Upgrading biogas produced via anaerobic digestion from urban sludge into biomethane by applying 2-stage membrane separation under pilot-scale conditions

C. Koutsiantzi[1], P. Gkotsis[2], A. Zouboulis[*, 2], 2, A. Liatsou[2], E.S. Kikkinides[1]

[1] Department of Chemical Engineering, Aristotle University of Thessaloniki

[2] Department of Chemistry, Aristotle University of Thessaloniki

Corresponding e-mail: zoubouli@chem.auth.gr

Outline

- Introduction / Biogas-Up
- Biogas Production and Pre-treatment
- Biogas Upgrading Unit - Fabrication
- Separation Results
- Conclusions

Introduction(I)

- Increasing organic waste disposal → emergent need for their use, aiming to renewable energy and nutrients’ recycling
- RePowerEU (May 2022): Goal of increasing the annual production and use of biomethane to 35 billion cubic meters by 2030 in the EU.
- Reduction of EU’s dependence on Russian fossil fuels

➢ Biomethane Industrial Partnership (BIP): participation of European Commission, European Union countries, industry representatives, feedstock producers, academia and non-governmental organizations

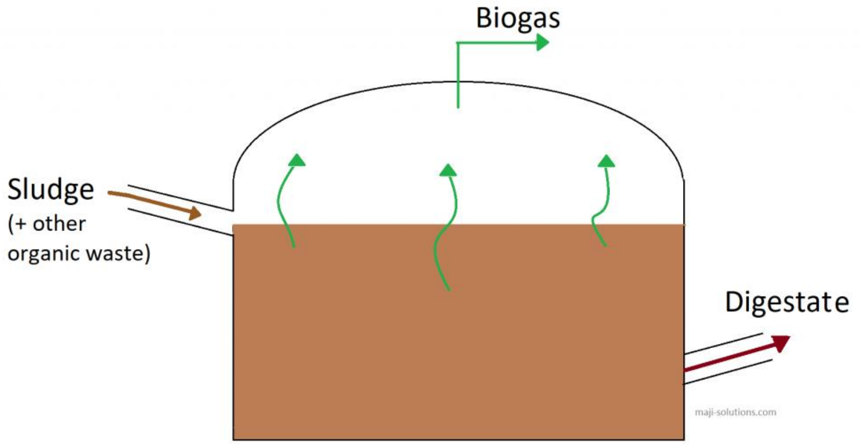
Introduction (II)

- Anaerobic Digestion (AD) → Crude biogas production, consisting of:
  - Methane (50-75%), Carbon Dioxide (50-25%)
  - Minor impurities (Hydrogen Sulfide H_2S, NH_3, Moisture, Siloxanes)
- Necessity of pre-treatment for the elimination of the minor impurities
- Biogas Upgrade: CO_2 separation from biogas

➡ Biomethane Production: Target of > 95% Purity

Co-generation of electrical and thermal energy

Transport (bio-CNG and bio-LNG)



Introduction – Biogas-Up Project

Biogas-Up project aims at:

- The holistic exploration of an innovative system for biogas upgrading, by using polymeric membranes.
- Enhancement of biogas production through the possible permeate recycling and CO_2 capture (and further utilization).
- A renewable energy technology, focusing on the production of **biomethane**.

In the present work accomplished:

- The design and construction of a pilot-scale biogas upgrading system in Thessaloniki's Wastewater Treatment Plant (Sindos, Gr).
- The design of a 2-stage membrane set-up for the upgrade of biogas, operating under pilot-scale conditions.
- The application of polyimide hollow fiber membranes (obtained from UBE Industries, Japan).
- The evaluation of separation efficiency and the achieved CH_4 recovery and purity.

Biogas-Up Partners

<u>Title:</u> Biogas upgrade with simultaneous recycling and utilization of carbon dioxide to optimize anaerobic sludge treatment.

