Role of bioelectrochemical systems in anaerobic methanation yield improvement

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Abstract

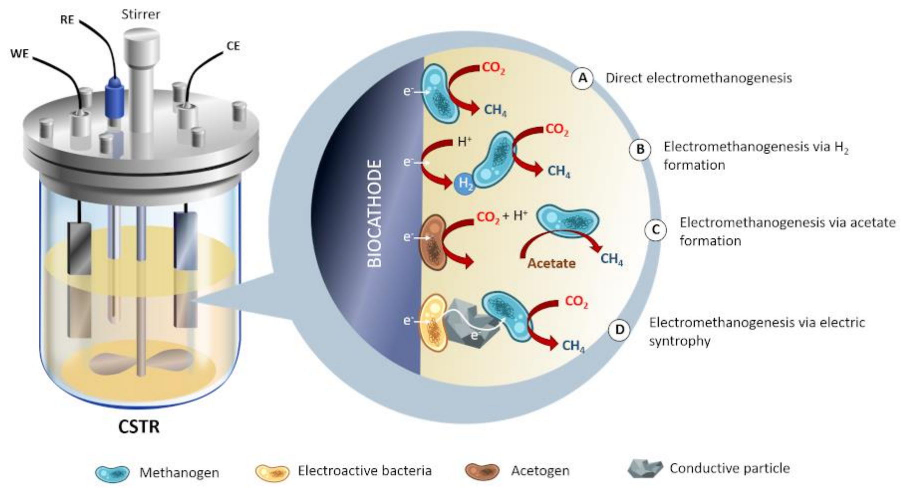
Anaerobic digestion (AD) is widely used for the treatment of municipal and industrial liquid wastes, process sludges and other biomasses (Cecconet et al 2022), and has attracted much attention due to relatively low capital and operational expenditures compared to other organics degradation processes in environmental remediation; in addition, it generates a biogas made up of 60–70% methane that can be further converted into electrical or thermal energy. The ongoing transition from fossil to renewable fuel-based economy confirms the central role of AD in circular economy-based waste processing (Callegari et al 2020); however, for enhanced sustainability, improved and consistent production of high quality biogas (i.e. high methane content) is needed (Li et al 2019).

Currently, AD's biogas must be used onsite with special generators, under reduced efficiency and substantial use limitations due to its composition. CO_2 must be removed from biogas before it can be stored or injected in national gas pipelines, as in untreated form it does not liquefy well, due to its CO2 content that may also induce storage tanks/pipes corrosion when combined with residual saturation water. Biogas conversion to biomethane (i.e. a gas fuel with > 96% CH_4 by volume, $H_2 \leq 2\%$ vol) will increase the original calorific value of 28–39 MJ/Nm, up to 51 MJ/Nm, making it compatible with natural gas standards (as per regulation EN 16723), with the possibility of a wider application range (fuels, industrial transformation uses).

Several studies were conducted to developing and validating technologies for AD improvement with regard to increased methanation efficiency (Dang et al 2016). Biomethanation normally occurs by converting biogas' carbon dioxide to methane by means of catalytic addition, allowing to increase the final volume of biomethane by approximately 80% from the same quantity of biomass, with addition of externally provided hydrogen. The process however, is expensive (H_2 is usually generated by water electrolysis) and the lesser the CO_2 in the biogas, the lower effort/cost is needed to purify it.

Bioelectrochemical Systems (BESs), and addition of Electrically Conductive Microparticles (ECMs) could both act as auxiliary technologies for improving biogas production in AD, as electrochemically active microorganisms catalyse CO_2 conversion into methane by direct or indirect electron transfer (DIET). Combining AD with BESs and/or ECMs could therefore accelerate organics conversion into biogas with higher methane fraction and could be a practical alternative to defray or limit biomethanation costs (De Vrieze et al. 2018; Wang et al 2021; Viggi et al 2017). Preliminary studies showed that application of small voltages to a hybrid AD/BES system could increase CH_4 production by over 2.5 times, with an energetically "richer" biogas composition (up to 98% CH_4), while improving COD removal by approximately 15%. However, issues still hinder further developments of this technology: for example, the long-term stability of bio-electrodes is still largely unexplored, as well as the influence of their configuration and deployment mode into the reactors.

This paper describes the preliminary results of an ongoing study to assess and optimize, through lab-scale testing, the impact of ECMs (iron oxides) and BES processes enhancement to AD, aimed at energy (biogas) recovery from treatment of selected sewage sludges of diverse origin.



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