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SYNGAS COMPONENTS RECOVERY DURING MEMBRANE GAS SEPARATION

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PRESENTATION OUTLINE

- **Introduction**, motivation
- **Challenges**
- **Experimental setup**, initial measurements
- **Real vs. Ideal Selectivity** (and permeability)
- **Component Recovery** as a solution
- **Conclusions**

INTRODUCTION

- **Motivation:** Gasification provides a solution for waste-to-fuels and waste-to-chemicals conversion.
- Gasification-produced syngas (H_2, CO, CO_2 and CH_4) requires improving before further utilization.

Solution = Membrane operations?

- Description of process is required
- How to describe multicomponent mixtures?

CHALLENGES

- Obtaining a reliable **parameter for description** of behavior:
  - Permeability usable for pure components
  - Selectivity? Is it constant?
  - Other parameters?
- **Multicomponent mixtures** description:
  - One component is easy, two components mixtures is doable.
  - Multicomponent (3+ mixtures) bring complications
- Finding a **simple enough** and **dynamic method** for prediction/modelling
  - Current state: Mostly numerical simulations

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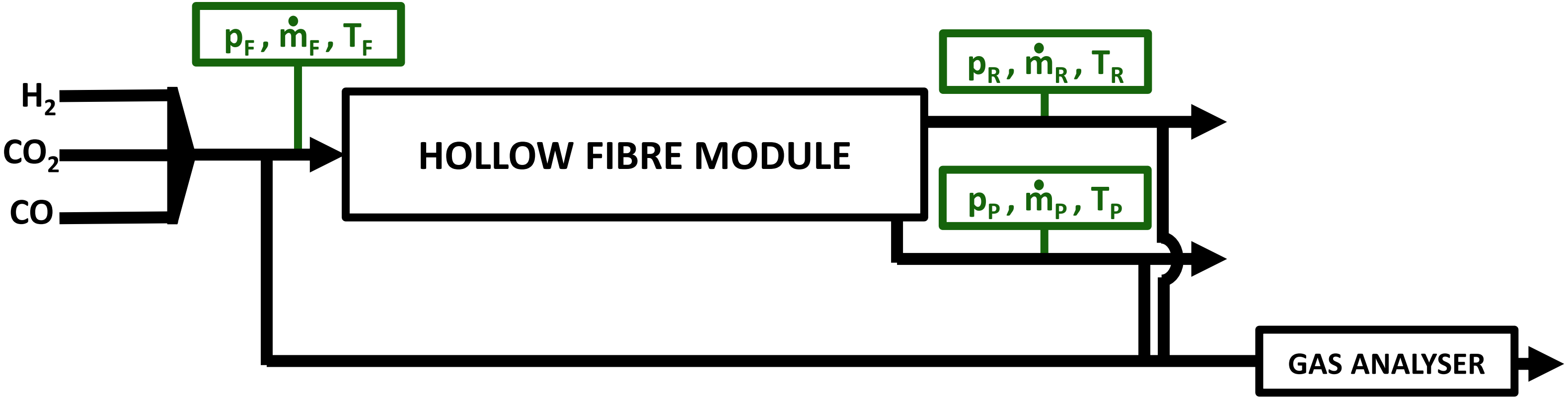
EXPERIMENTAL SET UP AND METHODS

- Laboratory membrane unit **Ralex GSU-LAB-200**
- Membrane module: Polyimide hollow-fibre module

($L = 290$ mm $D_o = 0{,}3$ mm $T_{Wall} = 12$ µm $N_{\#} = 3000$)



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EXPERIMENTAL SET UP AND METHODS

