Assessment of PVA Granules for Immobilizing Hydrogenotrophic Methanogens in Batch Biogas Upgrading Systems

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Abstract:

Power-to-Gas (PtG) strategies aim to convert surplus renewable electricity into storable energy carriers such as hydrogen (H_2) or methane (CH4). Within this framework, Power-to-Methane (PtM) offers a promising route by biologically converting H_2 and carbon dioxide (CO2) into synthetic natural gas via biomethanation (BM), driven by methanogenic archaea. Despite its sustainability, BM faces several technological limitations, including the poor solubility of H_2 and CO_2 in water, low growth rates of hydrogenotrophic methanogens, susceptibility to biomass washout, and mass transfer limitations that hinder overall process efficiency.

To overcome these constraints, this study evaluates the use of polyvinyl alcohol (PVA)-based granules to immobilize hydrogenotrophic methanogens (HM) for enhanced biogas upgrading under batch conditions. Immobilization improves biomass retention, protects microbial communities from environmental fluctuations, and enables easier handling and reuse in reactor systems.

A hydrogenotrophic microbial consortium, enriched from swine manure digesters, was encapsulated in PVA matrices at polymer-to-biomass ratios of 1:1, 2:1, and 3:1. Granules were assessed for mechanical stability, biomass leakage, methane productivity, and gas quality. The 2:1 formulation provided the best compromise between structural integrity and permeability, showing lower degradation (32.86 ± 0.27%) and biomass loss (38.82 ± 6.91%) after 70 days, while reaching 92.56% CH_4 in just 5 days.

In *in situ* biogas upgrading tests using real waste residues, HM-PVA granules combined with hydrogen injection achieved CH_4 concentrations up to 99.11% and CO_2 levels below 1%. Hydrogen uptake (0.97 $m^3\ H_2 \cdot d^{-1} \cdot m^{-3}$) and methane productivity (1.07 $m^3\ CH_2 \cdot d^{-1} \cdot m^{-3}$) outperformed hydrogen-only systems. Volatile fatty acid analysis confirmed reduced acetate accumulation, indicating improved metabolic efficiency.

Microbial community analysis revealed a robust mixed consortium dominated by strictly hydrogenotrophic archaea (*Methanobacterium species*) along with minor bacterial species, demonstrating successful encapsulation.

Overall, PVA-based immobilization offers a robust strategy for enhancing biological methanation, supporting renewable energy integration, CO_2 valorization, and circular bioeconomy initiatives.

Keywords:

Biomethanation, Hydrogenotrophic methanogens, Immobilization, Biogas upgrading, Power-to-Methane.