

« Gas Separation Processes: CAPE-OPEN unit operation for Sweep-based Membrane »

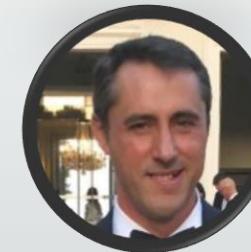
Nancy | 28 October 2021

Presentation

Brief description of the « team »

People involved in the project

- Éric FAVRE
 - Professor at l'Université de Lorraine (ENSIC) - UL
 - *180 publications, 15 brevets, more than 70 contrats with industry)*
 - Specialized on gas/liquid separation through membrane module
- Christophe CASTEL
 - Professor at l'Université de Lorraine (ENSIC) - UL
 - Specialized on gas/liquid separation through membrane module
- Roda BOUNACEUR
 - Research Engineer - CNRS
 - Expert on numerical development
- Jasper van Baten
 - CAPE-OPEN development



Historical

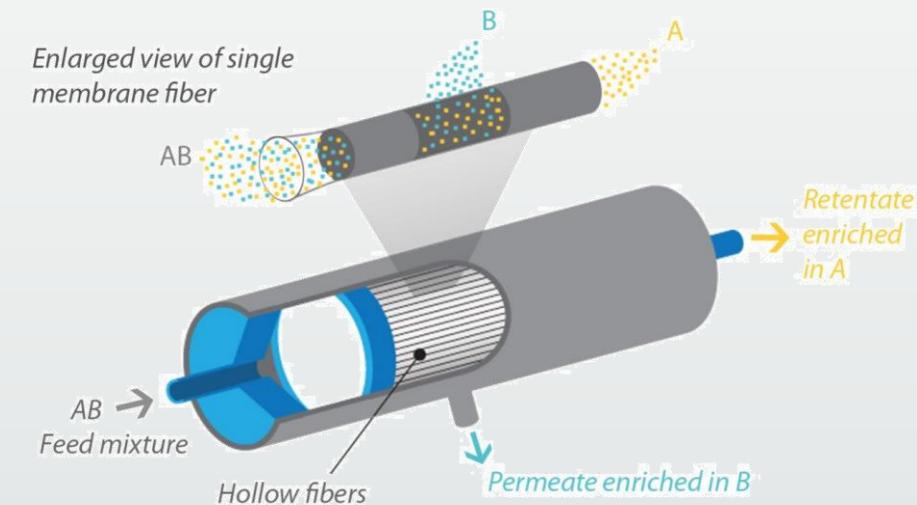
Previous developed Unit Operations

Membrane Gas Separation

Membrane separation technology offers an attractive solution for bringing environmental sustainability to the chemical industries.

Advantages of membrane technology

- ❑ **Simplicity**, plug-an-play process with no regeneration steps
- ❑ **Energy efficiency**, involves no phase change
- ❑ **Environmental friendly**, no chemical reactions or solvents are used
- ❑ **Compactness**, based on intensified separation process



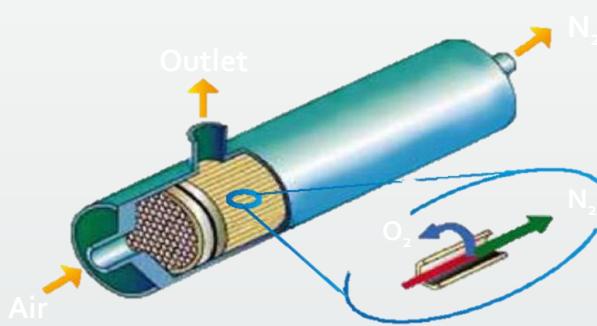
Membrane Gas Separation Simulator

- MEMSIC
 - Isothermal
 - Several transport models (Cross-Flow, Co & Counter current, PSR)
 - Several transfer models (constant permeability, dual-mode, flory-huggins, ...)
 - **Commercialized** (<http://memsic.tech/>)
- MEMSIC 2.0
 - Joule-Thomson effect
 - Pressure drop estimation
 - **Not commercialized**
- *SWEET*
 - *New tools*
 - *Energy mass balance*
 - *Co- or Counter -current flow pattern*
 - *The Pressure drop is considered*

