Soil and Water Resources Institute

ARISTOTLE UNIVERSITY OF THESSALONIKI

Waste·Management·Bioprocessing·Lab

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Comparative assessment of different packing materials in biological methanation

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Carbon Capture Utilization & Storage

- **Carbon dioxide released into the atmosphere → Global warming**

<u>Main contributors for the CO_2 emissions</u>:
- Fossil fuel combustion
- Deforestation

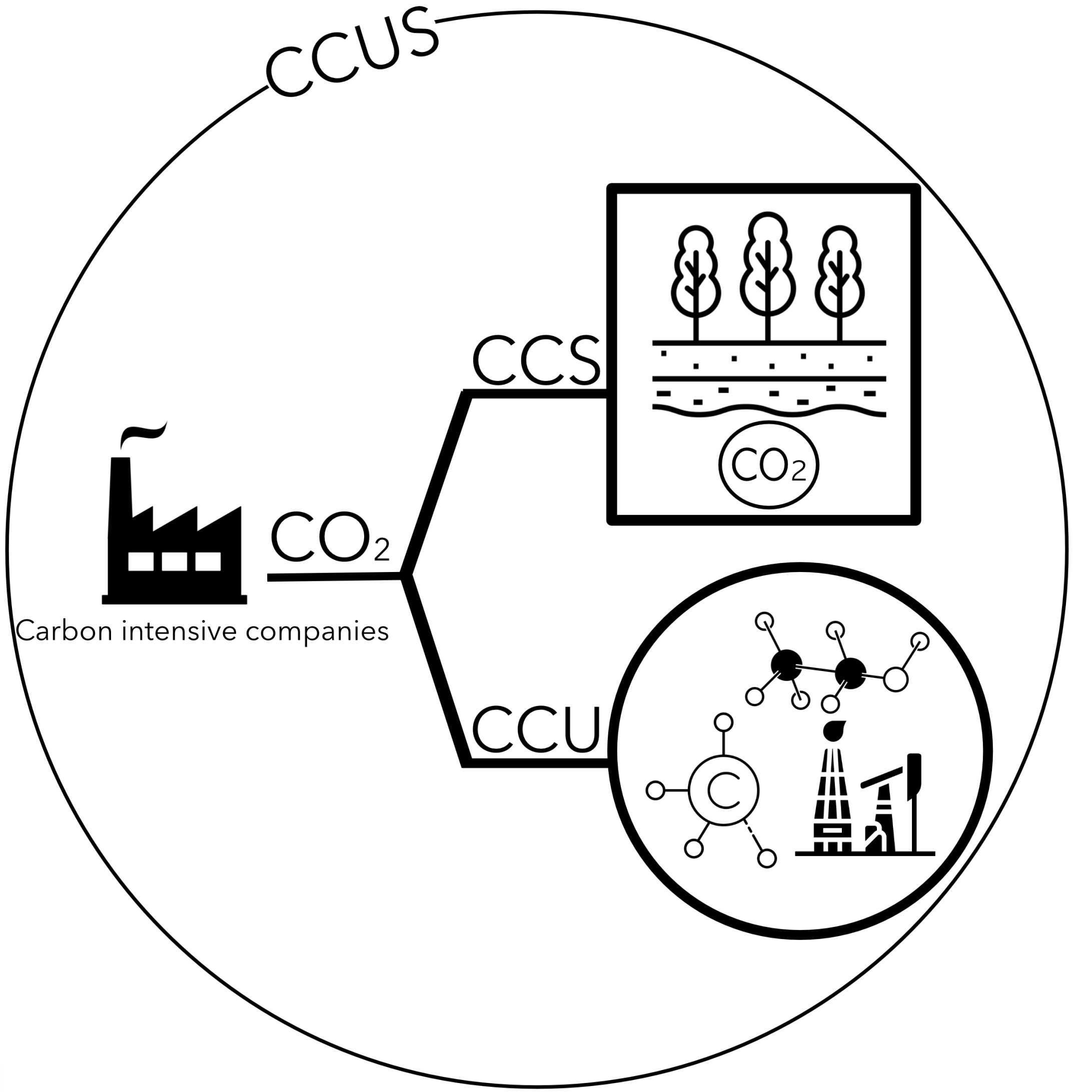
↓

The trend of atmospheric CO_2 emissions is on the rise

<u>Main mitigation strategies</u>:
- Carbon Capture and Storage (CCS)
- Carbon Capture and Utilization (CCU)

↓

CCUS



Methanation

Part of **Power to Gas** technology

Power-to-Gas (P2G) combines:

