Approaching Bioelectrochemical Systems to Real Facilities Within the Framework of CO_2 Valorization and Biogas Upgrading

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Abstract

Biogas production within wastewater treatment plants plays a decisive role in the water–energy nexus. Biogas obtained from sewage sludge digestion can be converted into biomethane as CO_2 emissions are reduced. Techno-economic assessment of the process is presented. Anodic valorization through chlorine production is performed. Potential impacts of this technology in a wastewater treatment plant are discussed.

Keywords

Microbial electrosynthesis • Biomethane • Carbon capture and utilization • Circular economy • Anodic valorization

1 Introduction

Carbon dioxide (CO_2) concentration in the atmosphere is rising as energy demand also does (EPA 2018; Hamiche et al. 2016). Meanwhile, it may suppose some effects to other interconnected critical resources such as water. In this sense, wastewater treatment plants (WWTPs) are an example of water–energy–CO_2 nexus as these facilities use energy-intensive processes and produce CO_2-saturated effluents to deal with water treatment. Biogas is the main product obtained from the anaerobic digestion (AD) of organic residues, which typically contains about 65% of methane (CH_4) and 35% of CO_2. Valorization of biogas in WWTP is carried out in cogeneration engines to obtain heat and electricity simultaneously (Appels et al. 2011). In order to increment biomethane content as a sustainable and affordable biofuel, nowadays biogas upgrading technologies are getting more interest (European Biogas Association 2013). However, some of them such as water scrubbing release high amounts of CO_2 to the atmosphere (Rotunno et al. 2017), increasing the global warming potential (GWP). Recently, the exploitation of CO_2 using bioelectrochemical system (BES) has been presented as an alternative to increase biomethane production and reduce CO_2 emissions from biogas upgrading (Batlle-Vilanova et al. 2015). This system was tested in treating both synthetic and real effluents to demonstrate the technical feasibility. Here, a techno-economic assessment, valorization alternatives through the production of chlorine compounds, and foreseen impacts that the application of both technologies would have in a case scenario are also analyzed and discussed.

2 Materials and Methods

A two-chamber tubular BES separated by a cation exchange membrane (CMI-1875T) was constructed at 25 ± 1 ºC. Graphite granules were used as the cathode (working electrode), while Ti-MMO was used as anode (counter electrode) and Ag/AgCl electrode was placed in the cathode chamber (−0.8 V vs. SHE) and used as a reference electrode. The system was operated in continuous flow (60 mL h^{-1}), and as the net liquid volume of the cathode and the anode was 0.3 and 0.5 L, the resulting hydraulic retention time (HRT) was 4.9 and 8.3 h, respectively. The cathode was inoculated with an enriched mixed microbial culture dominated by *Methanobacterium spp.*, first fed by the synthetic medium based on a modified ATCC1754 PETC and after 60 days with treated wastewater from a WWTP located in Lleida (Spain). In both cases, CO_2 gas (99.9%, Praxair, Spain) was used as the only carbon source to simulate the scrubber absorbent effluent after treating biogas.

On the other hand, an abiotic two-chamber H-shape BES separated by a cation exchange membrane (standard CMX

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Neosepta, Tokuyama Corp., Japan) was constructed focused on chlorine production in the anodic chamber. It consisted of a Ti-MMO electrode operated at +1.4 V versus SHE (Du et al. 2015), while graphite granules were used as a cathode electrode and Ag/AgCl electrode was used as a reference in the anodic chamber. The net liquid volume of the anode and the cathode was in both cases 0.12 L. The compartments were operated with a continuous flow of 15 mL h^{-1}, resulting in an HRT of 8 h. In this case, NaCl was added to the anode medium in different concentrations to assess chlorine formation. An overview of the whole process is exposed in Fig. 1.

Gas and liquid samples were periodically taken to measure pH, electric conductivity, and the production of organic compounds; free chlorine; and quantify gas production. Coulombic efficiency (CE) was also calculated to perform a techno-economic assessment and evaluate the impact of this technology in a real WWTP.

3 Results and Discussion

The proposed BES configuration was able to convert the CO_2 from biogas to biomethane. The CE was around 80% when the synthetic medium was used and diminished to 70% and when it was changed to real wastewater. This can be related to the low electric conductivity of the treated wastewater, which could have caused an osmotic stress period for the microorganisms and an increase of the overpotential of the system. These conditions led to a decrease of the intensity demand of the system. Moreover, CH_4 production rate also dropped to 38 mmol L^{-1} d^{-1} using real wastewater, but the process was still feasible. In addition, the gas composition was maintained at approximately 78% of CH_4 and the CO_2 transformation efficiency of 30% remained unaltered, showing the potential of BES to use real effluents for the transformation of CO_2 into CH_4.