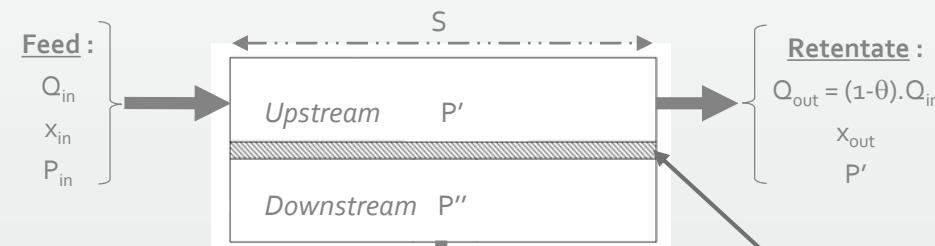
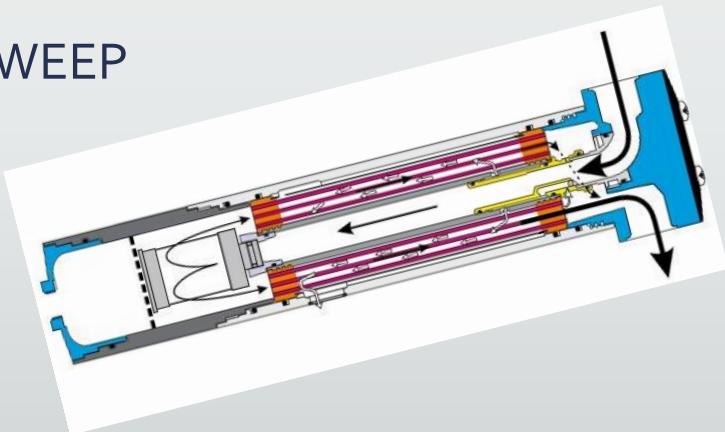


SWEEP

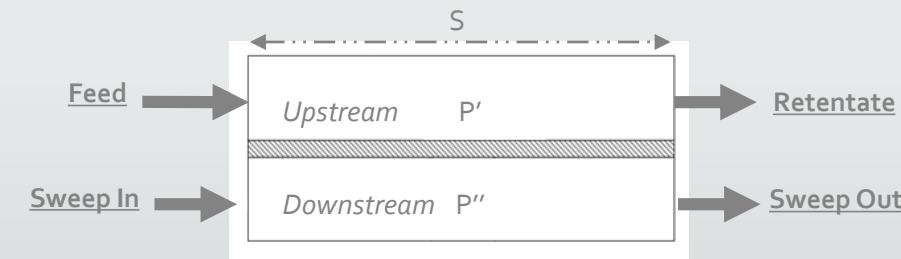
- MEMBRANE



- SWEEP



$$P' > P''$$



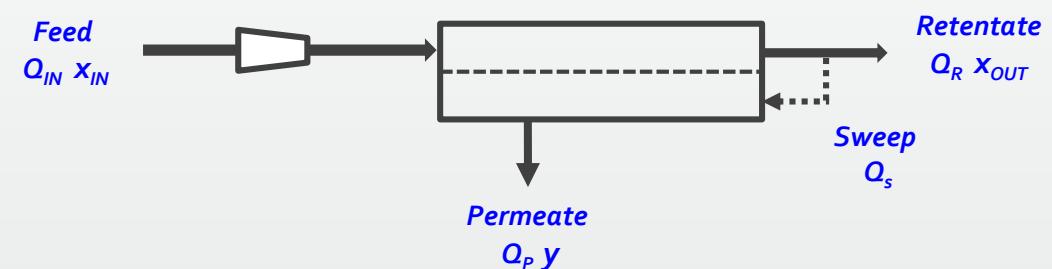
P' & P''
are not linked

SWEEP

- Retentate to permeate recycle – Retentate Recycle flow rate

Applications:

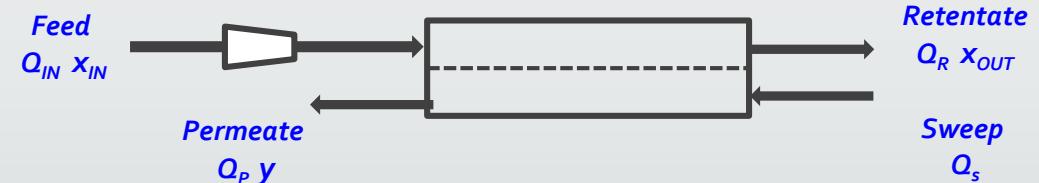
- Gas drying
- Air conditioning
- Fuel cell humidification
- Membrane energy exchanger



