Microscale dynamics of H_2, CO_2 and pH during H_2 supply to biogas reactors

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Introduction

Hydrogen produced from periodic excess of electrical energy may be added to biogas reactors where it is converted to methane that can be used in the existing energy grid. Hydrogen addition may result in CO_2 limitation and pH increase that can lead to reactor failure.

Objectives

We wanted to evaluate the microscale dynamics of CO_2, H_2, and pH when H_2 is supplied through a silicone membrane to slurry from a biogas reactor.

Methods

A mini-reactor with two compartments separated by a silicone membrane was designed (Fig. 1). The lower compartment was flushed with variable ratios of $CO_2/H_2/N_2$. An about 3-mm layer of slurry stabilized with 50-µm glass beads was placed on top of the membrane, and the headspace above the slurry was flushed with argon. Microsensors measuring H_2, CO_2 and pH were introduced from the top measuring through the slurry towards the silicone membrane.

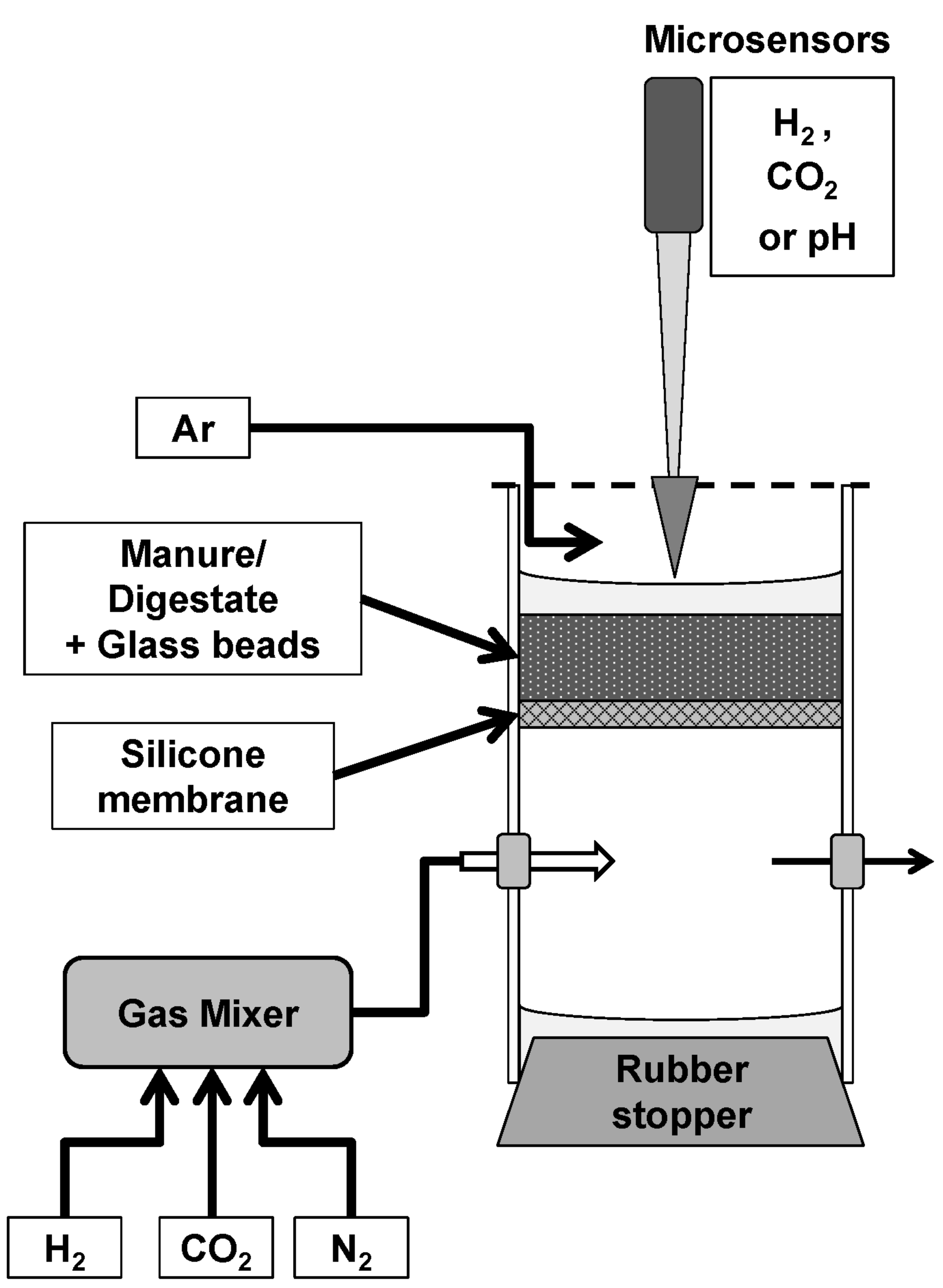

Fig. 1. Microscale membrane reactor for analysis of H_2 and CO_2 dynamics associated with H_2 feeding of biogas reactors.