Website: www.biogasup.gr

Partners:

- ✓ ELGO Demeter research organization,

  Waste Management and Bioprocessing lab
- ✓ Aristotle University of Thessaloniki,

  Department of Chemistry &

  Department of Chemical Engineering
- ✓ AKTOR with the collaboration of

  Thessaloniki Wastewater Treatment Plant (EYATh)

Duration: 2020-2023

Biogas Production

Thessaloniki Wastewater Treatment Plant (WWTP)

Anaerobic Digesters

- 6 large closed cylindrical tanks (V ~7. 500m^3/each)
- Operation at mesophilic region of 35 ℃.
- Residence time in the digesters: 17-18 days.
- Each tank employs 4 Heat-mixers:
  - Maintenance of temperature at 35 ℃
  - Sludge stirring inside of the tank

<u>Average Biogas Production Capacity</u>: ~20.000 Nm^3/day

Desulfurisation Unit (I)

- **Biofilters**

The biogas passes through the biofilter bed, and the pollutants are transported to the biofilm, where they are used by the immobilized bacteria as a carbon or energy source → Degradation/removal of H_2S. During the desulfurization process the biogas stream is cooled at 10° C and reheated at 30-35° C.

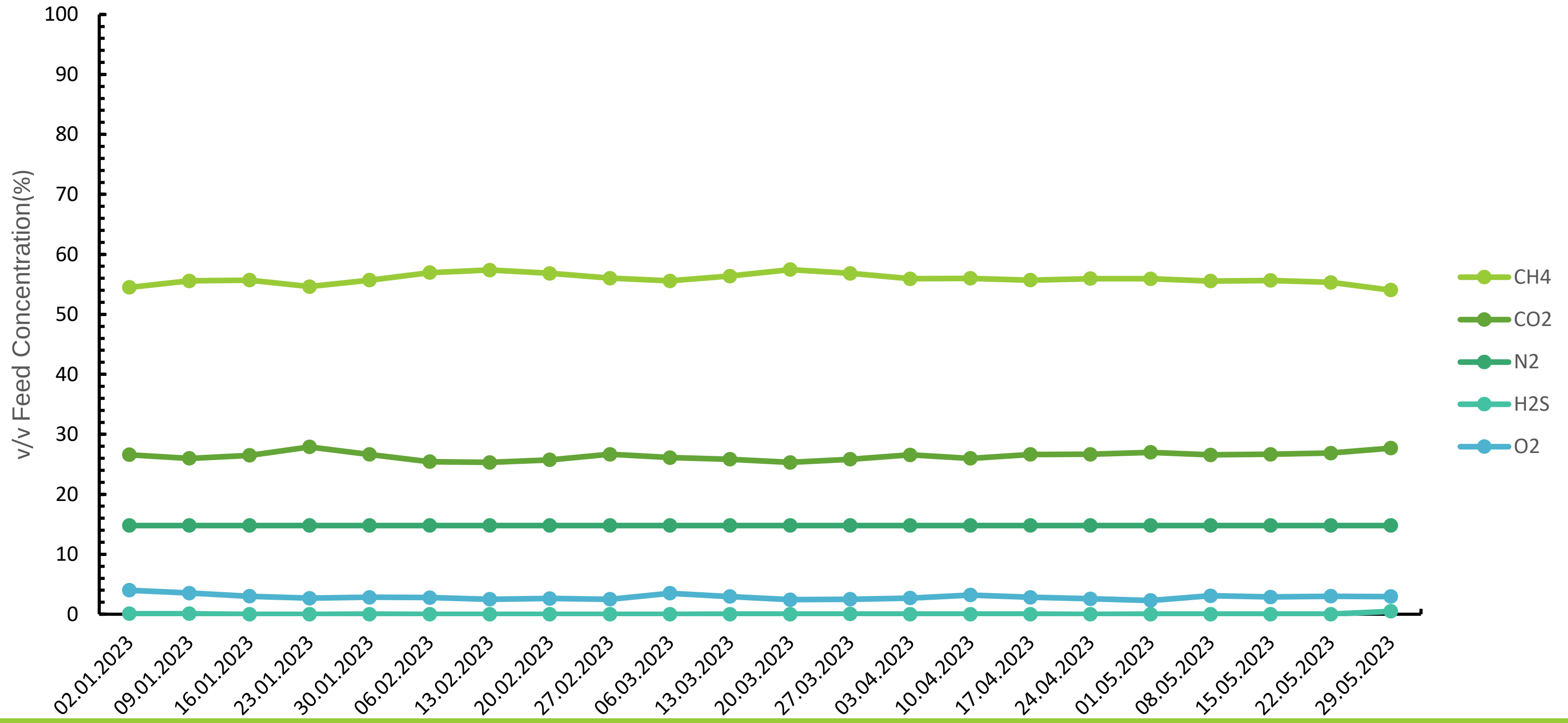
- However, the presence of aerobic microorganisms in this unit leads to increase of N_2 and O_2 concentrations in the pretreated biogas after H_2S removal.