- Retentate Sweep

Applications:

- Carbon capture with reactive membranes (sweep = humidity)
- High temperature reactive membranes (sweep = steam)
- Membrane gas contactor (sweep = air)



Plan

Plan – Case Studies with live presentations

- Case 1
 - Tsuru et al., 1995 – “Permeators and continuous membrane columns with retentate”
 - Experimental validation of our code
 - ProsimPlus®
- Case 2
 - Hao et al., 2014 – “Gas/gas membrane contactor – An emerging membrane”
 - The benefit of a sweep mode flow
 - Aspen HYSYS®
- Case 3
 - Gas drying – a previous study with a company
 - An industrial case
 - AspenPlus®



Case 1

Experimental validation of our code



Permeators and continuous membrane columns with retentate recycle

Toshinori Tsuru, Sun-Tak Hwang*

Center of Excellence for Membrane Technology, University of Cincinnati, Cincinnati, OH 45221-0171, USA

Received 16 February 1994; accepted in revised form 20 July 1994

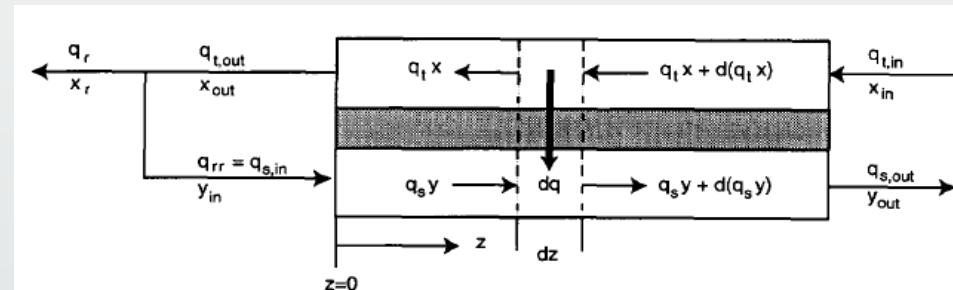
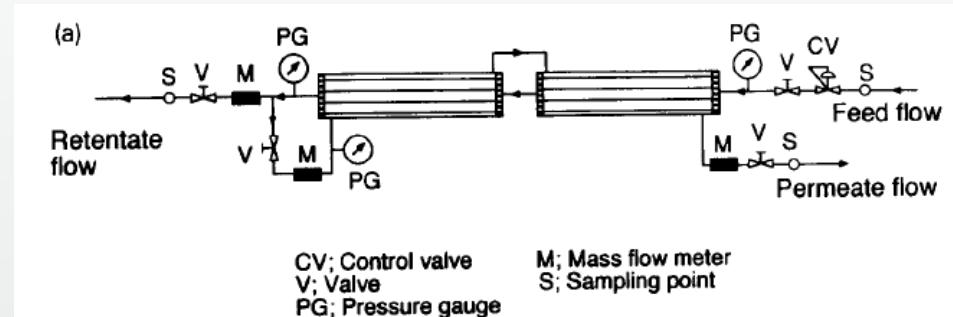
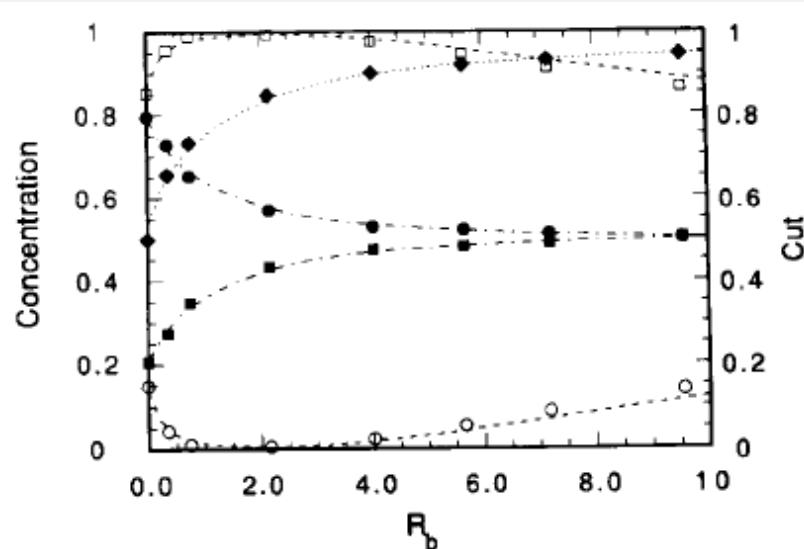
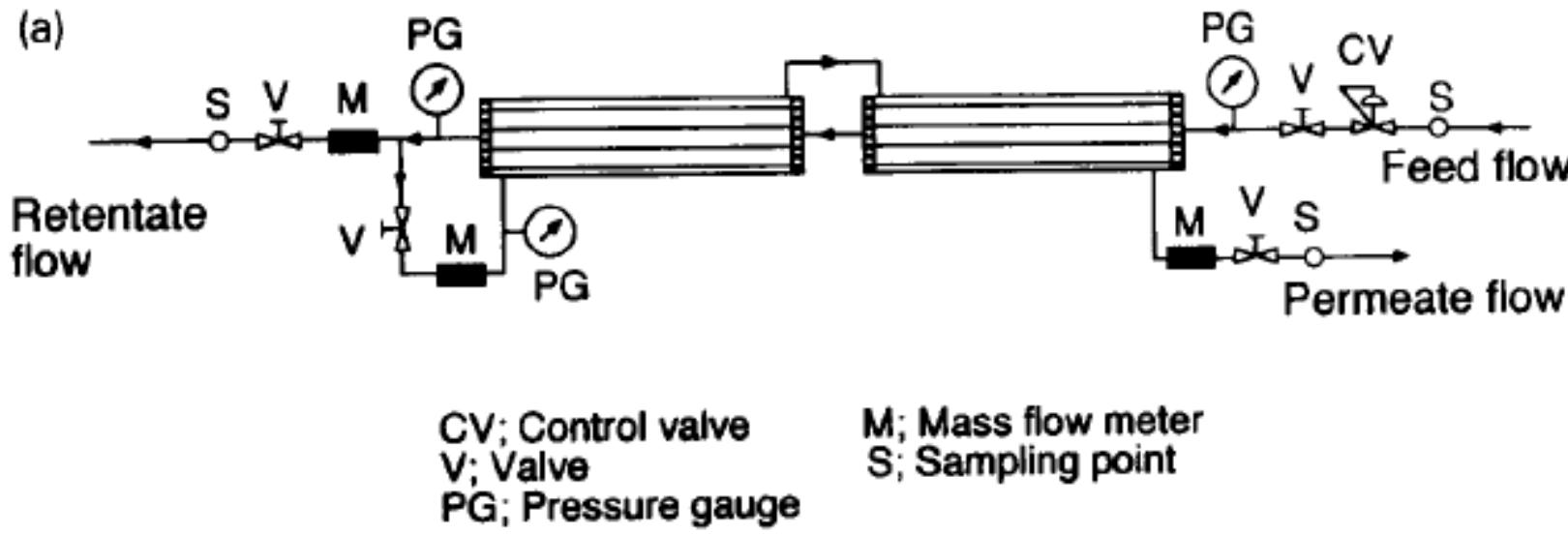