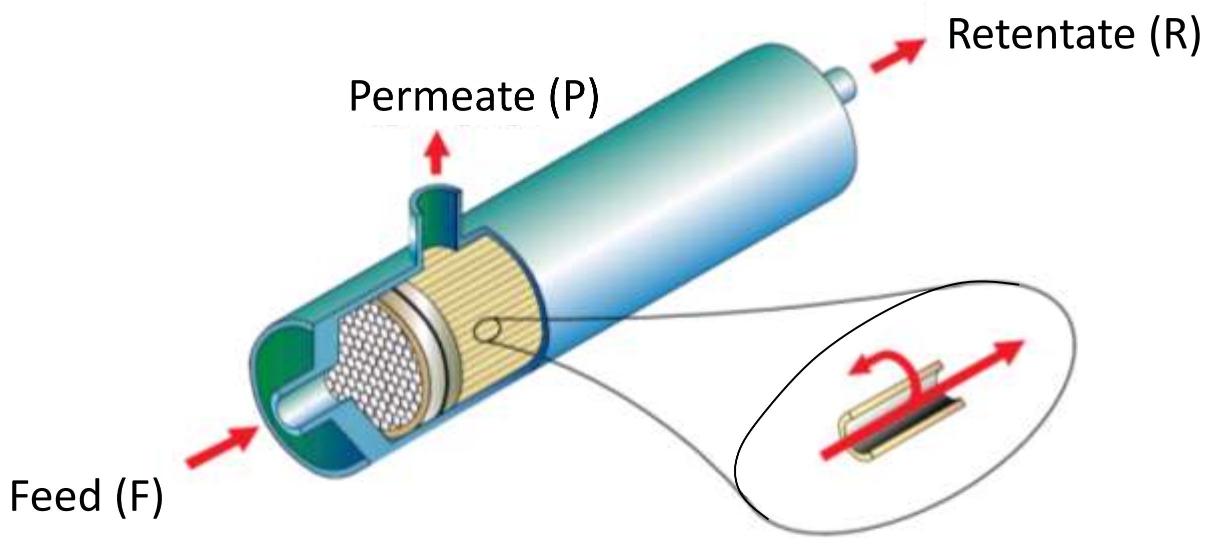


Image: Reynolds, Thomas & Bailey, Delbert & Lewinski, Daniel & Roseburg, Conrad & Palaszewski, Bryan. (2001). Onboard Inert Gas Generation System/Onboard Oxygen Gas Generation System (OBIGGS/OBOGS) Study.

EXPERIMENTAL SET UP AND METHODS

- Three model mixtures were tested
- Derived from biomass gasification-produced syngas.
  - Concentrations of components vary ~ gas. process conditions (literature rev.)

Label	$c_F(H_2)$ [%mol]	$c_F(CO)$ [%mol]	$c_F(CO_2)$ [%mol]
15-35-50	15	35	50
25-35-40	25	35	40
35-35-30	35	35	30

PURE COMPONENTS FOR MODULE DESCRIPTION

Permeability = how easily the component passes through a unit of area of the given membrane module at certain pressure difference

$$P_i = \frac{n_i * L}{S \cdot \Delta p} = \frac{J_i}{\Delta p}$$

	Permeability (Barrer)
H_2	1380 ± 62
CO_2	343 ± 11
CO	23 ± 1

$$1 \text{ Barrer} = 3.35 * 10^{-16} \frac{\text{mol m}}{\text{m}^2 \text{ Pa s}}$$