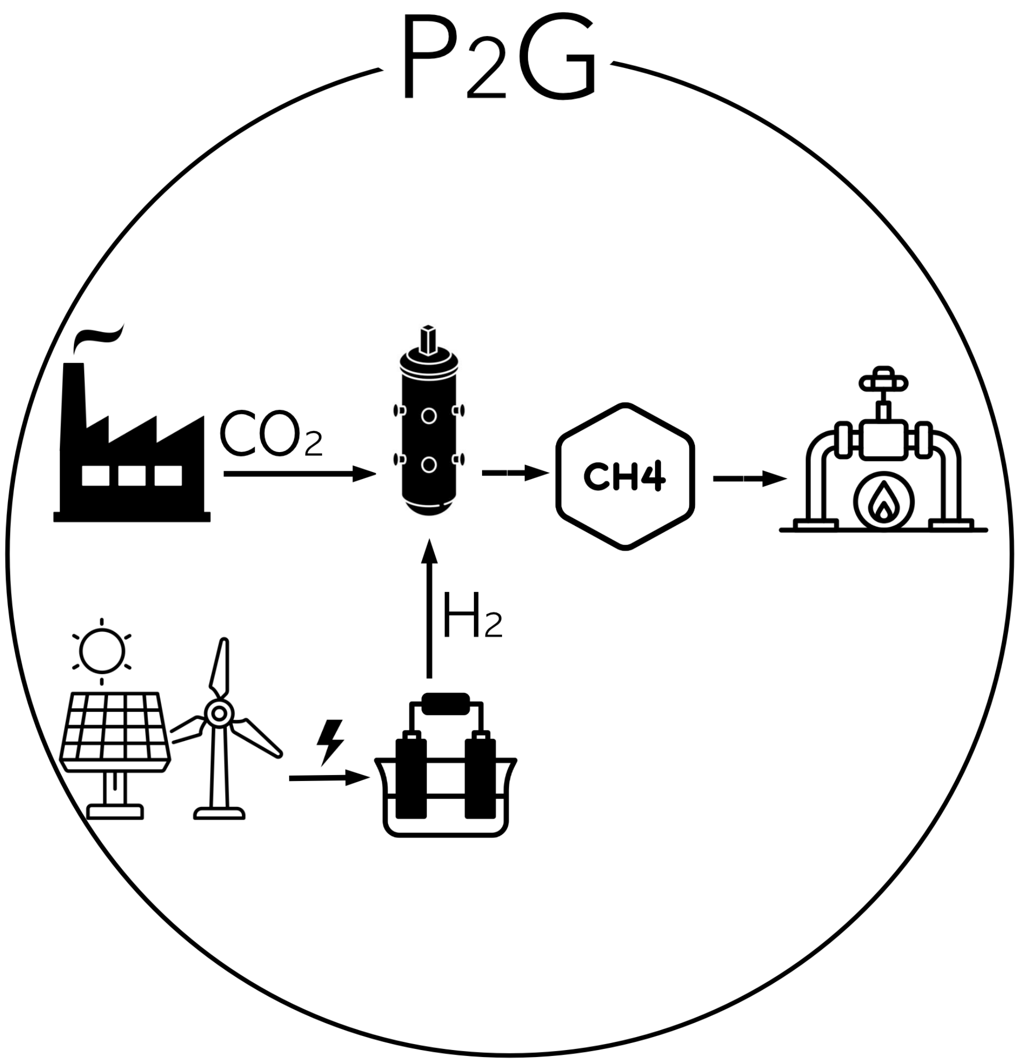
- Hydrogen production through PEM electrolysis exploiting the surplus renewable energy (e.g., wind, solar energy etc.)
- Methanation, where the produced H_2 reacts with CO_2 to yield CH_4

Methanation can be accomplished:

- Thermo-catalytically (Sabatier process)
- Biologically

Both processes share the same reaction:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad \Delta G^o = -130.7 \text{ kJ/mol}$$



Biological Methanation

Carried out by **Hydrogenotrophic Methanogens**:

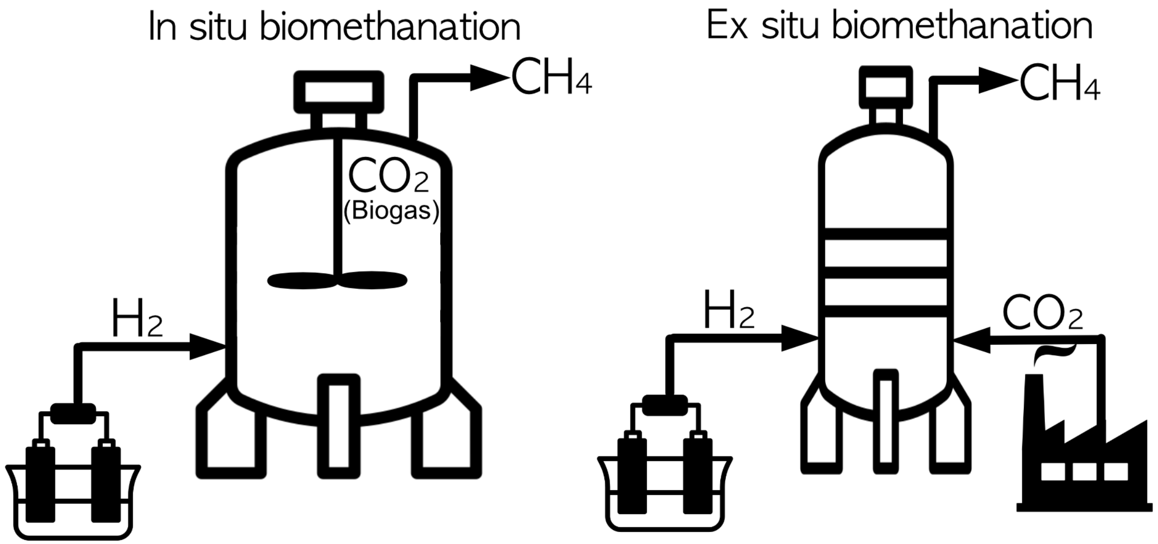
- Utilize H_2 as an electron donor
- Reduce CO_2 to CH_4

Influenced by several operating factors:

- **Temperature:**
  Thermophilic systems exhibit higher production rates
- **pH:**
  7-8 (optimum range)
- **Mass transfer of H_2:**
  The main obstacle to be tackled

Can be accomplished:

- *In-situ* or
- *Ex-situ*



Packing Materials in Biological Methanation

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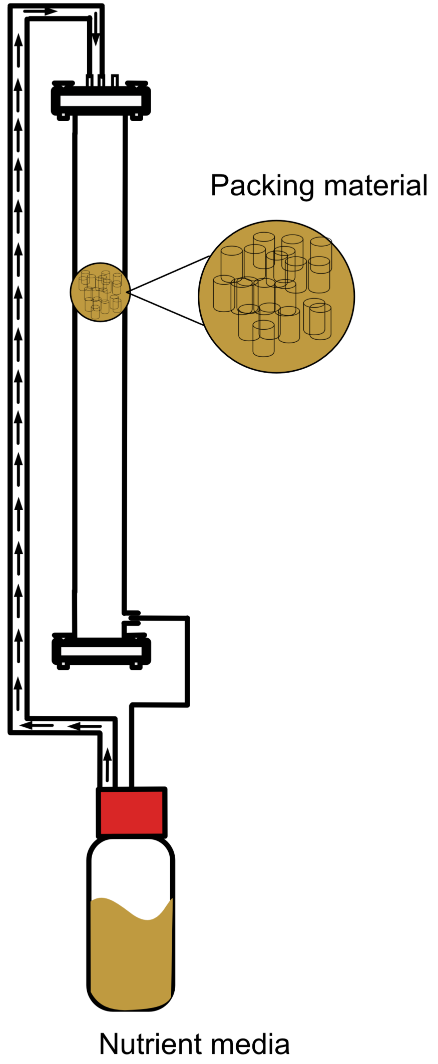
- **Low H_2 mass transfer** → limited H_2 conversion resulting in the accumulation of Volatile Fatty Acids
- **Trickle bed reactor (TBR)** the most promising technology for biomethanation, where hydrogenotrophic methanogens are immobilized onto a packing material
- By immobilizing the microbial cells, it is possible to increase the efficiency of substrate conversion and to shorten the necessary retention times

Optimal characteristics :

1. High surface area
2. Non-toxic
3. Reusable and cheap



Aim & Objectives

<u>The selection of appropriate packing material for the immobilization of biofilm – comparison among three different packing materials:</u>

- Raschig rings (0.01 m^2/g)
- Activated carbon (20 m^2/g)
- Biochar (10.5 m^2/g)

<u>Comparative evaluation of the three packing materials, in terms of:</u>

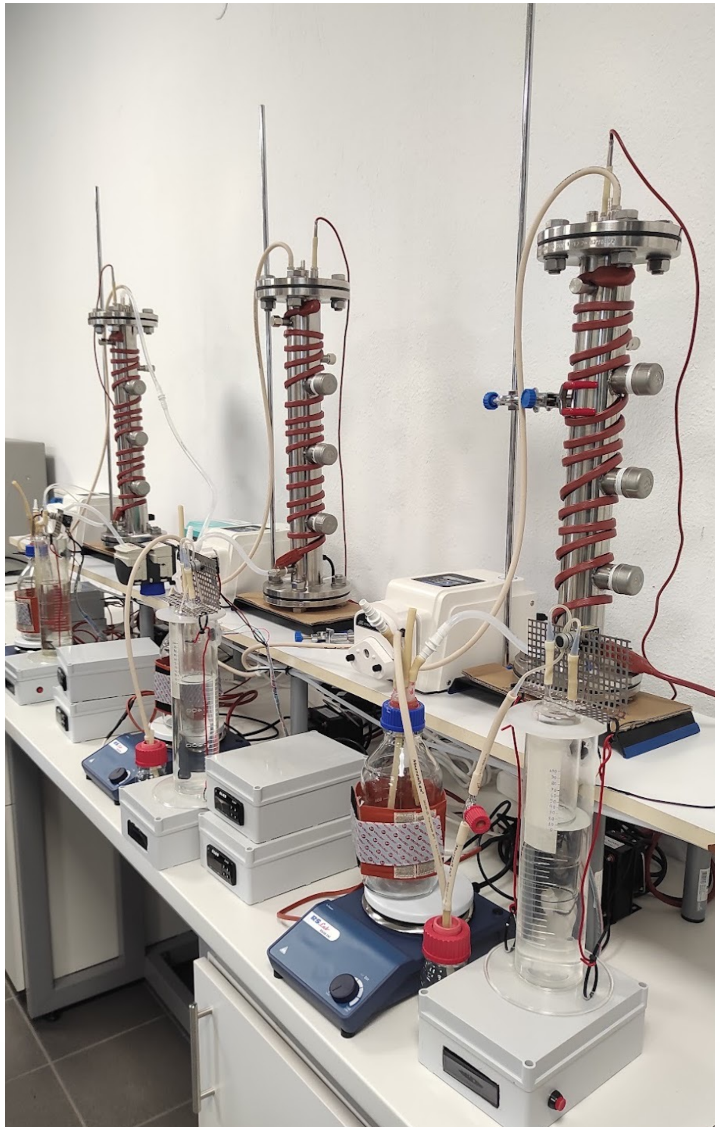
- Process efficiency:
  - output gas composition
  - average H_2/CO_2 utilization
- pH
- Volatile Fatty Acids (VFA)

Materials and Methods

Experimental procedure

Three custom-made TBRs, made of stainless steel were installed, with:

- 1-liter working volume
- 10:1 Height: Diameter ratio

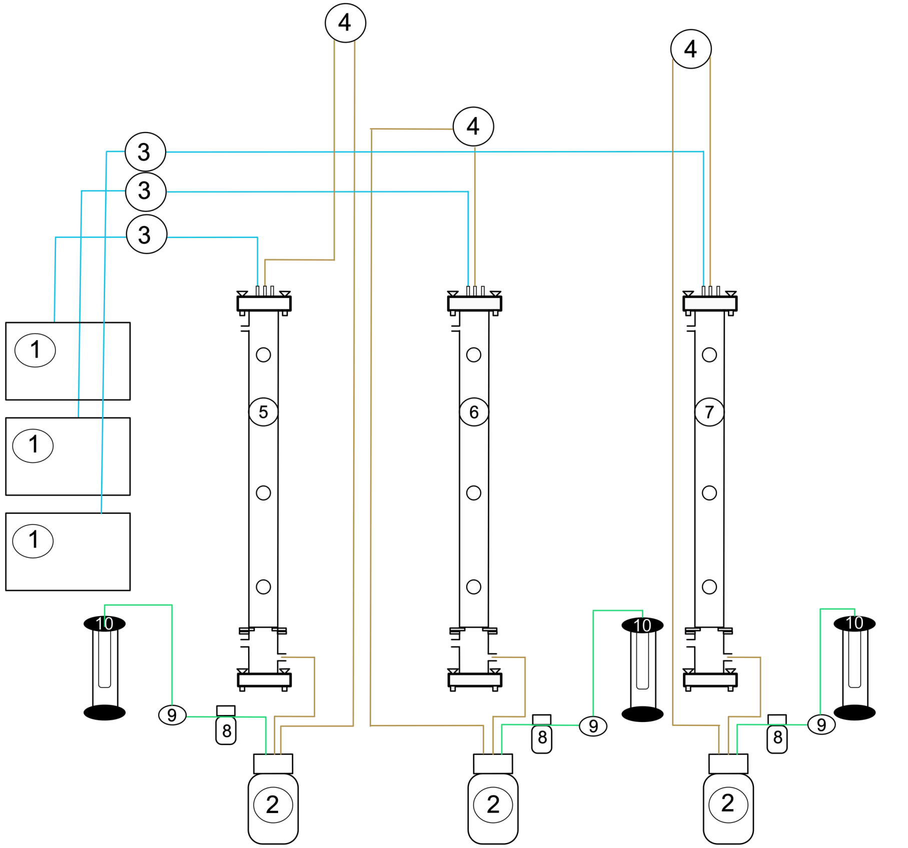


TBRs were tested in five different Gas Retention Times: 4 h, 3 h, 2 h, 1 h, and 45 min in terms of:

- Output gas composition determination (% CH_4, CO_2, H_2)
- VFA concentration determination (VFA, mg/L)
- pH measurement
- Produced output gas quantitative evaluation (mL)

Materials and Methods

Experimental setup

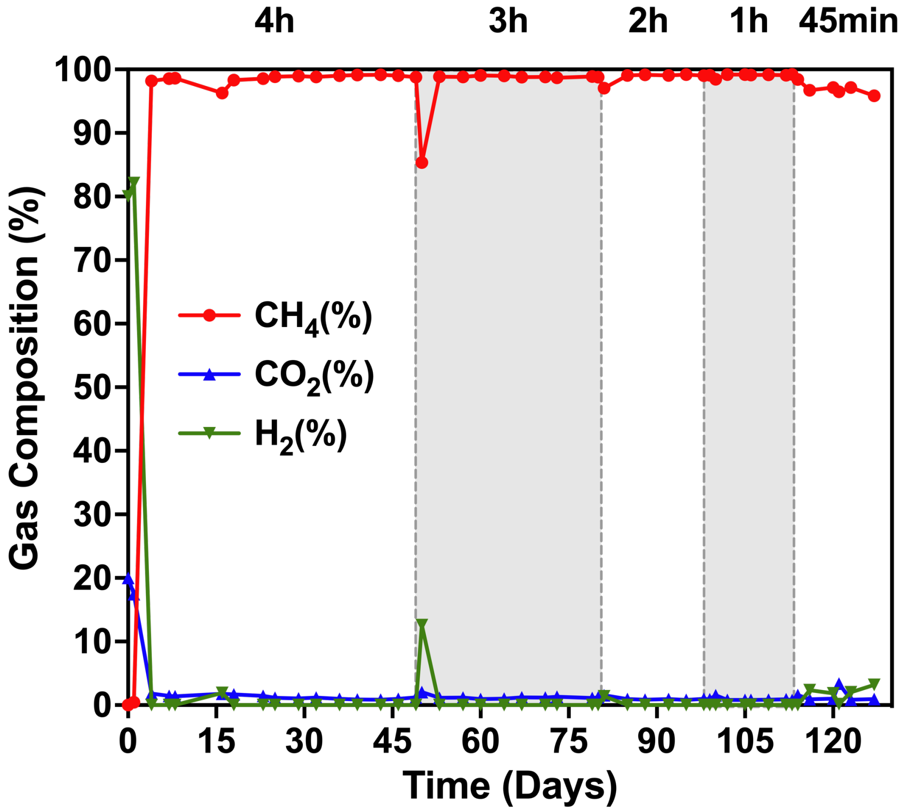


1. Gas bags
2. Nutrients solutions
3. Gas pumps (1 for each reactor)
4. Nutrients solution pump
5. Reactor R1
6. Reactor R2
7. Reactor R3
8. Water vapor traps
9. Gas sampling port
10. Gas counters

Results and Discussion

Output gas composition of TBR1 (Raschig rings)