The techno-economic assessment revealed the need to valorize also the anodic process of the BES, so the abiotic chlorine production was studied to be included in the process flow diagram of WWTPs. It determined a CE threshold minimum value of 13% to make the process economically viable, which was achieved when reaching a chlorine concentration of 60 mg L^{-1}. However, the utilization of more specific electrodes for chlorine production would lead to an increase of CE values with lower NaCl input. This product entails an added economic value of the process and rises the application potential of this technology in the current circular economy framework.

4 Conclusion

The feasibility of using water scrubbing-like effluents obtained during biogas upgrading as a CO_2 source in BES was demonstrated. In the real case scenario approach exposed in this study, this system may produce an extra 41 Nm^3/d of biomethane, which supposes an increase of 17.5% of CH_4 and a decrease up to 42.8% of CO_2 content in the biogas composition. Moreover, chlorine produced may be used as a disinfection agent in the tertiary treatment of WWTPs, reinforcing the industrial application of this technology. Further efforts must be focused on coupling both reactions in the same system with high product formation rates and enough CE to make the technology a viable and competitive option. Otherwise, the use of renewable energy is also an attractive option to reduce the operation costs of the system.

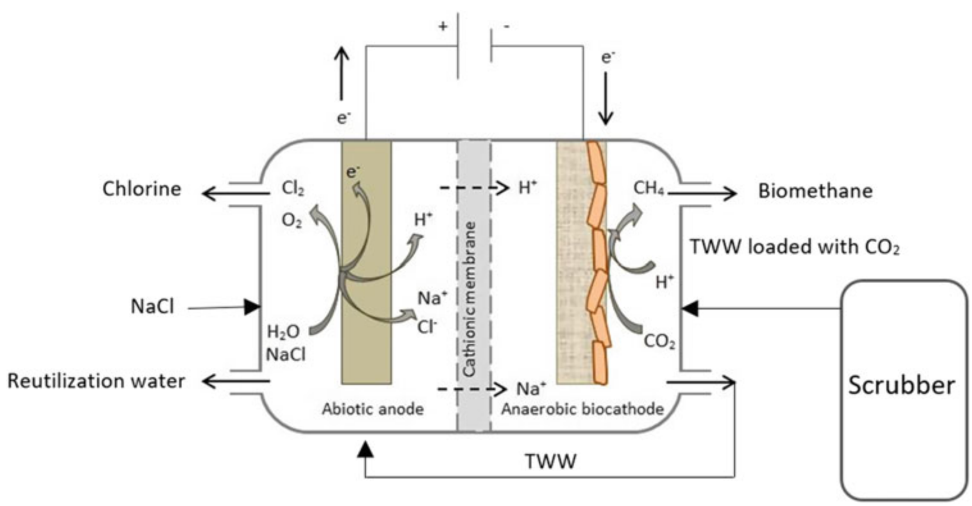

Fig. 1 BES implementation proposal within WWTP for biogas upgrading and chlorine production

References

Appels, L., Lauwers, J., Degrève, J., Helsen, L., Lievens, B., Willems, K. … Dewil, R. (2011). Anaerobic digestion in global bio-energy production: Potential and research challenges. *Renewable and Sustainable Energy Reviews*, *15*(9), 4295–4301. https://doi.org/10.1016/j.rser.2011.07.121.

Batlle-Vilanova, P., Puig, S., Gonzalez-Olmos, R., Vilajeliu-Pons, A., Balaguer, M. D., & Colprim, J. (2015). Deciphering the electron transfer mechanisms for biogas upgrading to biomethane within a mixed culture biocathode. *RSC Advances, 5*(64), 52243–52251. https://doi.org/10.1039/C5RA09039C.

Du, J., Chen, Z., Chen, C., & Meyer, T. J. (2015). A half-reaction alternative to water oxidation: Chloride oxidation to chlorine catalyzed by silver ion. *Journal of the American Chemical Society, 137*(9), 3193–3196. https://doi.org/10.1021/jacs.5b00037.

EPA. (2018). *Inventory of U.S. greenhouse gas emissions and sinks: 1990–2016*.

European Biogas Association. (2013). *Green gas grid. Proposal for a European biomethane roadmap*. Brussels, Belgium.

Hamiche, A. M., Stambouli, A. B., & Flazi, S. (2016). A review of the water-energy nexus. *Renewable and Sustainable Energy Reviews, 65,* 319–331. https://doi.org/10.1016/j.rser.2016.07.020.

Rotunno, P., Lanzini, A., & Leone, P. (2017). Energy and economic analysis of a water scrubbing based biogas upgrading process for biomethane injection into the gas grid or use as transportation fuel. *Renewable Energy, 102,* 417–432. https://doi.org/10.1016/j.renene.2016.10.062.