Fig. 3. Material balance for a permeator

$$q_{rr} = q_{s,in} = R_b q_r = R_b \frac{q_{t,out}}{1 + R_b}$$

Rb: Retentate Recycle Ratio



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Rb: Retentate Recycle Ratio

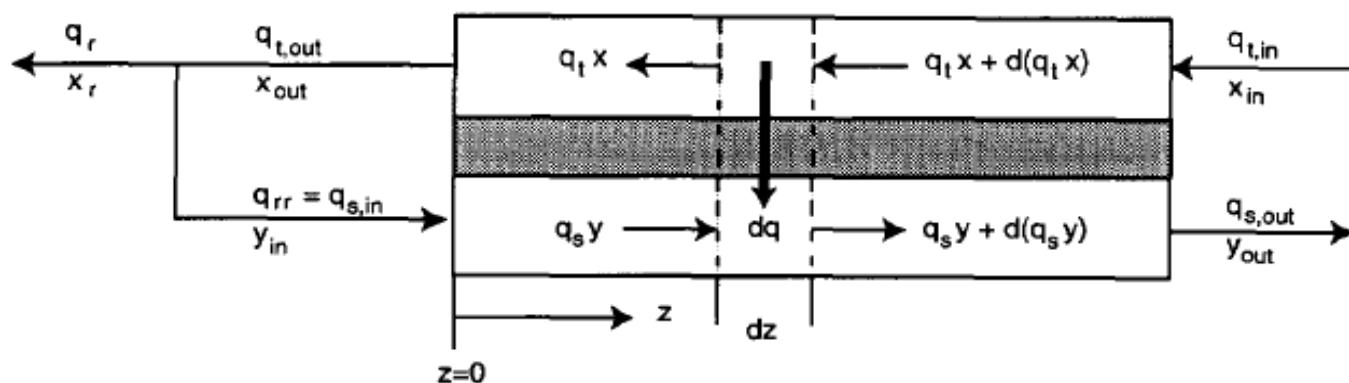
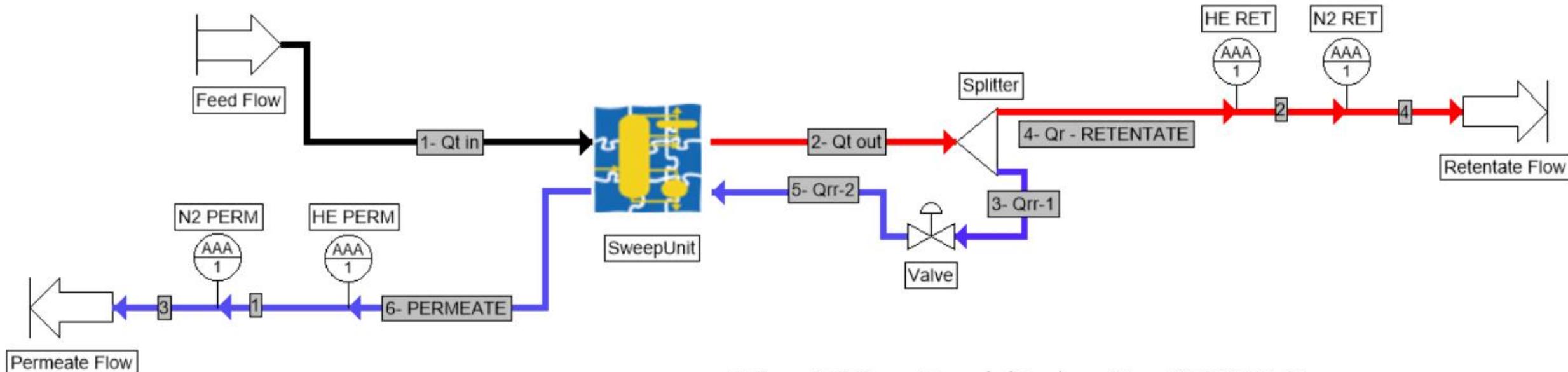


Fig. 3. Material balance for a permeator.

Fig. 5. Concentration as a function of recycle ratio. Permeator, He/N₂ separation (feed=0.48/0.52), $q_r=10\text{ cm}^3(\text{STP})/\text{min}$, $P_h=20$, $P_l=0\text{ psig}$, curves are calculated, points are experimental. Retentate (- - -): He (○), N₂(□); permeate (- · -): He (●), N₂ (■); cut (♦, ⋯).



