Demonstration of a biological sensor to determine hydrogen mass transfer in biological methanation using methanogenic Archaea

Marco Orthofer[a], Walter Hofmann[b], Christian Paulik[a], Simon K.-M. R. Rittmann[b], Markus Ungerank[c], Paul Voithofer[d], Josef Höckner[e]

[a] Institute for Chemical Technology of Organic Materials, Johannes Kepler University Linz, Austria
[b] Archaea Physiology & Biotechnology Group, Department of Functional and Evolutionary Ecology, University Vienna, Austria
[c] Creonia e.U., Perg, Austria
[d] Voithofer + Partner Unternehmensberatung GmbH, Steyr, Austria
[e] BioG GmbH, Utzenaich, Austria

Institute for Chemical Technology of Organic Materials

Introduction

FlaeXMethan describes an innovative process for the biological conversion of biogas with renewable hydrogen from surplus electricity electrolysis using methanogenic archaea.

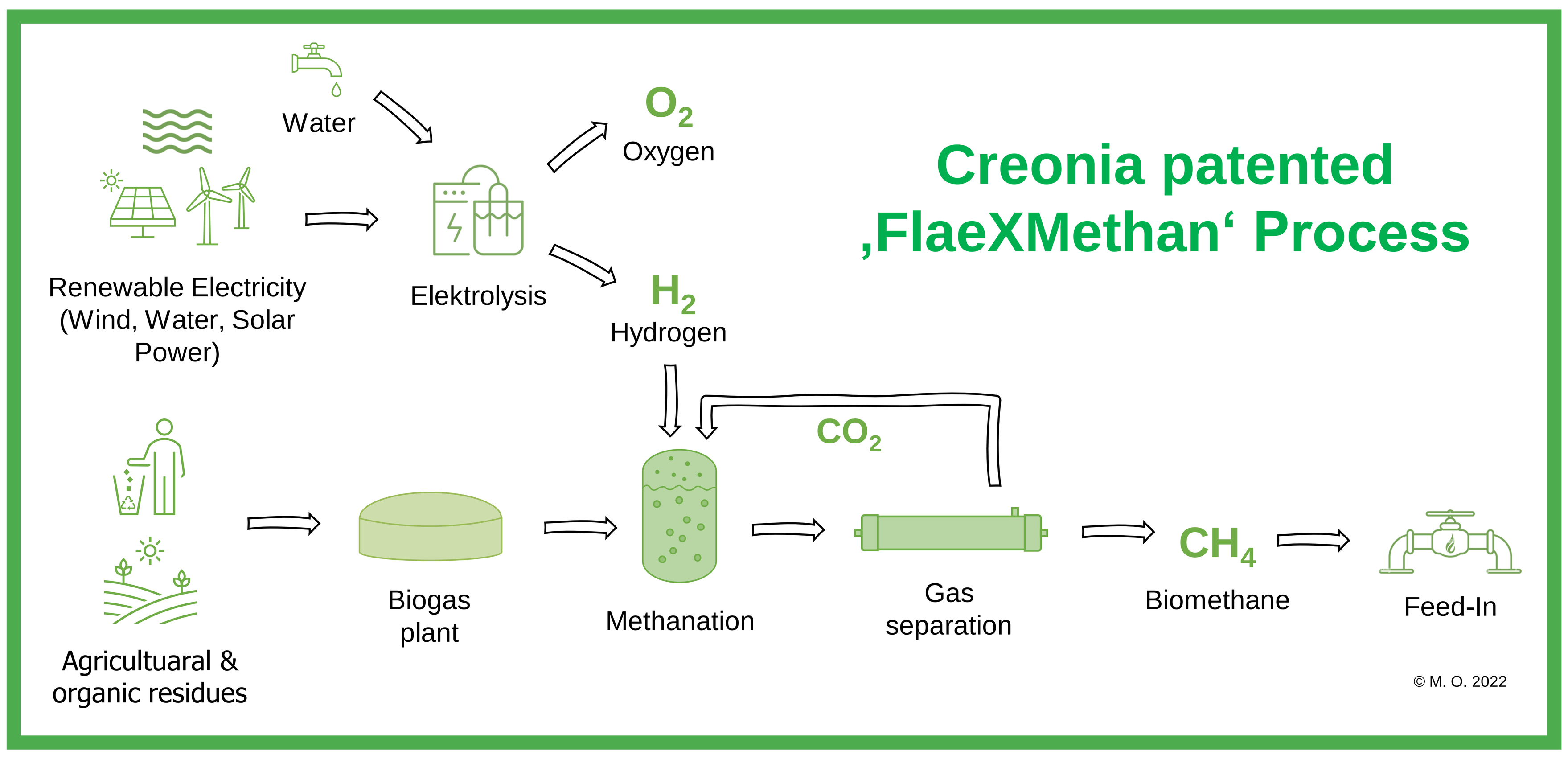
FlaeXMethan

Combination of
- Biogas plant
- Biological methanation
- Membrane-based biogas upgrading with integrated process control system