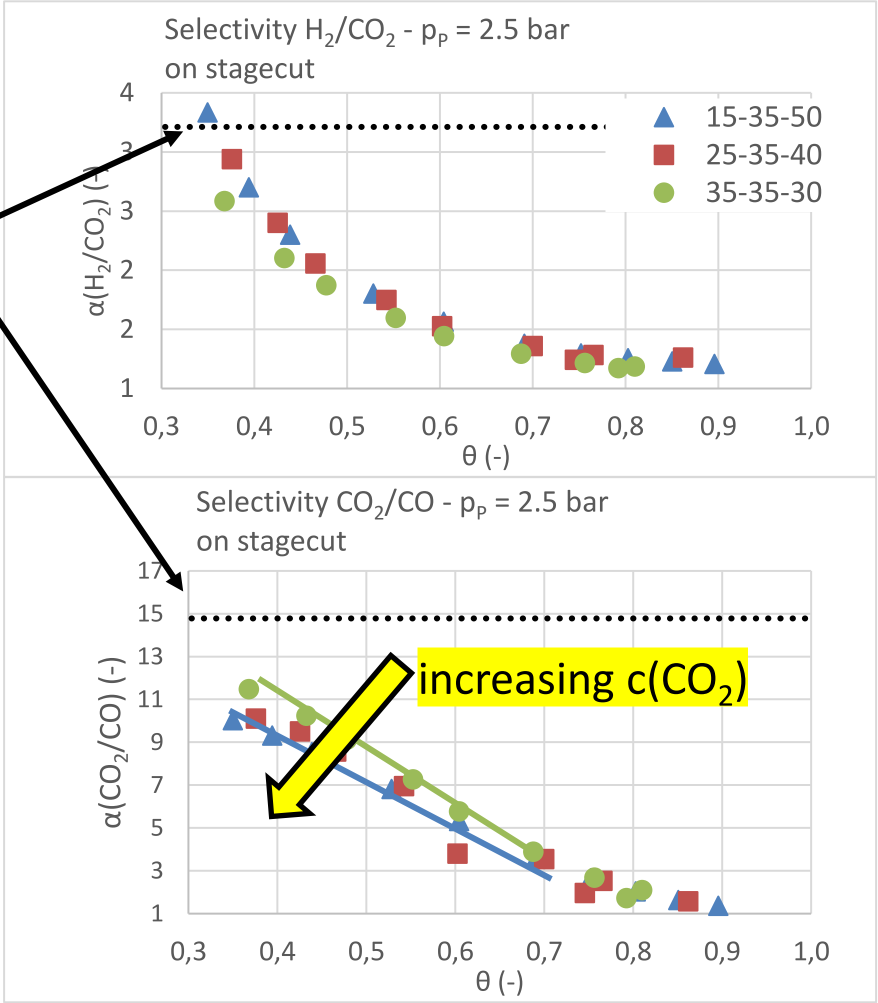
IDEAL vs. REAL SELECTIVITY

$$\alpha_{i,j} = \frac{P_i}{P_j}$$

Ideal	$\alpha_{i,j}$
H_2 / CO_2	3.21
CO_2 / CO	14.77

$$\theta = \frac{n_P}{n_F}$$

Min ($\alpha_{real}/\alpha_{ideal}$)	
H_2 / CO_2	~40 %
CO_2 / CO	~10 %



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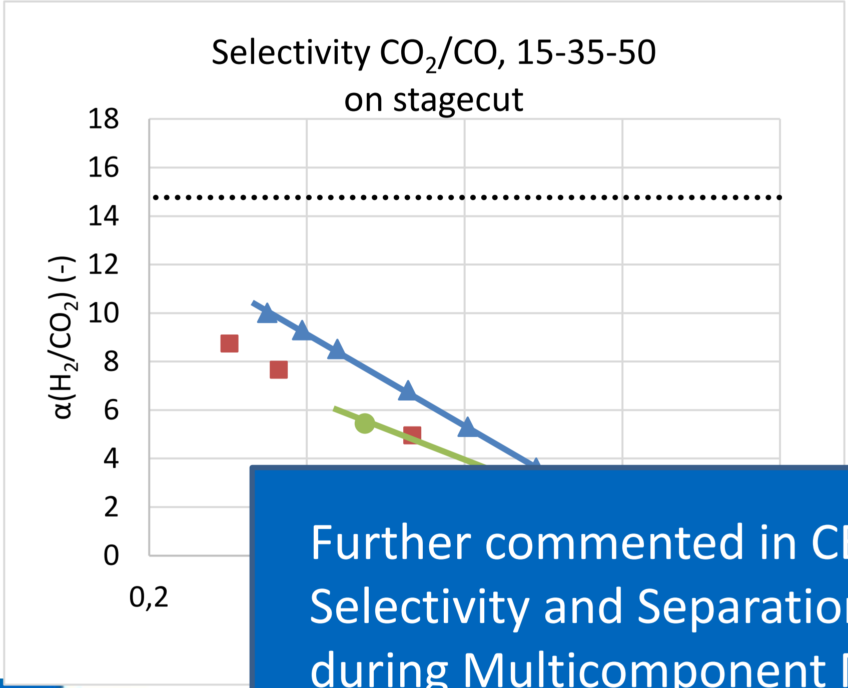
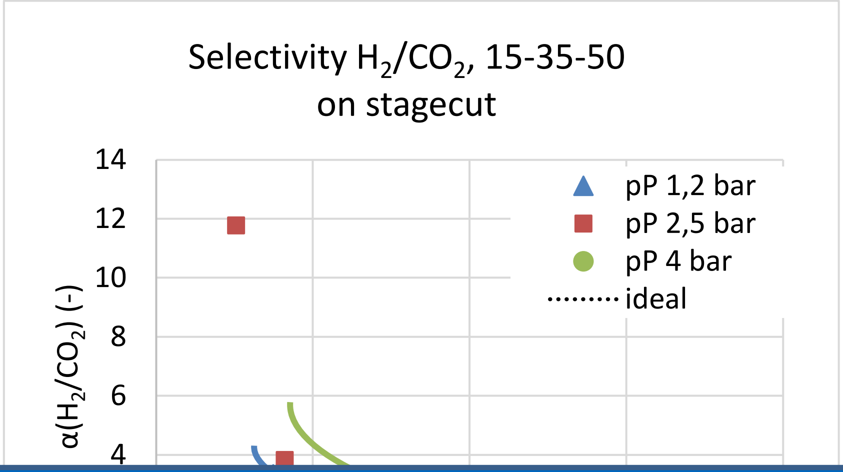
IDEAL vs. REAL SELECTIVITY

- Varying Permeate pressure





Further commented in CET: Seghman, P., Krátký, L., Jirout, T.: Selectivity and Separation Factor for Components during Multicomponent Membrane Gas Separation, CET (vol. 92)

COMPONENTS RECOVERY

- **Recovery = dimensionless**

  = percentage of the component that permeated through the membrane.