T. Tsuru, S.-T. Hwang / Journal of Membrane Science 98 (1995) 57–67

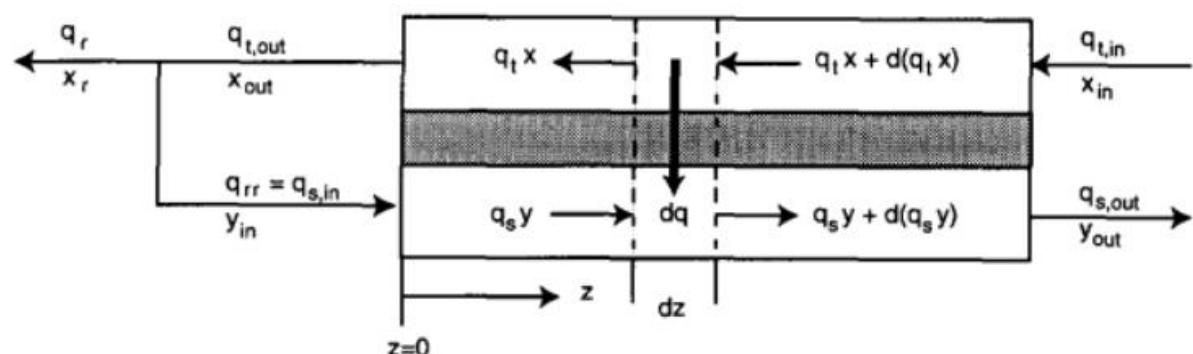
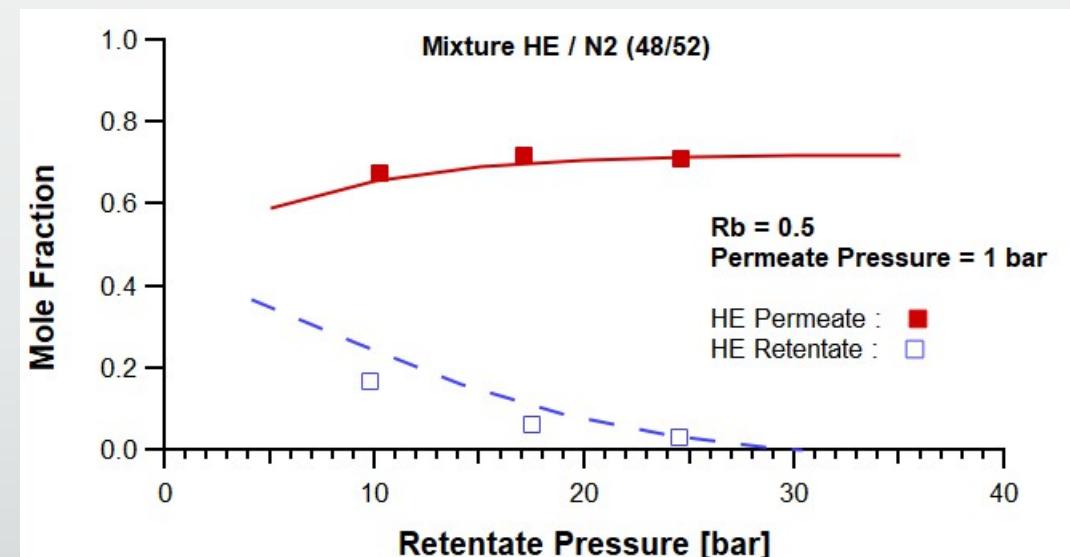
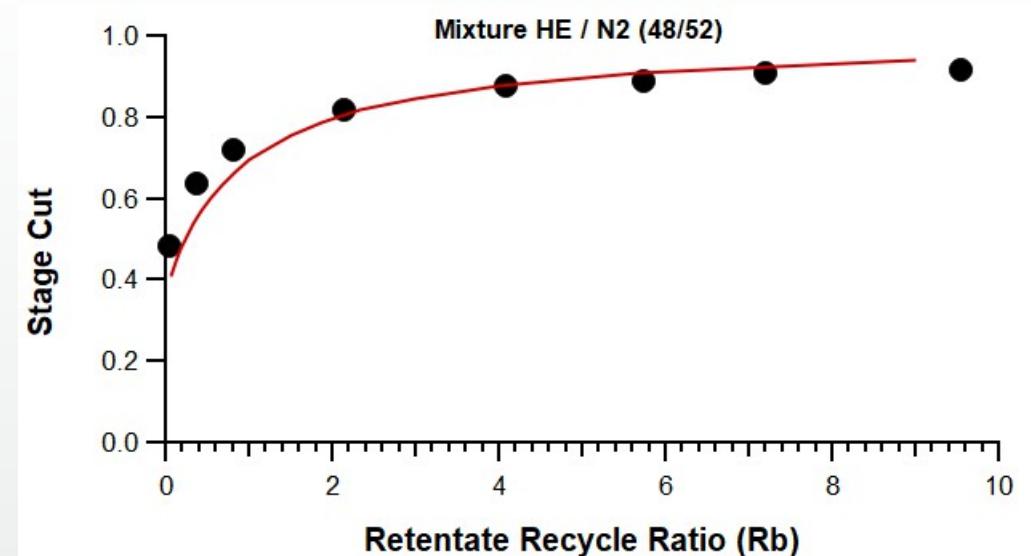
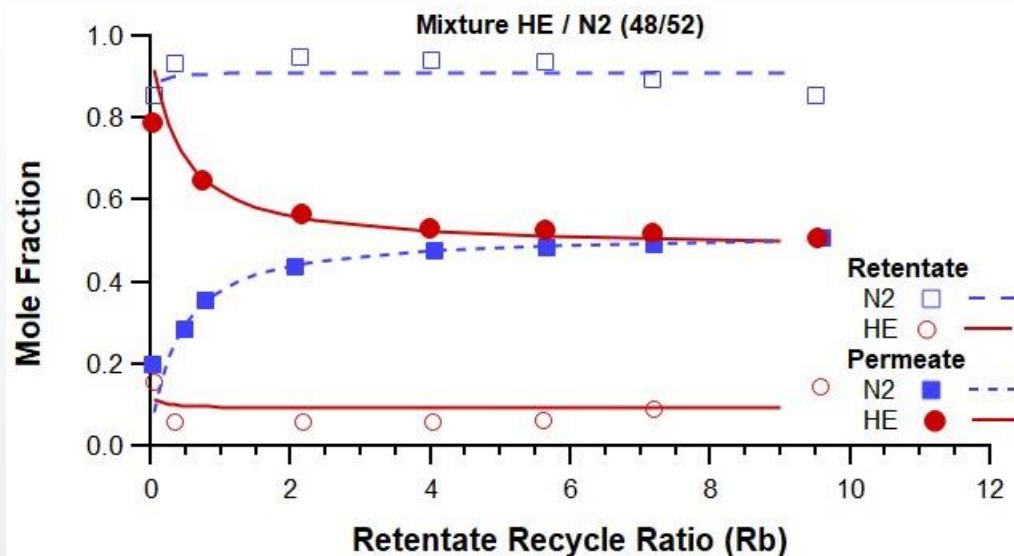