Aiming for
- Biologically produced methane from renewable, excess CO_2 and renewable H_2
- Improving the efficiency of existing biogas plants

To produce biomethane as
- Energy storage
- 100% renewable C1 building block for the chemical industry
- Sector coupling electricity/gas

FlaeXMethan is able to significantly contribute to the energy transition. It provides a possibility to convert excess electric energy into a storable chemical form - methane - which can be processed, stored and used with already existing infrastructure.



Background

- Gas-liquid mass transfer coefficient is the essential design parameter for methanation bioreactors
- Theoretical estimation of the $k_L a(H_2)$ via measurement of $k_L a(O_2)$ and correlation via diffusion constants
- $k_L a(O_2)$ relies on response time of sensors
- Current theories assume rapid conversion of hydrogen by the cells
- High performance gas-liquid mass transfer is crucial for overall process efficiency
- Gas transfer characteristics between bioreactors and microbiology are not well understood
- Determination of $k_L a$ for any biological system and any reactor configuration

Marco Orthofer

PhD Thesis in the field of biotechnological process development at the Institute for Chemical Technology of Organic Materials at the Johannes Kepler University Linz.

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Experimental

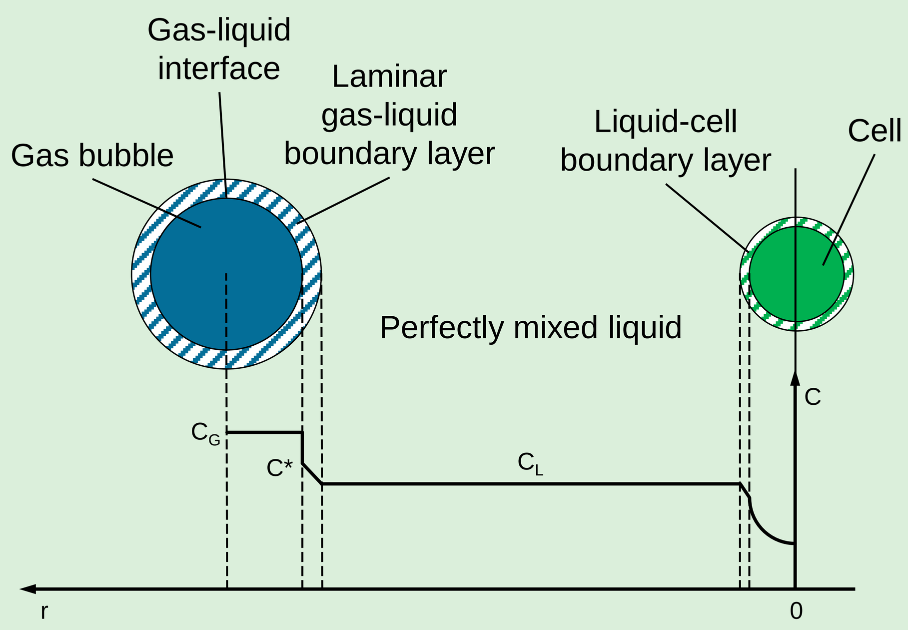

Figure 1: Schematic representation of gas liquid mass transfer from bubble towards cell [1, 2].

Biological methanation of hydrogen and carbon dioxide in fed-batch cultivation mode. By assuming full conversion of H_2/CO_2 to CH_4 once in the liquid phase, the methane evolution rate (*MER*) is solely dependent on its gas-liquid mass transfer. This enables calculation of $k_L a$ values based on produced methane and establishes a biological sensor for hydrogen mass transfer determination.

Results

The hydrogen uptake rate (*HUR*) describes the mass transfer of hydrogen across the system bubble to cell.

$$CUR \cdot CO_2 + HUR \cdot 4\,H_2 \rightarrow MER \cdot CH_4 + WER \cdot 2\,H_2O + r_{(X)} \cdot X \qquad (1)$$

$$HUR = \frac{\mathrm{dc}}{\mathrm{dt}} = k_L a * (C^* - C) \qquad (2)$$

Reformulating Eq. (1) and (2) can be results in a $y = k \cdot x + d$ equation with *k* representing $k_L a$ (Fig. 2 right).