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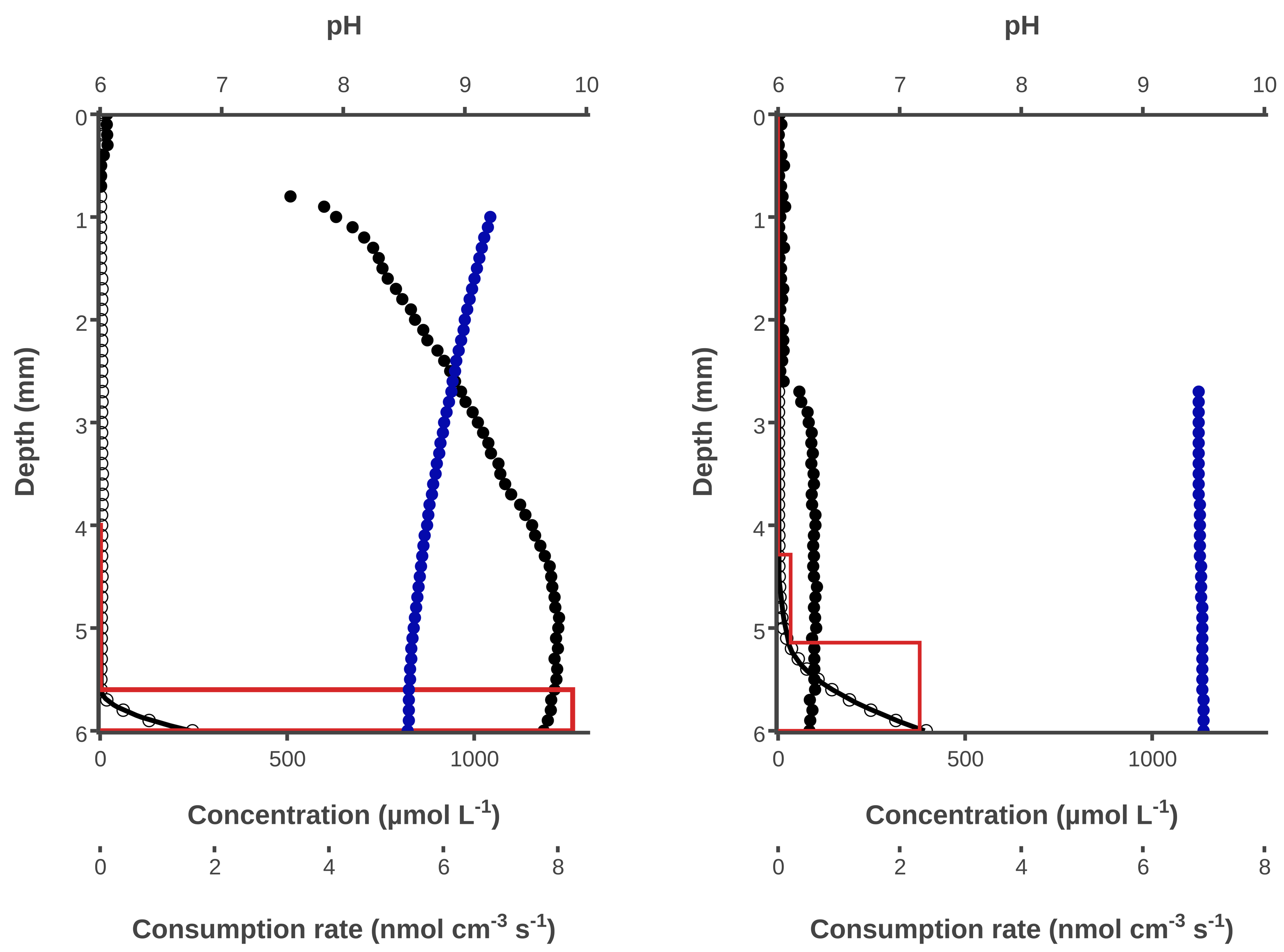

Figure 2. Left: H_2 (o), CO_2 (●), and pH (●) profiles in membrane reactor slurry 1 h after addition of the slurry while supplied with 75% H_2 and 25% N_2 below the membrane. Also shown is the modeled H_2 consumption rate (red line box). Right: Profiles in the reactor 10 h after the gas mixture was changed to 75% H_2 and 25% N_2.

Results

- H_2 was initially consumed in a very narrow zone of only 400 µm and with a rate of 0.33 nmol cm^{-2} s^{-1} when high CO_2 was present. The maximum specific rate of 8 nmol $cm^{-3}s^{-1}$ corresponds to a CH_4 production rate of 4 L per liter slurry per day.
- CO_2 depletion for 10 h led to a pH increase from 8.5 to 9.5, and the H_2 penetration into the slurry increased to 1700 µm. The H_2 consumption rate decreased to 0.22 nmol cm^{-2} s^{-1}.
- It is evident from Figure 2 that CO_2 is not in equilibrium with the total inorganic carbon pool due to slow hydration and dehydration between CO_2 and carbonic acid.

Conclusion

Supply of H_2 through silicone membranes allows for efficient and full conversion of H_2 to CH_4 which will not be possible by direct gas addition where H_2-containing bubbles will rise to the surface. However, the H_2 addition should not exceed the internal CO_2 supply from biomass degradation and still allow for pH values <9