Table 1: Initial conditions before desulfurisation

CH_4 (% v/v)	65-71
CO_2 (% v/v)	28-31
Pressure (mbar)	18
Temperature (°C)	<35 - 38 (digesters' temperature)
H_2S (ppm)	5.600 – 8.900
Average daily capacity (m^3/day)	20.256

Desulfurisation Unit (II)

- Biogas feed concentration v/v% before entering the (membranes) upgrading unit
- 4 months of operation and sampling



Polyimide Membrane Unit

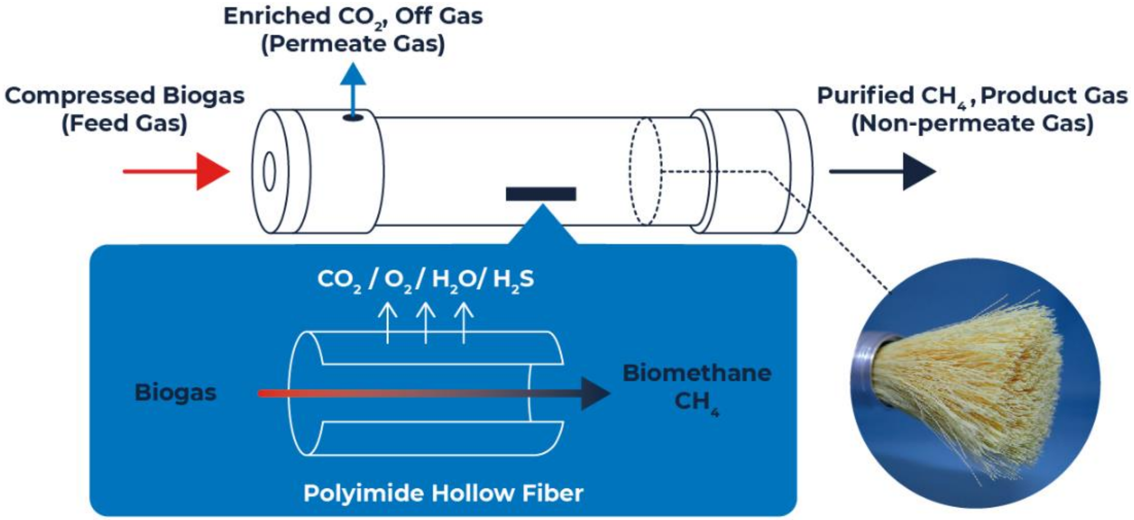
Biomethane exploitation in the WWTP:

- Connection to the central feed line of co-generation engines.

- ➢ 2 stage separation with Polyimide Hollow fiber membranes
- ➢ Recirculation of the 2nd stage permeate stream
- ➢ Membranes from UBE Industries Ltd. (Japan)

Operating conditions of pilot membrane unit

Initial flow rate (m^3/hr)	20.0
Flow rate after recirculation (m^3/hr)	26.3
Operation Pressure (MPa)	1.03
Temperature (℃)	25



Compressor

Manufacturer: Adicomp S.A. (Italy)

