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Hydrodynamic pore-space alteration induced by site-extracted methanogenic Archaea: A microfluidic approach towards subsurface Geo-methanation.

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The prediction of subsurface hydrogen methanation is crucial for large-scale hydrogen storage and carbon dioxide utilization. To describe and model subsurface carbon dioxide reduction in the presence of hydrogen, a detailed understanding of substrate transport mechanisms and their impact on microbial growth in porous media is necessary. Accumulated microorganisms' impact on hydraulic properties, especially porosity and permeability, is central to access risks such as bio-clogging. This study aims to address these complexities by performing microfluidic experiments under saturated flow conditions, using a realistic microbial consortium from a pilot site in Austria and Methanobacterium formicicum, a hydrogenotrophic model species the most abundant methanogen found in the reservoir brine.
The study specifically emphasized the impact of headspace gas composition (i.e., substrate gas concentrations), total pressure, nutrient availability, and the addition of organic substrates. The goal was to unravel the effects of these factors on microbial growth and methanation rates. Microfluidic experiments involved colonizing pore spaces with microorganisms and studying their growth and hydraulic properties. Biomass accumulation was characterized using high-resolution optical time-lapse images, and intrinsic biomass permeability was quantified through numerical pore-scale simulations. Despite biomass accumulation, a distinctive channel formation was observed, vastly retaining the original permeability. Matching simulation results to experimental pressure responses revealed a biomass permeability of approximately 100 ± 50 mD in all cases. These findings have significant implications:
(1) Clogging may be prevented by the observed channel formation, which allows nutrients to reach the biomass. (2) The high intrinsic biomass permeability may allow for an advective rather than diffusive nutrient supply, which may maintain high gas conversion rates. (3) Methanobacterium formicicum shows higher growth rates and a greater impact on permeability than the consortium, which explains the field observation and can be used as a design parameter for subsurface hydrogen conversion.
While preliminary results indicate disparities in conversion rates between the microbial consortium and isolated species, independent investigations in incubated core reactors align with the simulated methane yield on the field scale and analytically determined conversion rates during the microfluidic experiments.

Keywords: Hydrogen, Geo-methanation, Archaea, Bio-reactive transport, Biofilms, Biomass permeability, Hydrodynamics, Porosity-permeability relationship

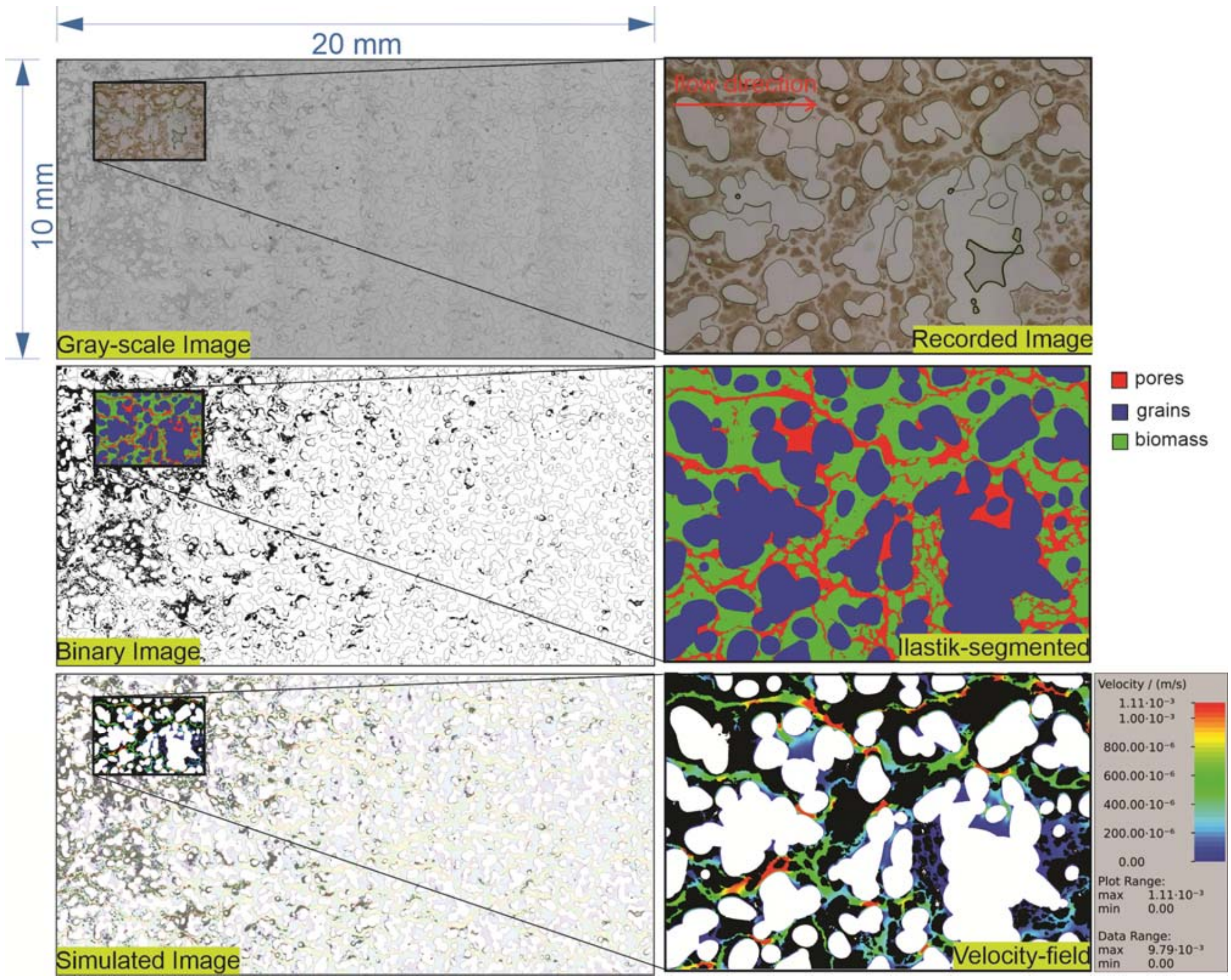

Fig.: Workflow summary: (1) Raw image recording; (2) Binarization and Segmentation; (3) Numerical Flow Simultion and Velocity-field Extraction.