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Electrochemically Enhanced Biomethanation for Methane Production from High-Organic-Load Food Waste

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ABSTRACT

Anaerobic digestion of food waste is widely recognized as an effective biological pathway for converting organic waste into methane-rich biogas while simultaneously reducing the environmental burden associated with organic waste disposal. However, treating food waste at very high organic loading (chemical oxygen demand, COD \approx 260 g/L; total solids, TS \approx 240 g/L) often results in process instability. Rapid hydrolysis and acidogenesis under these conditions promote excessive accumulation of volatile fatty acids (VFAs), leading to a decline in pH (<5) and subsequent inhibition of methanogenic microorganisms. These limitations significantly reduce methane productivity and compromise reactor's stability. Electrochemically Enhanced biomethanation has recently emerged as a promising strategy to address these challenges by enhancing extracellular electron transfer (EET) and promoting electroactive microbial pathways that facilitate the conversion of intermediate metabolites into methane.

In this study, electrochemically enhanced biomethanation of high-organic food waste was systematically investigated under multiple operational configurations, including direct substrate digestion, substrate dilution, pH adjustment using buffering agents, and a combined dilution with a pH control strategy. The experimental reactors were equipped with graphite and copper-coated graphite electrodes functioning as the anode and cathode, respectively. Electrochemical characterization of the substrate was first conducted using cyclic voltammetry (CV) to identify its redox-active behavior and determine the optimal operational potential. Based on the redox characteristics identified through CV analysis, the reactors were operated under an externally applied potential to stimulate electroactive microbial processes. In addition, electrochemical impedance spectroscopy (EIS) was performed to evaluate the interfacial electrochemical resistance of the electrode substrate system. The electrochemical observations were further correlated with conventional biochemical analyses, including total solids (TS), volatile solids (VS), chemical oxygen demand (COD), and volatile fatty acid (VFA) profiles.

The CV analysis revealed a dominant redox peak around 0.7 V, indicating a favorable potential window for enhanced microbial electron transfer and electro-assisted metabolic activity.

Accordingly, the reactors were operated at an applied potential of 0.7 V. The EIS results provided insights into key electrochemical parameters, including solution resistance (R_s) and charge transfer resistance (R_{ct}), which were strongly influenced by substrate viscosity and suspended solids concentration. Among the tested configurations, the electrode-assisted reactor treating the undiluted substrate demonstrated superior performance, achieving a biogas yield of $0.33 \text{ m}^3/\text{kg VS}_{(\text{Reduced})}$ with approximately 50% VS reduction.

The enhanced performance indicates improved VFA utilization and stabilized methanogenic activity under electrochemical stimulation. The integration of electrochemical stimulation with optimized substrate conditions enhanced electron transfer processes, improved VFA conversion, and maintained reactor stability without extensive dilution or chemical buffering. Overall, this study highlights the potential of integrating electrochemical diagnostics with electrode-assisted biomethanation to optimize high-strength food waste digestion and maximize methane recovery.

KEY WORDS

Electrochemically Enhanced Biomethanation; Electron Transfer; Food Waste; High Organic Load; Cyclic Voltammetry; Electrochemical Impedance Spectroscopy

BIOGRAPHY

Sarva Sai Nikhilesh Gantala is a PhD candidate in the BITS-RMIT cotutelle doctoral program, conducting research in Chemical and Environmental Engineering with an interdisciplinary integration of biotechnology and chemical engineering principles. His work focuses on electrobiomethanation of organic waste to enhance biomethane production efficiency through electrode-assisted anaerobic digestion systems. He holds a Bachelor of Technology in Biotechnology from GITAM University, India and a Master of Technology in Biotechnology from Andhra University, India. Through his doctoral research, he aims to develop innovative strategies for improving organic waste valorisation and renewable bioenergy generation.

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