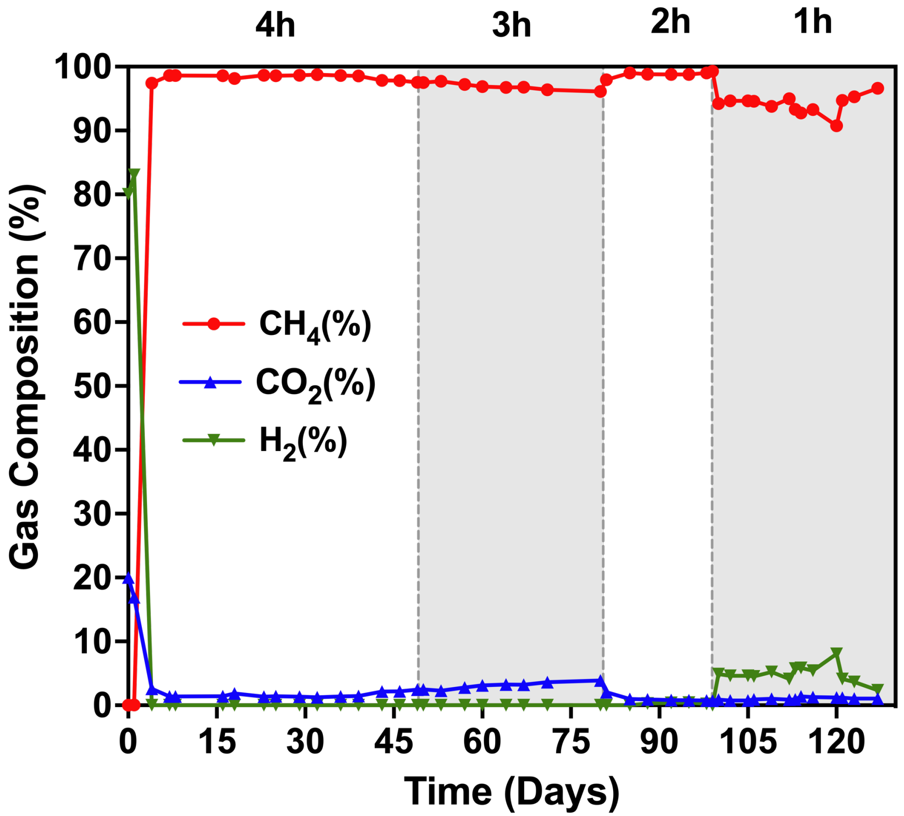
- **Quick adaptation** (4 days) for the microbial community applying 4 h GRT
- A drop during the 1st day of 3 h GRT, **consistent with other similar research**
- Stable CH_4 production for all GRTs examined
- CH_4 composition higher than 98% in 4, 3, 2, 1 h GRT
- CH_4 composition higher than 95% in 45 min GRT



Results and Discussion

Output gas composition of TBR2 (Activated carbon)

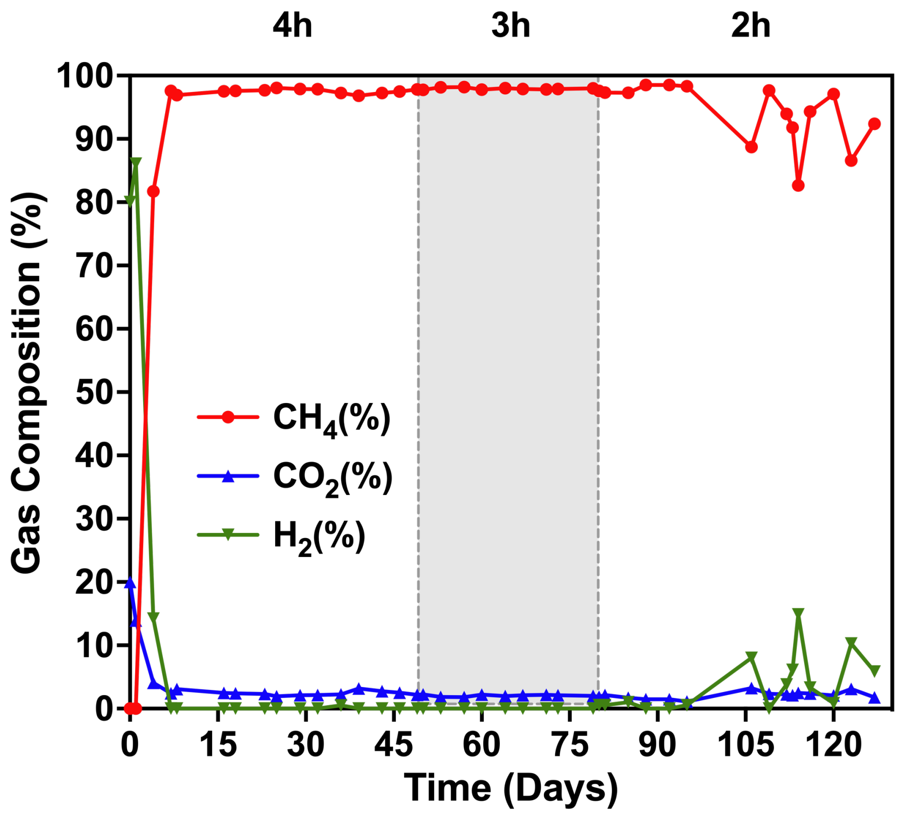
- **Quick adaptation** (4 days) for the microbial community, applying 4 h GRT
- **No decline** in the process efficiency after the reduction from 4 to 3 and to 2 h GRT
- Increased CH_4 composition for 2 h GRT (>98%)
- A drop in the 1st day of 1 h GRT, **consistent with other similar research**
- Relatively unstable operation during 1 h GRT



Results and Discussion

Output gas composition of TBR3 (Biochar)

