Upgrading biogas produced via anaerobic digestion from municipal waste into biomethane by 2-stage membrane separation in pilot-scale conditions.

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Abstract
Municipal bio-waste can be a valuable source for bioenergy. Today, biomethanation can be regared as a "Waste-to- Energy" technology, standing as a potential alternative to fossil fuels.The composition of crude biogas, produced by the process of Anaerobic Digestion of residues like sewage sludge, landfills residues or agricultural waste, varies and depends on the production conditions (pH, etc.). The main constituents of raw biogas are: CH_4 and CO_2, as well as minor concentrations of water (H_2O), ammonia (NH_3), nitrogen (N_2), oxygen (O_2) and minor but harmful concentrations of Hydrogen Sulfide (H_2S). H_2S may affect the contacting materials of the separation unit, so it is immediately removed from raw biogas, using biological methods (Gkotsis et al., 2022).

In this work, the biogas upgrading process in a 2-stage pilot scale CO_2 separation unit, using high-CO_2-selectivity commercial membranes is investigated, after previous laboratory tests on artificial CO_2/CH_4 mixtures (Koutsiantzi et al., 2022) and Mathematical Modelling of the separation process. The raw biogas producedat the anaerobic digester of the Thessaloniki Wastewater Treatment Plant at Sindos, Greece (TWWTP), after the desulphurizationunit where H_2S is removed,consists of its 2 main ingredients: CH_4(60-65 mole %) and CO_2(40-35 mole%)(Table 1). Its initial pressure is fixed at 1 bar and the volumetric flow rate should be around 20 m^3/hr, according to the setup constructor.

Before the separation, the biogas stream enters the compressor where it reaches the desired pressure value (3-12 bars), and after compression the gas enters the 1st membrane where the separation leads to 2 streams: the permeate stream (permeate 1) which is removed with high CO_2 purity (> 90%). The retentate stream (retentate 1) after exiting the 1stmembrane module, enters the 2ndidentical module and the permeate 2 stream is removed for recycling, while the retentate 2 stream constitutes the high purity biomethane stream, which is the product stream. Pressure Indicators (PI) are connected to each stream outlet and inlet. Volumetric flowmeters are connected at the entrance of the 1st stage to calculate the initial flow rate of the biogas.

The samples of the biogas on each stage of the process are collected every week, in continuous flow after 24h of operation of the separation unit to reach steady state. Then, gas chromatography (GC) is used to analyze the composition of each gas sample at every stage of the upgrading.

Table 1Raw biogas composition right before upgrading

	12/07/2022	**12/13/2022**
NITROGEN (% mole)	1.5459	0.9976
OXYGEN (% mole)	0.3810	0.2376
METHANE (% mole)	61.3423	61.8349
CARBON DIOXIDE (% mole)	35.5692	35.6481
HYD. SULFIDE (% mole)	1.1616	1.2818
TOTAL (% mole)	100	100

The membrane modules that are installed in the unit were bought by UBE Industries Ltd, Japan and are 2 identical polyimide hollow fiber membranes, especially designed for CO_2 separation. According to UBE Industries, the stage cut that is achieved during the first stage is 0.29 and at the 2nd stage is 0.74.
The optimalsetup which was proposed from the manufacturer is presented at the PID diagram at Fig. 1.
Different range pressures are tested, affecting the stage cut and residence time in the membrane.

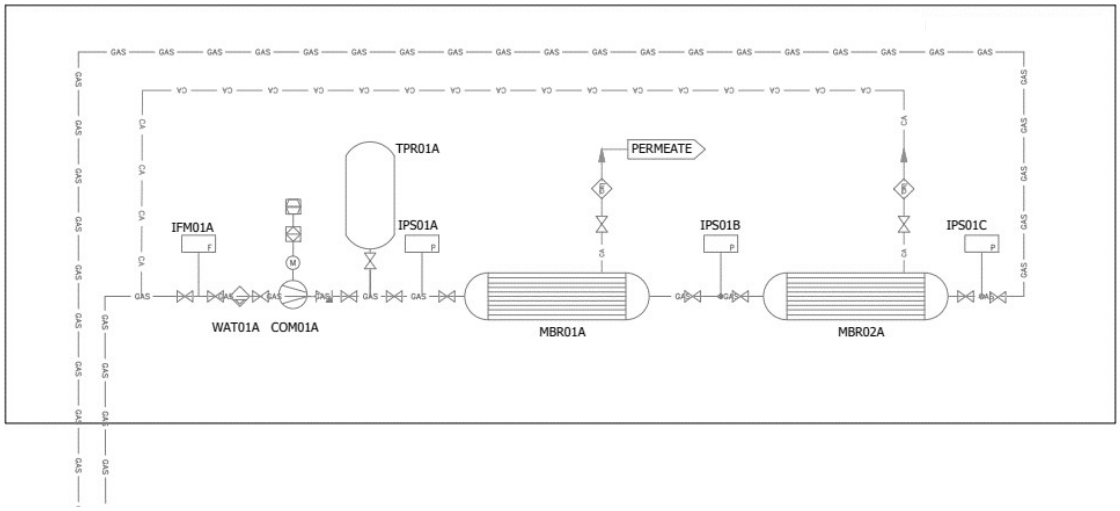

Figure 1: PID Diagram of the membrane separation unit (IFM01A=Flowmeter, IPS01A/B/C=Pressure Indicators, MBR01A/B= Membrane Modules, COM01A= Feed Compressor, TPR01A= Storage Tank)

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