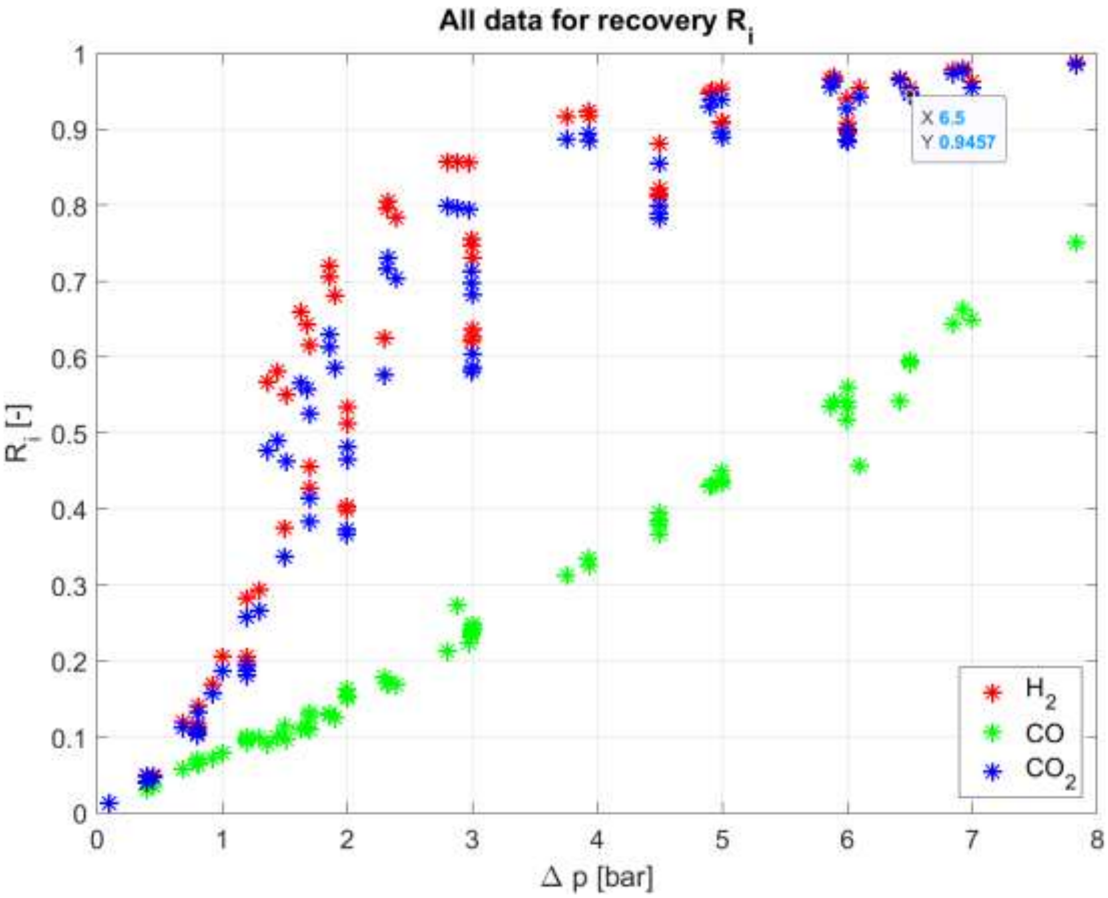
$$R_i = \frac{(n_i)_{Perm.}}{(n_i)_{Feed}}$$

- Advantages:
  - Relative to components: Easy to compare components in one mixture
  - Value **range** unaffected by module and process conditions: Ability to compare different modules and technologies
  - Bottom and Upper boundaries: Ranges between (0; 1)

COMPONENTS RECOVERY - All data

Tested **3 model mixtures** for **3 permeate pressures.**

p_P = 1.0, 2.5 and 4 bar mixtures as mentioned before.



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MODEL FUNCTION AND DIMENSIONLESS PRESSURE

- Based on experimental data and dimensionless analysis, following equation proposed:

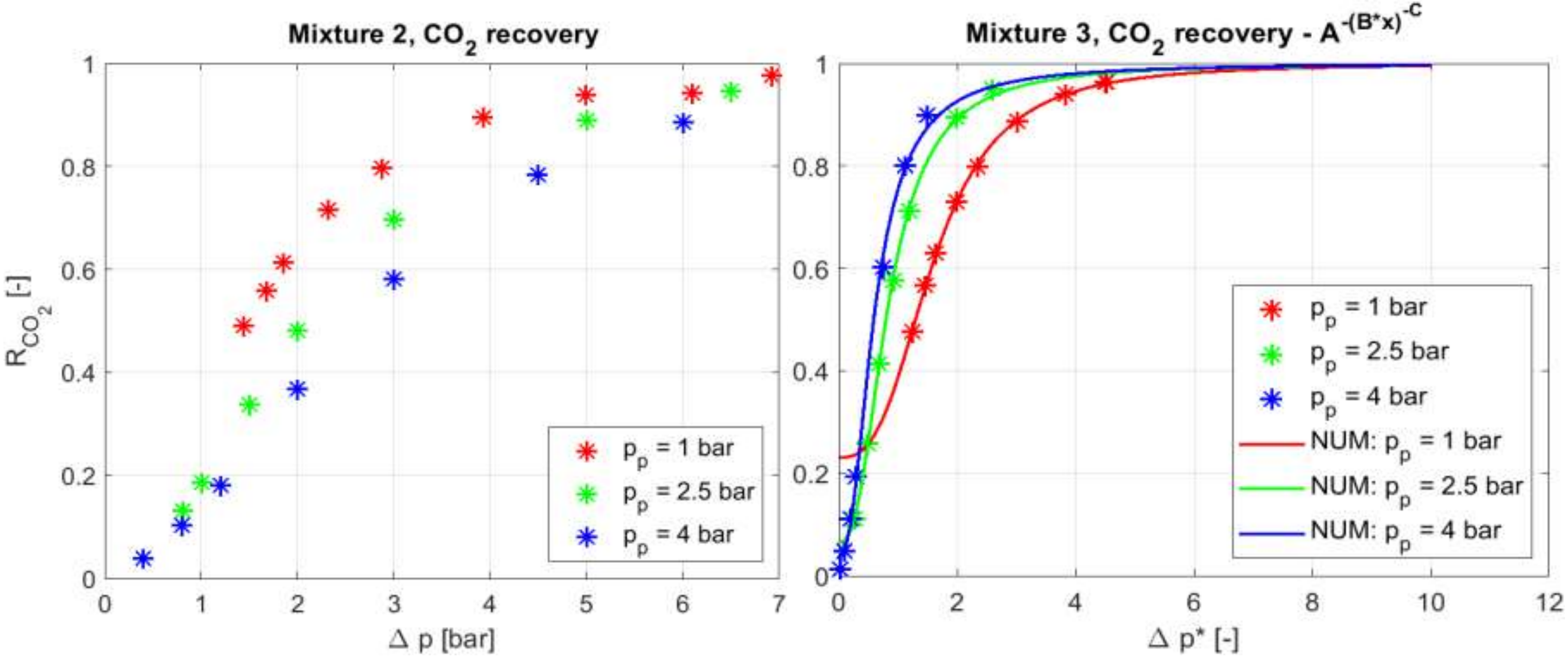
$$R_i = A \wedge \left[-\frac{1}{B + C * (p^*)^D}\right]$$

where A, B, C, D will be parameters defined during following studies, and x is dimensionless pressure defined as:

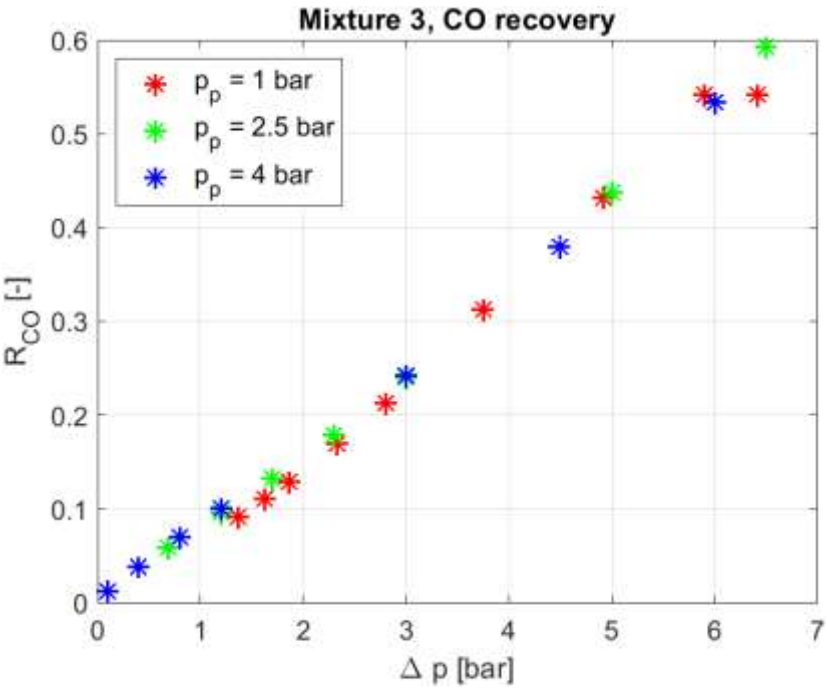
$$p^* = \frac{p_F - p_P}{p_P}$$

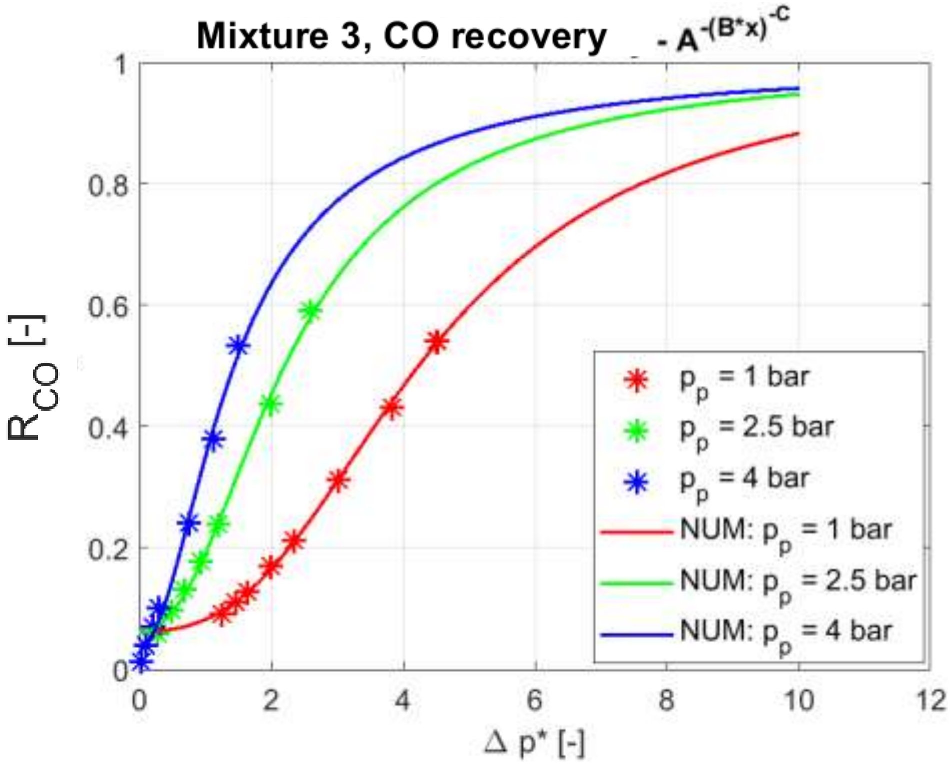
where p_F is Feed pressure and p_P is Permeate pressure.

