Pilot scale biomethanation system for capturing and utilization of CO_2 from exhaust gases

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Keywords: hydrogenation, biomethane, decarbonisation
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The operation of the pilot scale methanation system relies on the coupling of hydrogen (H_2) with carbon dioxide (CO_2) to produce biomethane using naturally occurring mixed cultures of hydrogenotrophic methanogens, based on the following reaction:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (1)$$

Methanation is a low-complexity biological process (also called biomethanation) that requires less energy consumption regarding system engineering and operational control compared to thermochemical ones. Furthermore, it complies with the principles of the circular economy by offering a valorisation pathway for CO_2 waste streams (especially from carbon-intensive industries and power plants using fossil fuels), which can also be coupled with carbon capture technologies (Angelidaki et al., 2018; Sieborg et al., 2021).

Trickle bed reactor (TBR) appears to be more efficient in achieving methane (CH_4) of high quality and large yields compared to other reactor types used for biomethanation. In TBRs, the microbes can be immobilised on the packing material, which should have a high surface area for gas-liquid mass transfer favouring the high density and activity of methanogenic archaea (Tsapekos et al., 2021).

The "heart" of the pilot scale methanation system consists of the one trickle-bed continuous reactor (R-201 in Figure 1) designed to be approx. 100 L with the capacity to capture and utilize approx. 8.0 kg CO_2 per m^3 of reactor volume when operating in normal conditions (meaning Gas Retention Time, GRT of 1h). The reactor is made of stainless steel and consists of three individual compartments to ensure stable operation in malfunction (e.g., clogging of packing material). Each compartment is equipped with individual temperature-control thermal jackets to maintain and operate at a temperature range of 55 ± 2°C and individual temperature sensors to monitor and log their operating temperatures. The pressure inside the anaerobic reactor is monitored and logged through a pressure meter.

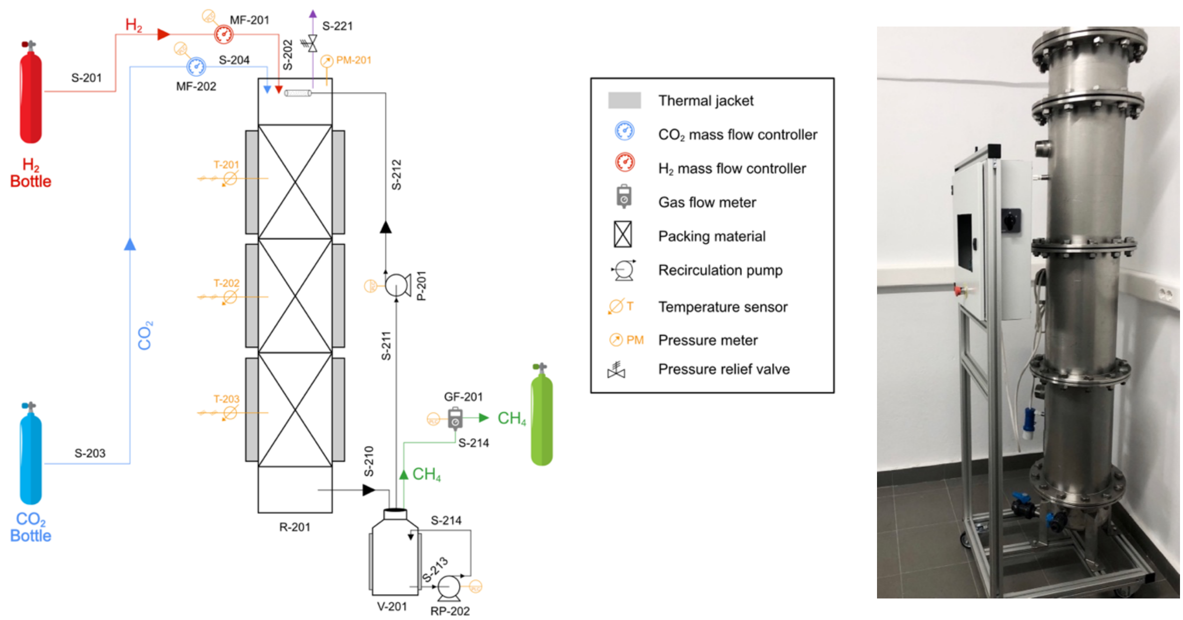

Figure 1. Schematic diagram of the pilot methanation system (left); Photo of the trickle-bed continuous reactor.

The methanation system consists of an anaerobic vessel (V- 201 in Figure 1), which is used to recirculate the liquid inoculum in the reactor by means of a peristaltic pump, aiming to achieve a homogenous wetting of the packing material inside the reactor without flooding. In this way, a moist environment, nutrients and trace elements are provided to microorganisms. The anaerobic vessel is equipped with a temperature-control thermal jacket to maintain the operating temperature at 55 ± 2°C. An output stream from the anaerobic vessel drives the over-pressured air phase to the gas flow meter to monitor and log the overall production of biomethane.
Mass flow controllers regulate the supply of gases (CO_2 and H_2) into the anaerobic reactor.
The process monitoring and data logging of the methanation system are controlled by an automated Programmable Logic Controller (PLC) system with remote access capability. In more detail, the pilot methanation unit can operate automatically, with continuous monitoring and recording of the main operating parameters, while also permitting remote monitoring and control through PLC-based long-distance control modules.

Operation conditions of the methanation system

The main objective of the current study concerns the implementation and monitoring of the biomethanation process at pilot scale conditions. The main process parameter during the operation of the prototype pilot methanation unit is the gas retention time of the anaerobic reactor, and the aim is to achieve stable operation conditions at GRT values of at least 2h. The primary operating conditions of the prototype pilot methanation unit regarding the influent flow rates of CO_2 and H_2 are presented in Table 1.

Table 1. CO_2 and H_2 flow rates for different Gas Retention Times (GRT).

Gas Retention Time (GRT), h	**6**	**3**	**2**	**1**	**0.5**
Total gas input (L/h)	16.8	33.7	50.5	101.1	202.1
H_2 input (L/h)	13.5	26.9	40.4	80.8	161.7
CO_2 input (L/h)	3.4	6.7	10.1	20.2	40.4
max CO_2 capture capacity (kg/day)	0.1	0.3	0.4	0.9	1.7
max. kg CO_2 capture capacity (per m^3 reactor)	1.4	2.9	4.3	8.6	17.3
actual kg CO_2 capture (per m^3 reactor)	1.3	2.6	3.9	7.8	15.6

Acknowledgement

The project "LIFE CO2toCH4 - Demonstration of a mobile unit for hybrid energy storage based on CO_2 capture and renewable energy sources" (LIFE20 CCM/GR/001642) is co-funded by LIFE, the EU's financial instrument supporting environmental, nature conservation and climate action projects throughout the EU.

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