G/L ratios (Centeno Mora et al., 2023). Expected removal efficiencies for D-CH_4 and D-H_2S can be as elevated as 100%, depending on the technique and the operating conditions.

Figure 2 presents the decision flowsheet proposed for the selection of the D-CH_4 and D-H_2S mitigation strategy.



STP scale	Decentralized or small scale STP Centralized (medium scale) STP	Possible path Centralized (large scale) STP
Expected condition	*It is **not** economically feasible to recover D-CH_4*	*It is economically feasible to recover D-CH_4*
Rational decision	D-CH_4 and D-H_2S should be oxidized or used in the liquid post-treatment.	D-CH_4 should be recovered into a CH_4-rich waste gas and the remaining dissolved gases oxidized or used in the liquid post-treatment.
Mitigation strategies	One stage: A, C, D	Two stages: Stage 1: B for D-CH_4 Stage 2: A, C or D for the remaining D-CH_4 and D-H_2S
Complementary considerations	A waste gas is formed in strategy A. It should be oxidized (e.g. biofilters)	The recovered gas should be mixed with biogas and upgraded (Stage 1). A waste gas is formed in strategy A (Stage 2). It should be oxidized.

Figure 2. Flowsheet for the selection of the mitigation strategies for D-CH_4 and D-H_2S in the effluent of anaerobic reactors treating sewage.

Figure 2 shows that for small or decentralized municipal WWTPs, in which the recovery of D-CH$_4$ into a concentrated gas is not feasible (the mass of CH$_4$ does not compensate for the cost incurred in its recovery and upgrade), an oxidation of CH$_4$ and H$_2$S strategy in one stage should be considered. This can be performed after their desorption from the liquid phase (Strategy A), or directly in the liquid post-treatment (Strategies C or D, if its beneficial use for denitrification is considered). For larger WWTPs, in which D-CH$_4$ recovery is economically feasible to be blended with biogas (increasing the energy potential of the anaerobic-based municipal WWTPs), two stages are proposed. The first stage should consider the recovery of D-CH$_4$ (Strategy B), whereas the second stage would focus on the oxidation/destruction/beneficial use of the remaining D-CH$_4$ and D-H$_2$S (Strategies A, C or D). For medium scale WWTPs, a more detailed analysis of cost/benefit should be performed to conclude on the D-CH$_4$ recovery feasibility.

The exact threshold of D-CH$_4$ recovery feasibility for each municipal WWTP scale has not been already defined, and it should vary for every country or region, depending on parameters such as the energy cost, considered technique, capital and operating costs, existence of a carbon market, among others.

In conclusion, the proposed scheme allows a more rational selection of the mitigation strategy for the dissolved methane and sulfide in anaerobic based municipal WWTPs.

ACKNOWLEDGMENTS

The authors want to acknowledge the *Vicerrectoría de Investigación* of the University of Costa Rica for the financial support to develop the research projects C3608 and C4046, related to this abstract. In addition, the following Brazilian institutions are acknowledged: Fundação de Amparo à Pesquisa do Estado de Minas Gerais – FAPEMIG; Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq; Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES - Finance Code 001

REFERENCES

Centeno Mora, E., Souza, C. L., Bressani-Ribeiro, T., & Chernicharo, C. A. L. (2024). Dissolved methane. In *Anaerobic Treatment of Domestic Wastewater: present status and potentialities* (pp. 207–236). IWA Publishing. https://doi.org/10.2166/9781789063479_0207

Centeno Mora, E., Souza, C. L. de, Neves, T. de A., & Chernicharo, C. de L. (2023). Characterisation and perspectives of energetic use of dissolved gas recovered from anaerobic effluent with membrane contactor. *Bioresource Technology*, *367*, 128223. https://doi.org/10.1016/J.BIORTECH.2022.128223

Centeno Mora, E., Fonseca, P., Andreão, W. L., Brandt, E., Souza, C. L. De, & Chernicharo, C. A. L. (2020). Mitigation of diffuse CH4 and H2S emissions from the liquid phase of UASB-based sewage treatment plants: challenges, techniques, and perspectives. *Environmental Science and Pollution Research*, *27*(29), 35979–35992. https://doi.org/10.1007/s11356-020-08644-0

Chernicharo, C. A. L., & Bressani, T. (Eds.). (2019). *Anaerobic Reactors for Sewage Treatment: Design, Construction and Operation*. IWA Publishing. https://doi.org/10.2166/9781780409238

Souza, C. L., Chernicharo, C. A. L., & Aquino, S. F. (2011). Quantification of dissolved methane in UASB reactors treating domestic wastewater under different operating conditions. *Water Science and Technology*, *64*(11), 2259–2264. https://doi.org/10.2166/wst.2011.695

van Lier, J., Seco, A., Jefferson, B., Ersahin, M. E., & Robles, Á. (2019). *Upgrading anaerobic sewage treatment applying membranes: AnMBR and UF post filtration*.