COMPONENTS RECOVERY – selected CO_2 data

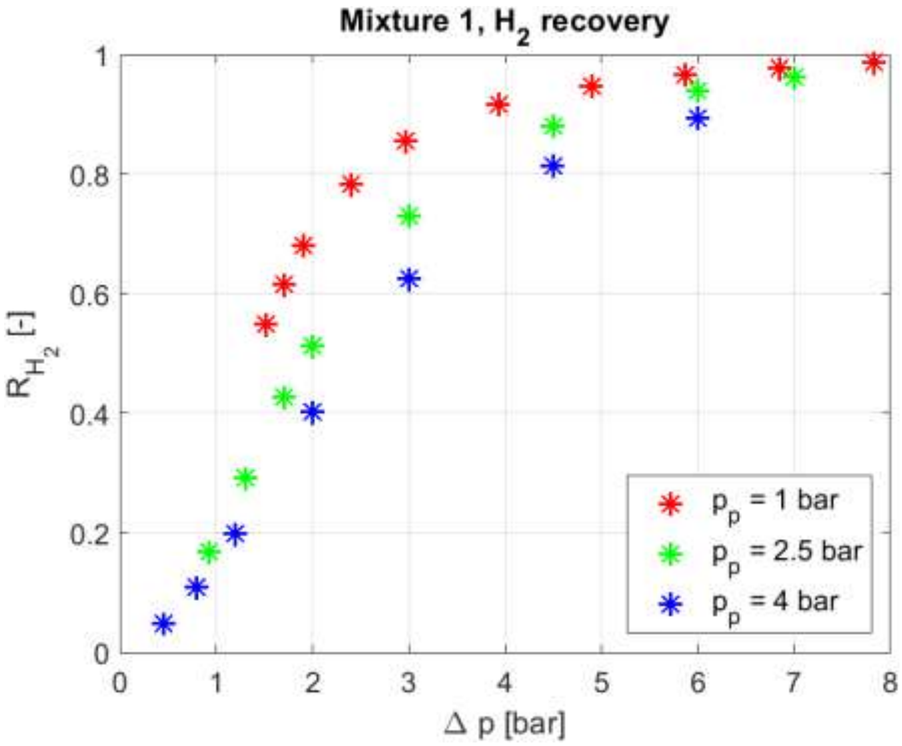


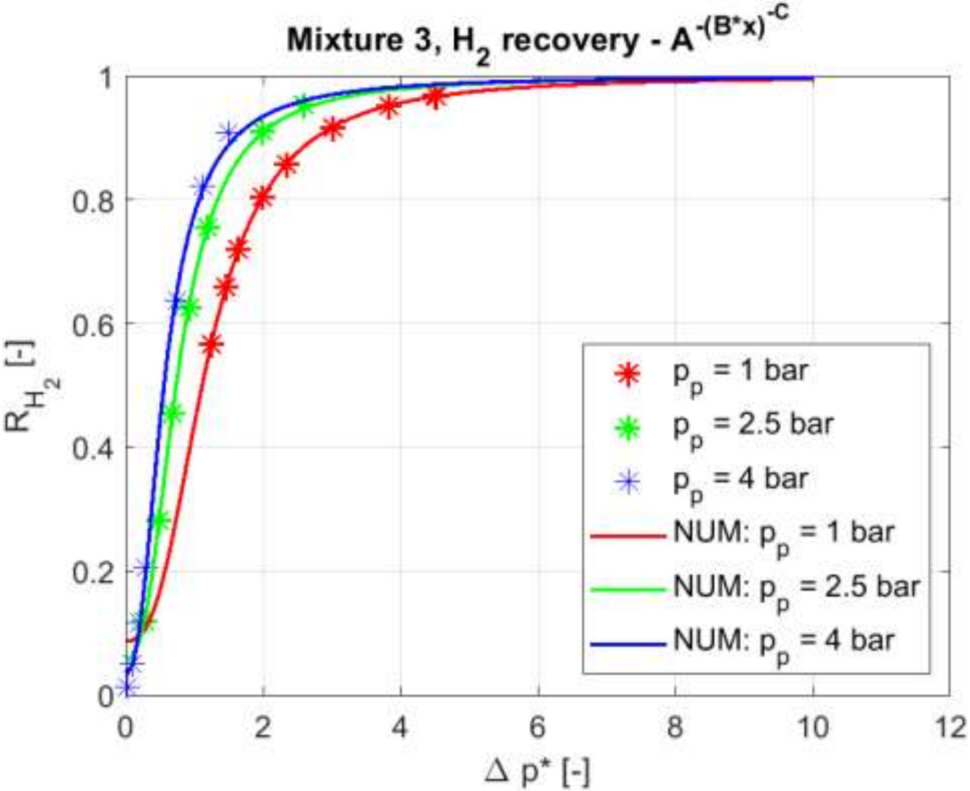
COMPONENTS RECOVERY – selected CO data



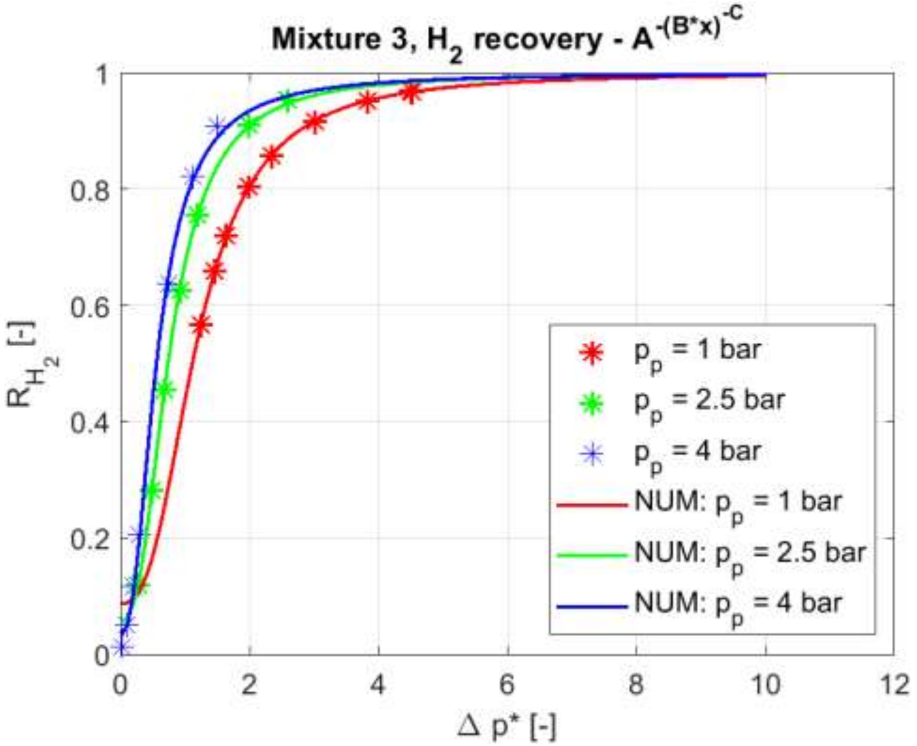


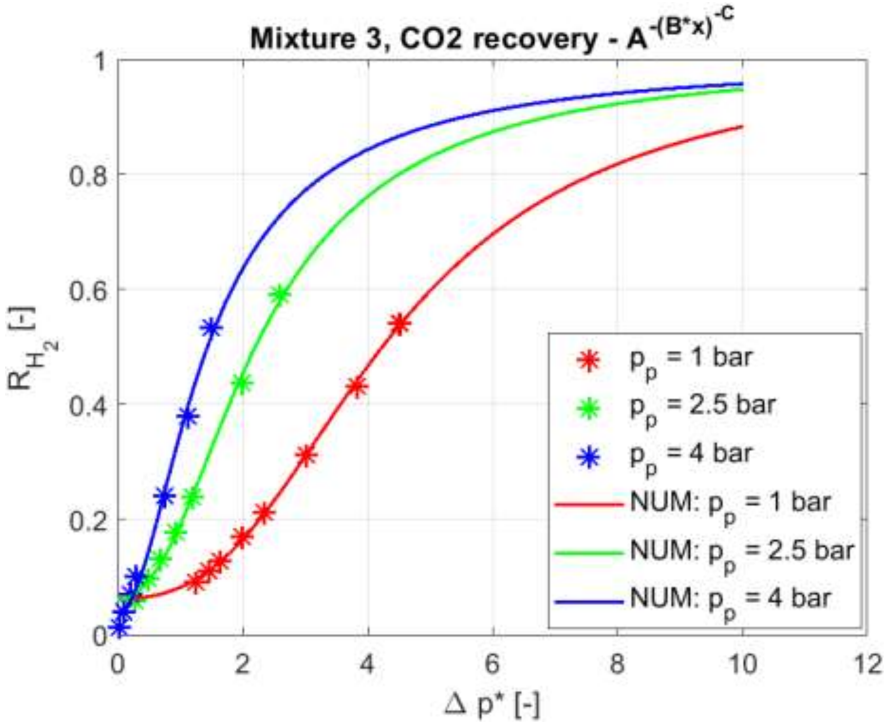
COMPONENTS RECOVERY – selected H_2 data





COMPONENTS RECOVERY – comparison

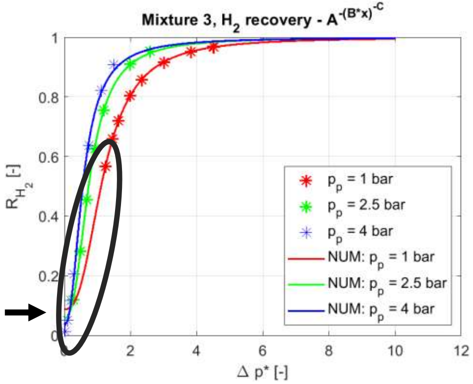


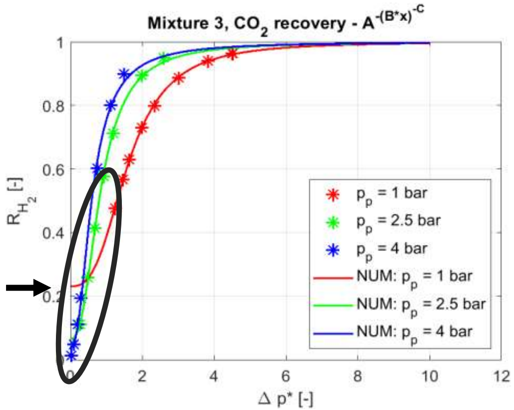


COMPONENTS RECOVERY
– further research

- More data in the low Δp* range (low Δp).
- Denser data for precise fits.
- Parametrisation using dimensionless criteria

$$\left(\Psi = \frac{N*\pi*D_E}{L};\quad P_i^* = \frac{P_i*L*p_P}{n_F};\quad \phi_{i,j} = \frac{P_i}{P_j}\right)$$





Run. experiments: 4 p_P values (1.5, 2.5, 3.5, 4.5) for 4 mixtures (3 overlapping)

CONCLUSIONS

- Ideal selectivity (or pure component permeabilities) should not be used as a fixed value for simulating a multicomponent mixture separation process
- Significant decrease in selectivity (some cases down to 10 % of ideal value) that is dependant on composition and process conditions
- Component Recovery could be suitable for process description (dimensionless, comparable, normalized between 0-1)

THANK YOU FOR YOUR ATTENTION

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- Visegrad Fund

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CCUV4 - Green Deal strategies for V4 countries:
The needs and challenges to reach low-carbon industry.

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