SEAI National Energy Research, Development & Demonstration Funding Programme

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Development of a novel methanogenic biotechnology incorporating conductive carriers for the efficient recovery of energy from wastewater

Abstract

Generation of renewable bioenergy from wastewater through anaerobic digestion is a crucial method for confronting two of our most pressing contemporary challenges: energy generation and pollution control. According to Ireland's National Biomethane Strategy, an anaerobic digestion industry could be scaled to produce the 2030 Government target of up to 5.7 Terawatt hours (TWh) of indigenously produced biomethane. However, the efficiency of anaerobic digestion is low due to the slow growth of anaerobic microorganisms and the complex cooperation among syntrophic microorganisms. Recently, the concept of microbial niche nexus has been proposed to enrich diverse microbial communities for enhancing system resilience and stability. Furthermore, conductive materials have been shown to improve anaerobic digestion efficiency by enhancing electron transfer between syntrophs, which can be affected significantly by oxidation and reduction potentials of liquid solution and conductive materials. Therefore, the objective of this project aims to sustainably generate bioenergy from wastewater by developing a novel high-efficient anaerobic methanogenic biotechnology. The research outputs will provide solutions for simultaneous renewable energy generation and wastewater treatment, which can contribute to the sustainable development of circular bioeconomy and the mitigation of greenhouse gas (methane) emissions

Research Outcomes

(1) With two types of operational modes, continuous-flow reactors (CFRs) and sequencing batch reactors (SBRs) were operated with or without the addition of tetracycline. Tetracycline inhibited the removal of chemical oxygen demand (COD) by 23.9% in CFRs and 20.5% in SBRs, and led to the accumulation of volatile fatty acids (VFAs, mainly **propionic acid**). When CFRs and SBRs were employed along with the dosage of powdered activated carbon (PAC) to enhance tetracycline removal during anaerobic digestion of complex organic compounds. PAC increased the maximum methane production rate by 15.6% (CFRs) and 13.8% (SBRs). The presence of *Geobacter* in conjunction with the detected **ethanol** in batch experiments of CFRs suggested the potential presence of direct interspecies electron transfer, elucidating the enhanced pollutant removal of CFRs.

(2) SBR and CFR were adopted in ethanol-fed systems with or without the supplement of PAC to examine their effects on ethanol metabolic pathways. Notably, the operational mode of SBR and the presence of CO_2 facilitated ethanol metabolism towards propionate production. Moreover, SBRs exhibited superior biomass-based rates of ethanol degradation and methanogenesis, surpassing those in CFRs by 53.1% and 22.3%, respectively. Remarkably, CFRs with the extended solids retention time enriched high relative abundances of electroactive *Geobacter* of 71.7% and 70.4% under conditions with and without the addition of PAC, respectively.

(3) CFRs and SBRs were operated with sludge retention times (SRTs) of either 15 or 30 days. Complete propionate removal was achieved in reactors with a 30-day SRT, while those with a 15-day SRT showed removal percentages of only 29% to 38%.

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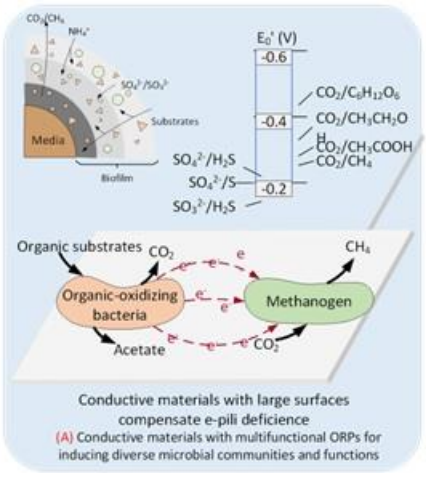
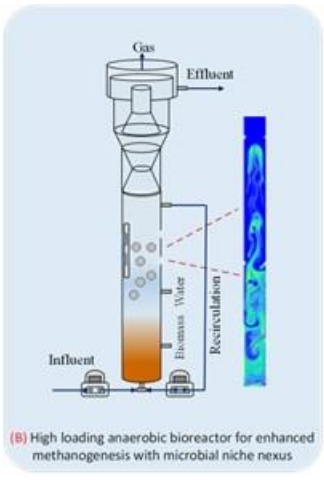
A short SRT enriched *Desulfobulbus* populations in both CFR (3.30%) and SBR (2.88%). However, *Syntrophobacter* was more prevalent with an extended SRT, as indicated by relative abundances of 0.97% in CFR and 2.18% in SBR. Therefore, propionate degradation depended mainly on *Desulfobulbus* at shorter SRTs, while *Syntrophobacter* took on a major role in propionate removal at longer SRTs.





(4) A comprehensive computational fluid dynamics model was developed for the simulation of formulated computational domains of the bioreactor. The configuration of baffle arrangement in the reactor can sustain the solid particles in the domain. In Reactor without a baffle in the centre, the particles moving up along with the gas bubbles are hindered by the baffle of collector and deviate from the path line. However, still maximum solids reach near the outlet section. On the other hand, the reactor with designing a baffle in the centre restricts the rapid movement of solid particles towards the outlet section and hence contributes to less movement of solids to the upper zone; moreover, it was observed that solids striking the central baffle improves the mixing inside the reactor through recirculation and particle to particle momentums.

Recommendations

Our project has two main outcomes: (1) regarding fundamental research, conductive materials can alleviate inhibition, electroactive microorganisms can be enriched in CFRs, and propionic acid degradation can be enhanced by adopting a high SRT; and (2) regarding technology development, mass diffusion and biomass retention can be achieved by designing baffle within bioreactors, and the incorporation of diverse microorganisms can enhance system performance. These outcomes can be applied to the Irish scenarios, such as the use of grass as the feedstock for anaerobic digestion, which can be achieved through enriching grass degradation microorganisms and acclimating ethanol metabolic pathways. For promoting anaerobic digestion, professional training and national strategies should be adopted. Especially, understanding the metabolic pathways can benefit the practice of anaerobic digestion, and professional training and system testing/monitoring should be supported by relevant programmes. In addition, systematic design should be conducted, such as the availability of feedstock should be assessed for the design of anaerobic digestion systems incorporating the life cycle assessment of materials flow, and national platform should be designed by introducing the design-build-test-learn cycle for sharing experiences.

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