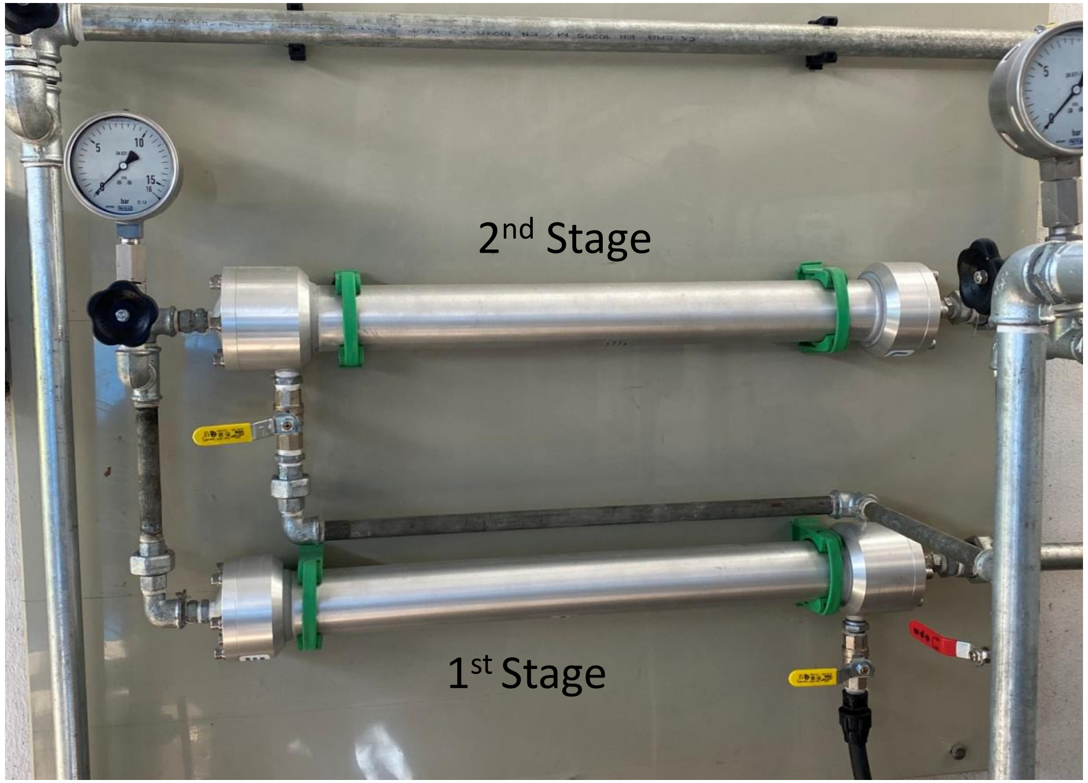
- Biogas pressure after desulfurization: Ambient 0.1 MPa

→ Needs compression to reach the desired separation pressure for the efficient operation of membranes

Effective driving force during separation: ΔP = 11.3 MPa

Biogas pressure after compression: 11.3 MPa

Biogas membrane Upgrading Unit (I)



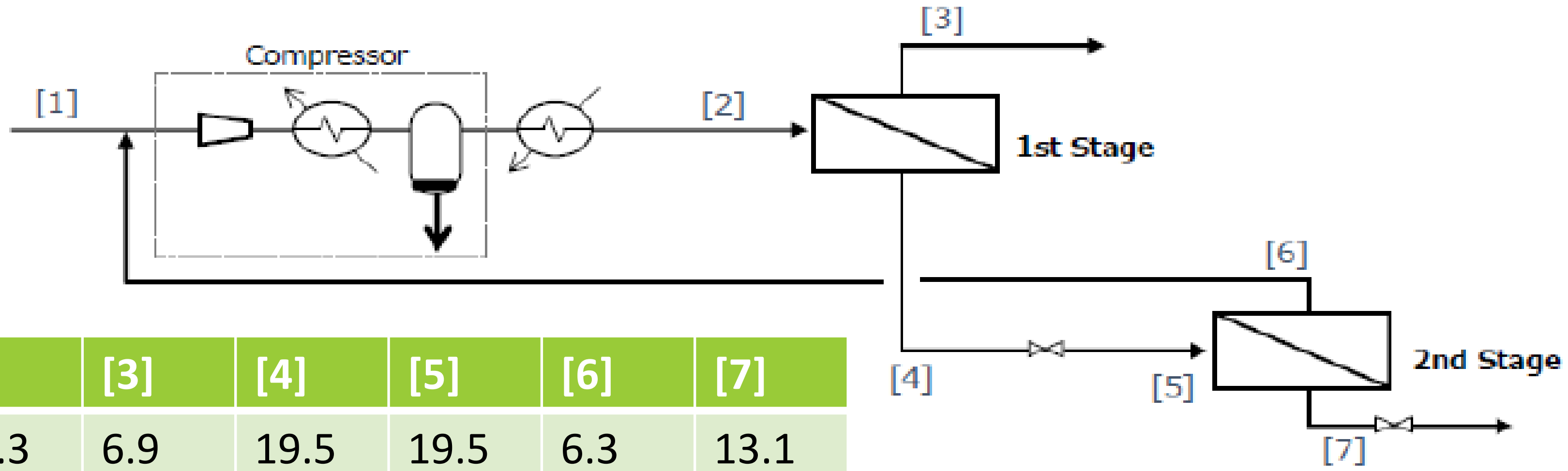
- Pressure Indicators at every stream for ΔP control