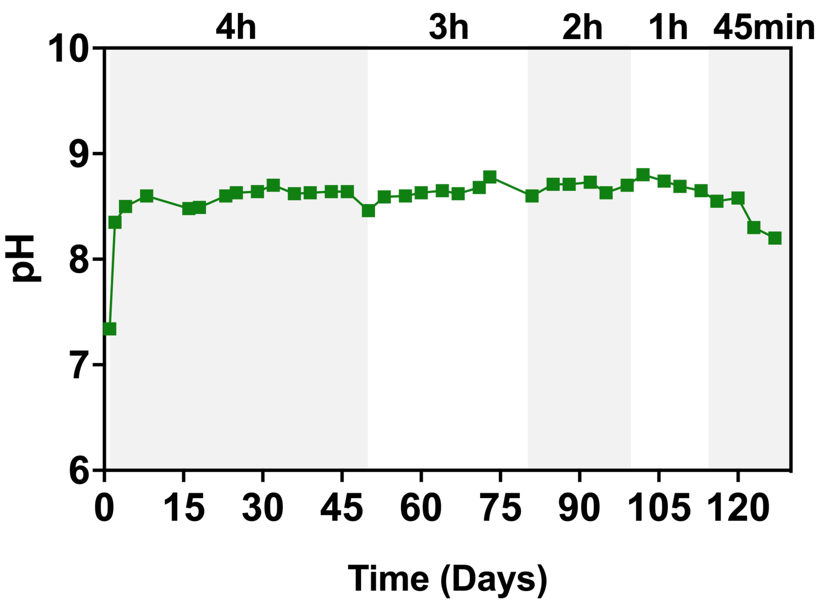
- Necessary adaptation time: 4 h GRT (7 days)
- **No decline** in the process efficiency after the shift from 4 to 3 h GRT
- Increased CH_4 composition, by using 3 h GRT (>98%)
- Restart of the operation during the application of 2 h GRT

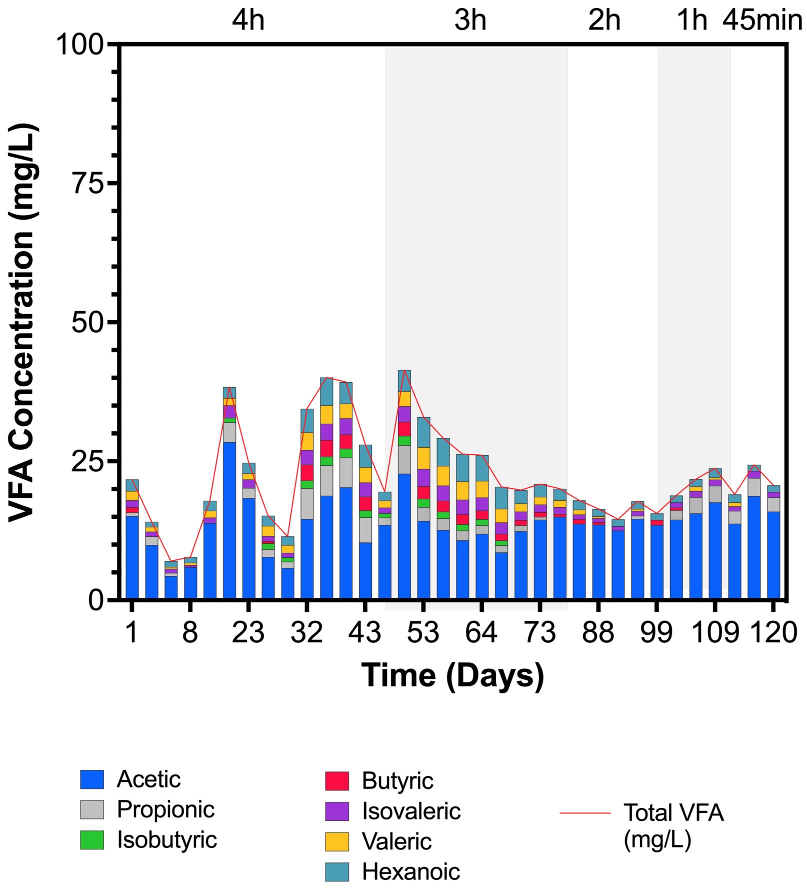


Results and Discussion

pH values and VFA concentrations of TBR1 (Raschig rings)

- TBR1 slightly out of the optimum range of pH values (8.5-8.6), **consistent with other similar research**
- pH stable during all the examined GRTs of TBR operation
- **Total VFAs concentration quite low** (Highest recorded value: 41.4 mg/L) in relation to the existing literature
- Slight upward trend of VFAs after the 18th day, due to the VFA contained in the nutrient/feed solution