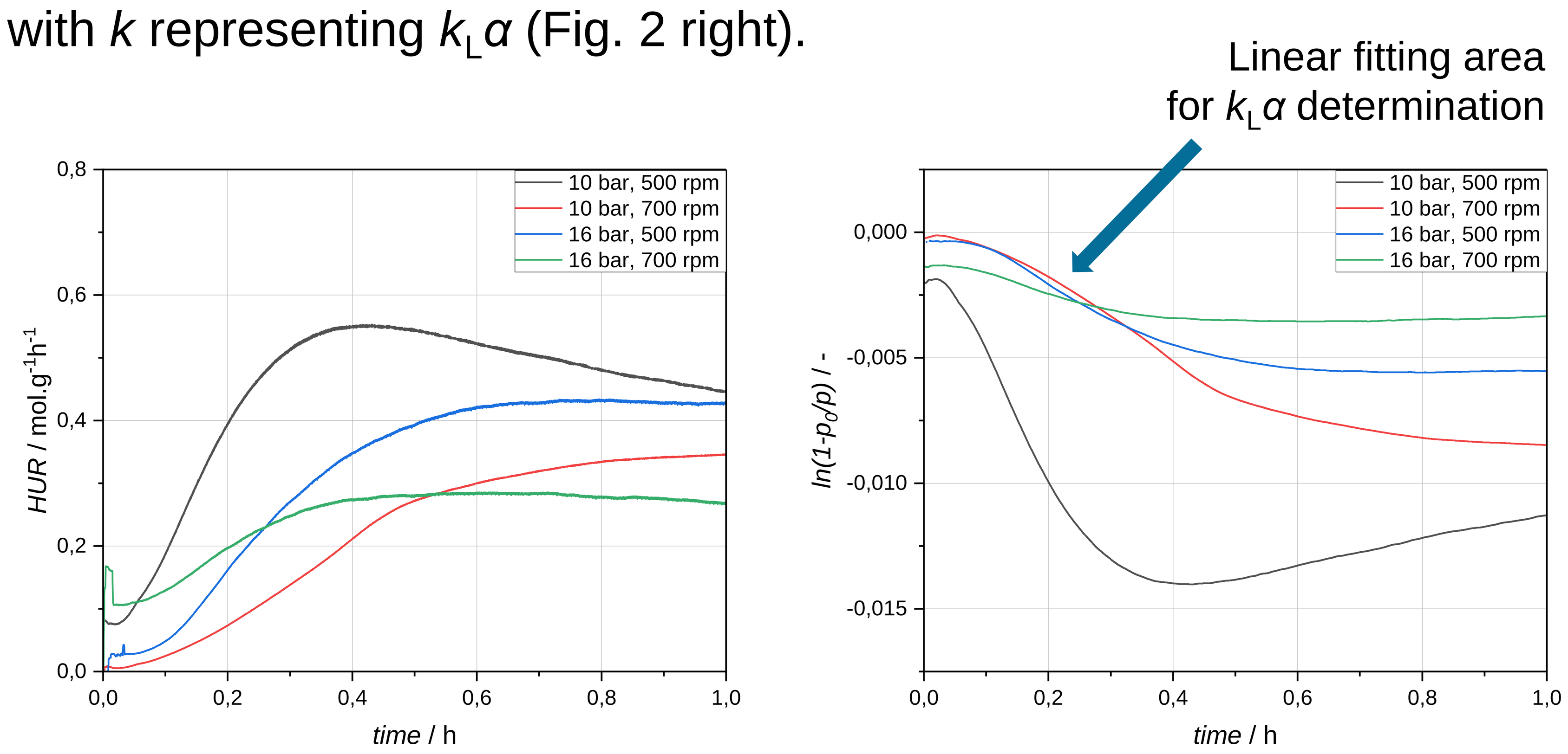

Figure 2:
left: Calculated hydrogen uptake rate (*HUR*) from online off-gas analysis at different pressure and stirring settings and fixed gassing rate.
right: Plot of integrated and substituted form of Eq. (2) for $k_L a$ determination.

Conclusion

- Biological limitations restrict determination of mass transfer properties
- Higher stirring speeds result in lower $k_L a$ values indicating formation of vortices and less gas dispersion
- Higher system pressure does not show a significant increase in mass transfer, indicating biological limitations
- Highest $k_L a$ determined at 0.05 s^{-1} (10 bar, 500 rpm)
- Results illustrate importance of in-depth understanding of mass transfer characteristics for the optimization of the biomethanation process

References:
[1] Hass, Pörtner (**2009**): Praxis der Bioprozesstechnik. 1. Aufl. Heidelberg: Spektrum Akademischer Verl.
[2] Henzler, Chem.-Ing.-Tech. 54 (**1982**) Nr. 5, p. 461 - 476

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