1st stage: Retentate → feed for the 2nd stage
Permeate → CO_2 – rich stream with can be captured for possible re-utilization

2nd stage: Retentate → Final biomethane /Product stream
Permeate → Recirculation and re-entry at the initial feed

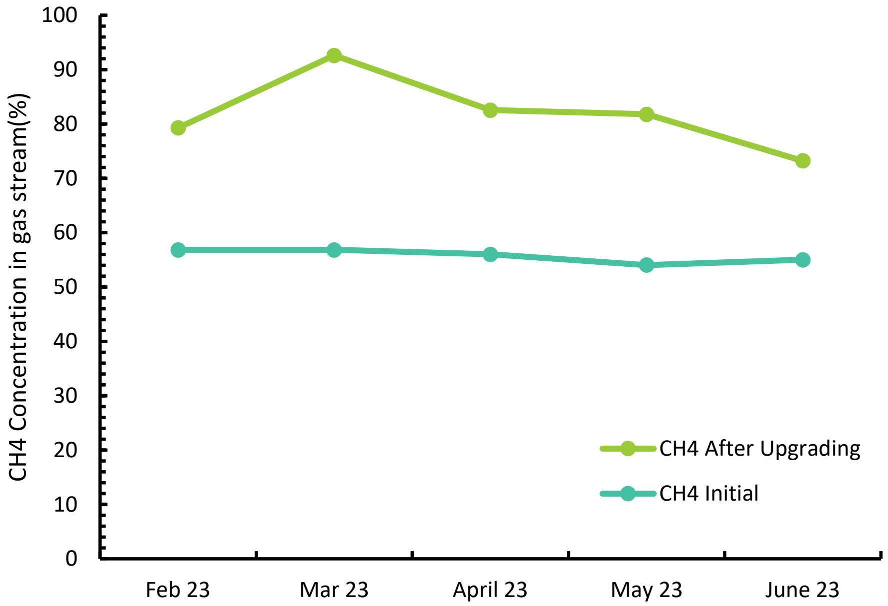
Biogas Upgrading Unit (II)

Process Flow Diagram



No.	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Flow rate (m^3/h)	20	26.3	6.9	19.5	19.5	6.3	13.1
Pressure (MPaG)	0.0	1.13	0.0	1.1	1.1	0.0	1.09
Mol% (composition)							
CH_4	51.52	45.87	4.73	60.38	60.38	27.98	75.96
CO_2	30.74	31.79	85.71	12.76	12.76	36.68	1.25
N_2	14.78	16.58	3.24	21.29	21.29	22.29	20.81
O_2	3.46	5.76	6.31	5.57	5.57	13.04	1.97
Total	100	100	100	100	100	100	100

Produced CH_4 Purity and recovery investigation



Recovery Investigation

$$\% \, Recovery_{CH4} = \frac{Q_{CH4,retentate\ side} \times \%CH_4 Purity_{retentate}}{Q_{CH4,feed}}$$

Average experimental CH_4 recovery	93.8 %
Theoretically calculated CH_4 recovery	96.75 %
Theoretical – experimental deviation	3.1 %