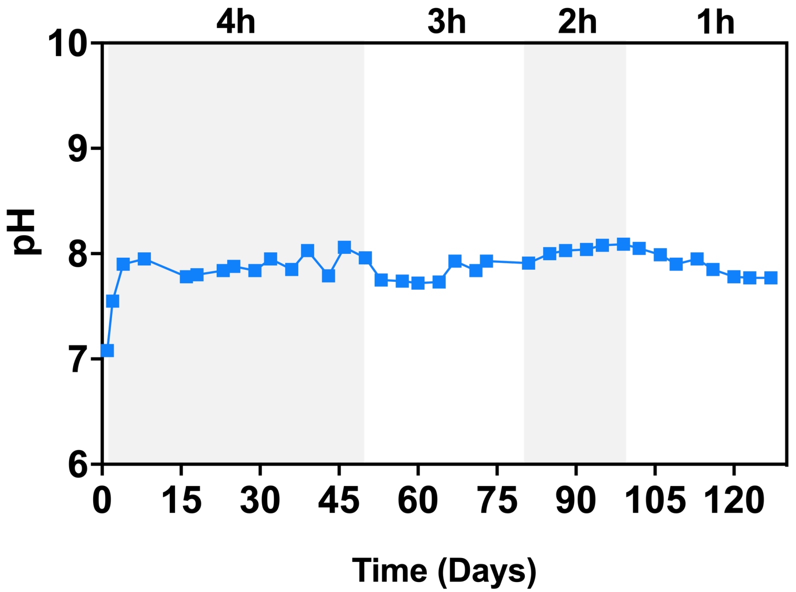


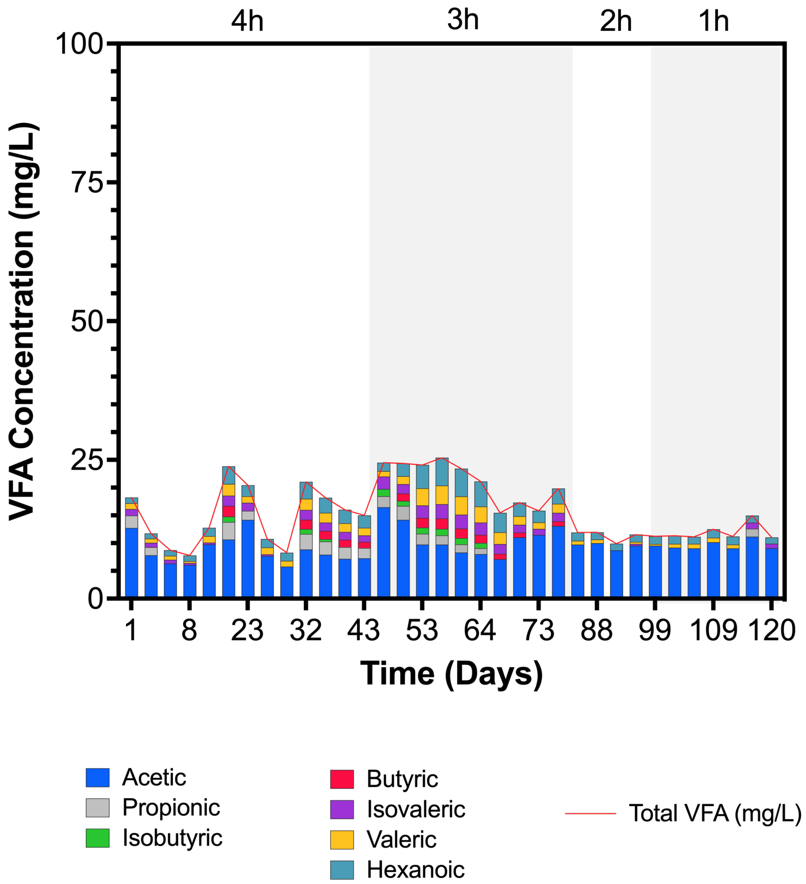


Results and Discussion

pH values and VFA concentrations of TBR2 (Activated Carbon)

- TBR2 **in optimum range of pH** values (7.7-8)
- pH stable during all the GRTs of TBR operation
- **Total VFAs concentration quite low** (Highest recorded value: 25.4 mg/L) in comparison with the existing literature
- Slight upward trend of VFAs after the 18th day, due to the VFA contained in the nutrient solution

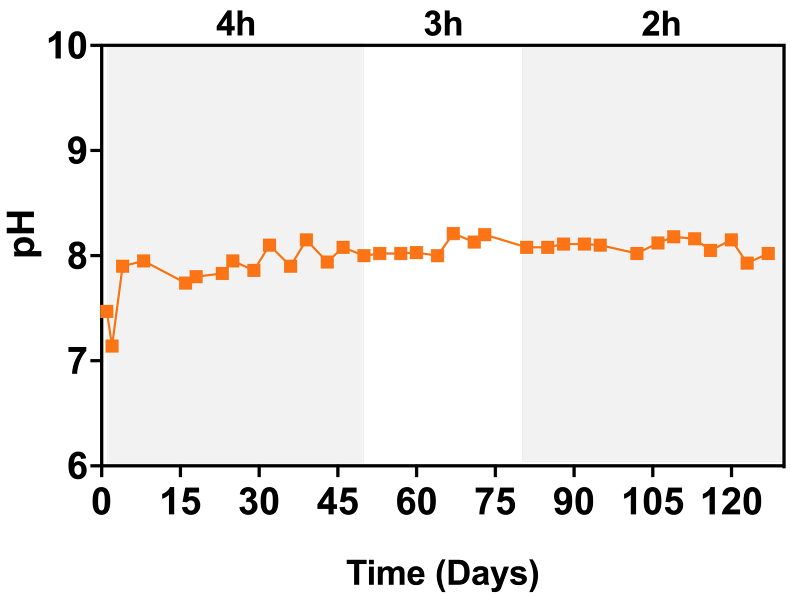


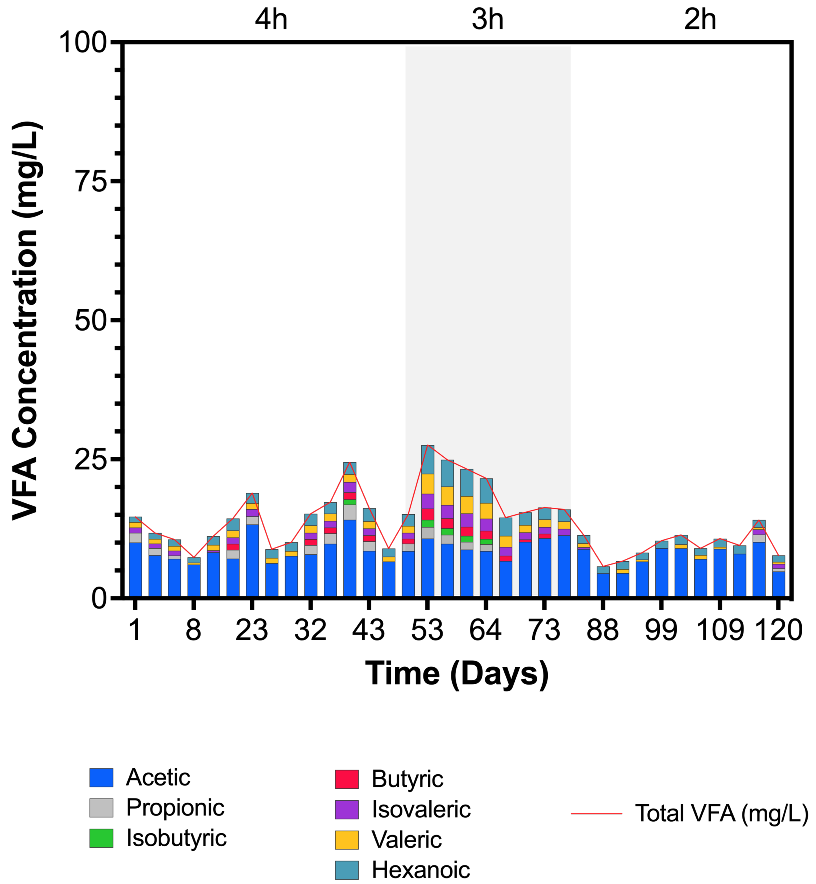


Results and Discussion

pH values and VFA concentrations of TBR3 (Biochar)