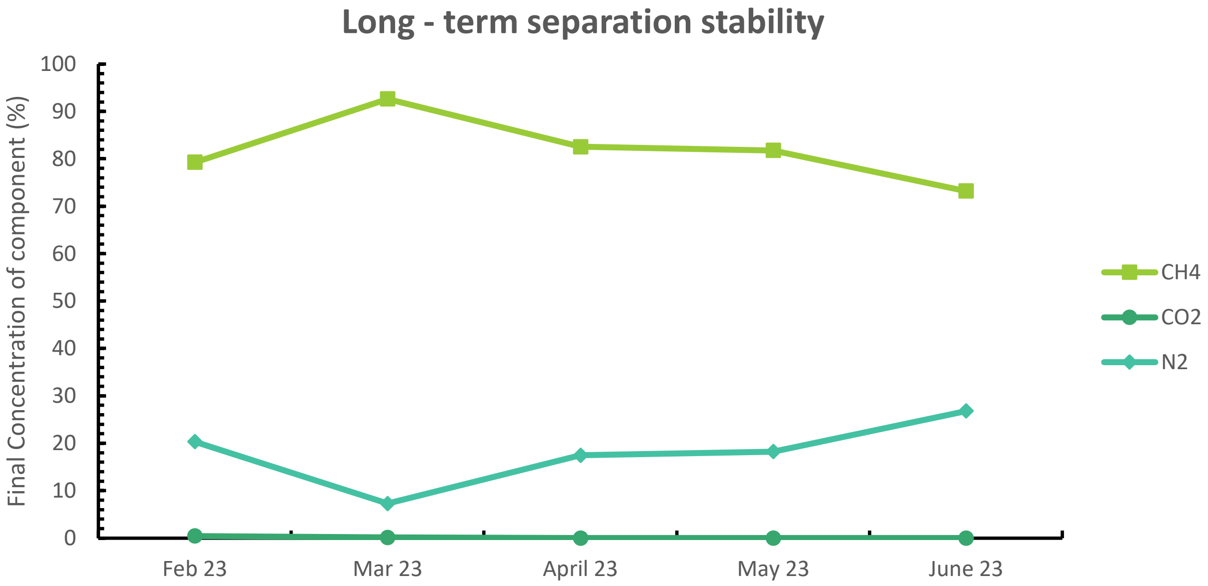
Results

Biogas concentration analysis
GC – 2014 (Shimadzu, China)

Average % Purities and Recoveries of CH_4

	AVERAGE CH_4 PURITY	AVERAGE CH_4 RECOVERY
FEB-23	79.3	91
MAR-23	93.2	100
APR-23	79.1	93.9
MAY-23	80.6	96.7
JUNE-23	79.9	96.9

Results



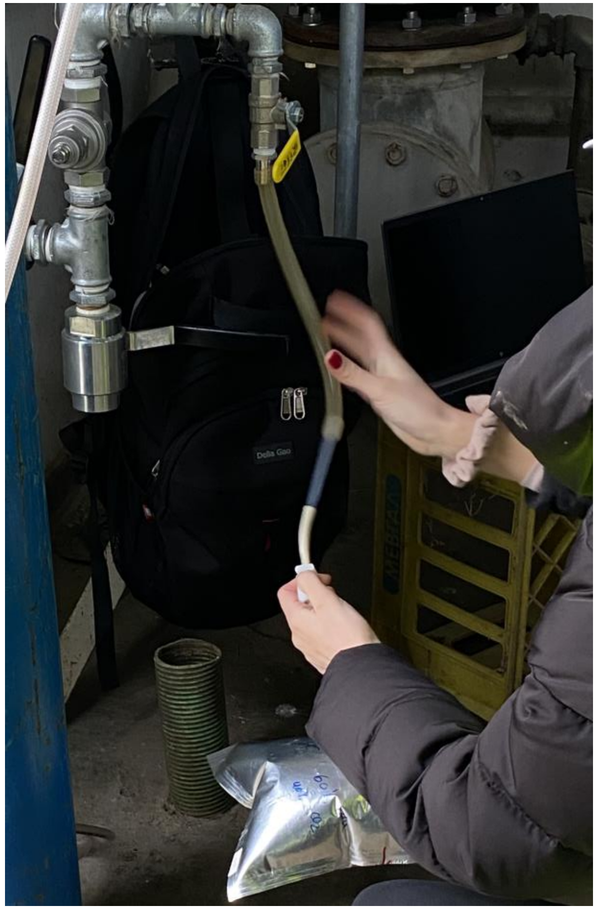
<u>**Study of the process stability**</u> during:

a) Continuous operation for 2 hours and sampling each 30 minutes.

b) Monthly operation, comparing the average CH_4 concentrations.

Conclusions (I) - general

- Achieved CH_4 purity: > 80%
- Achieved CO_2 elimination in the product stream.
- N_2 content in the product stream: ~ 20%
- CH_4 Recovery : 93.8 %



Conclusions (II) - specific

- Long-term feed composition stability study of the pre-treatment process and the feed stream of the pilot upgrading plant.
- Study of the long-term stability of final product composition by comparing recommendations for the samples during the 5 months of operation of pilot-plant
- Study of the short-term stability of the composition of product by comparing the analysis of the samples taken at a fixed interval of 30 minutes after 2 hours.

Thank you for your attention

QUESTIONS?????

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