- TBR3 **in the optimum range of pH** values (7.9-8.1)
- pH stable during all the examined GRTs of TBR operation
- **Total VFAs concentration very low** (Highest recorded value: 27.6 mg/L) in relation to the existing literature
- Slight upward trend of VFAs after 18th day due to the VFA contained in the nutrient solution

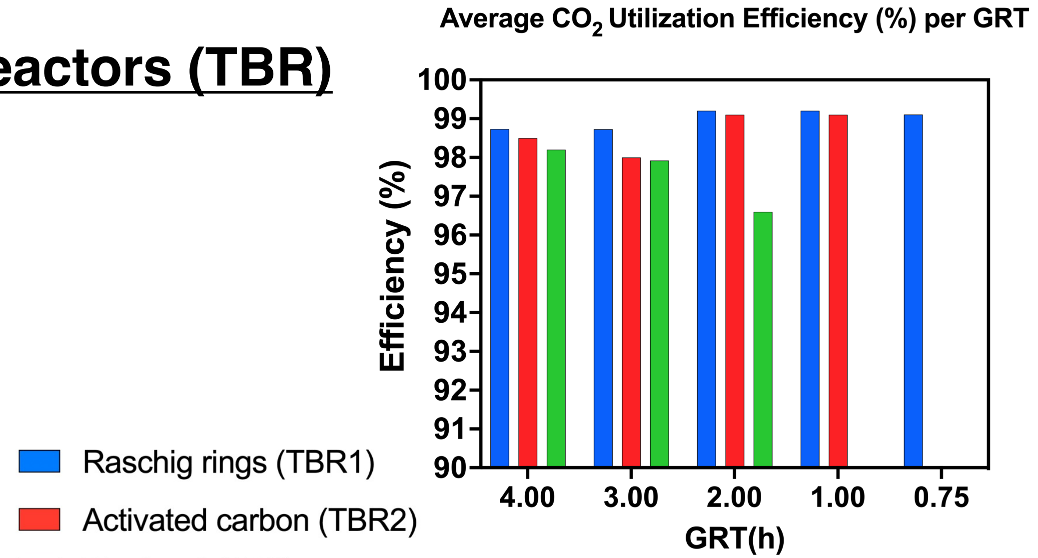


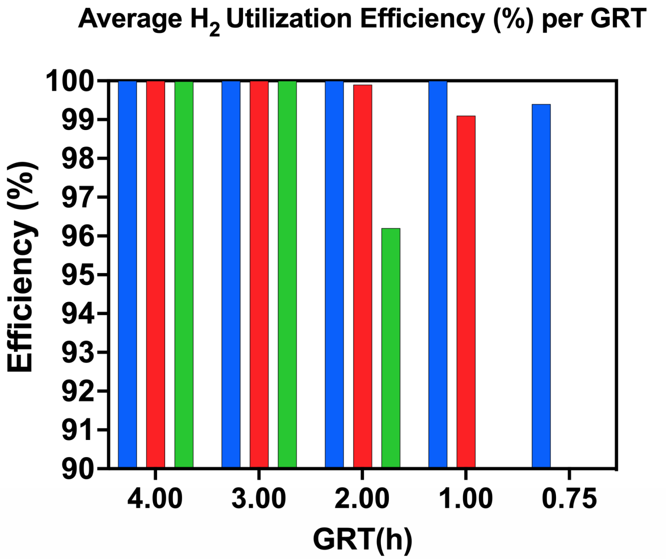


Results and Discussion

Average CO_2/H_2 utilization efficiency (%) of Trickle Bed Reactors (TBR)

- High H_2 utilization efficiency (100%), when applying 4 and 3 h GRT for all the three examined TBRs
- A sharp drop for the case of biochar and for 2 h GRT (96.2%), unstable operation of TBR2
- Lower H_2 utilization efficiency for the case of activated carbon and for 1 h GRT
- High CO_2 utilization efficiency (over 98%), when applying 4 and 3 h GRT for all the examined three TBRs
- A sharp drop for the case of biochar by using 2 h GRT (96.6%), unstable operation of TBR2
- High CO_2 utilization efficiency for the case of Raschig rings even for 45 min GRT (99%)





Conclusions

- **Raschig ring** found as more suitable packing material, than activated carbon and biochar
- Raschig rings achieved:
  - Output CH_4 composition in TBR1 higher than 98% for GRT 4, 3, 2 and 1 h
  - **Satisfactory and stable pH values for the operation,** although slightly higher than the optimal range
  - Low VFA concentrations (lower than 50mg/L)
- Comparing GRT 2 h → **Distinction between biochar-Raschig rings performance**
- Comparing GRT 1 h → **Distinction between activated carbon-Raschig rings performance**
- Biochar needs further investigation for lower GRT values

Acknowledgements

The "Demonstration of a mobile unit for hybrid energy storage based on CO_2 capture and renewable energy sources (LIFE CO_2toCH_4 - LIFE 20/CCM/GR/001642)" project has received funding from the LIFE Programme of the European Union.

Thank you for your attention!

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