Fig. 3. Material balance for a permeator.





Points: experimental data from Tsuru et al. (1995)

Lines: simulation from Prosim®

Case 2

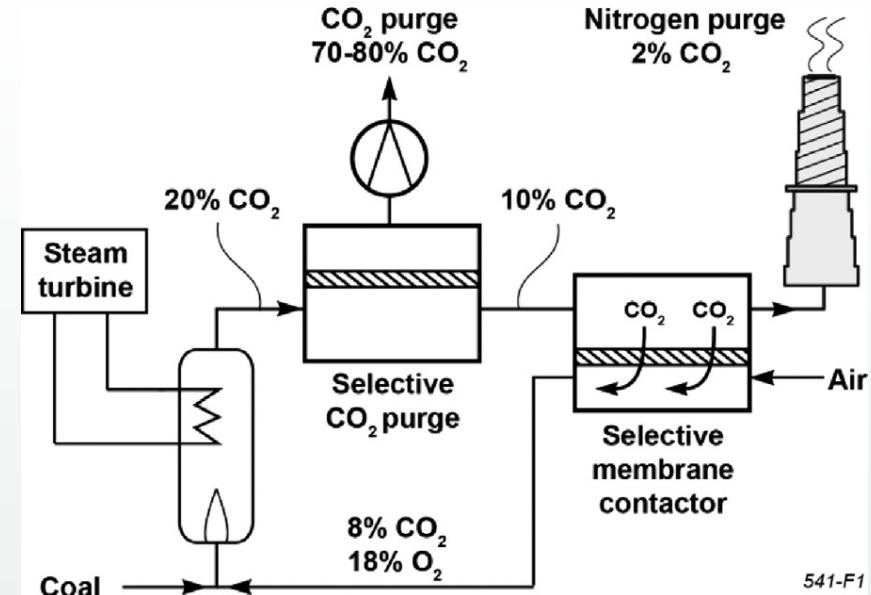
The benefit of a sweep mode flow



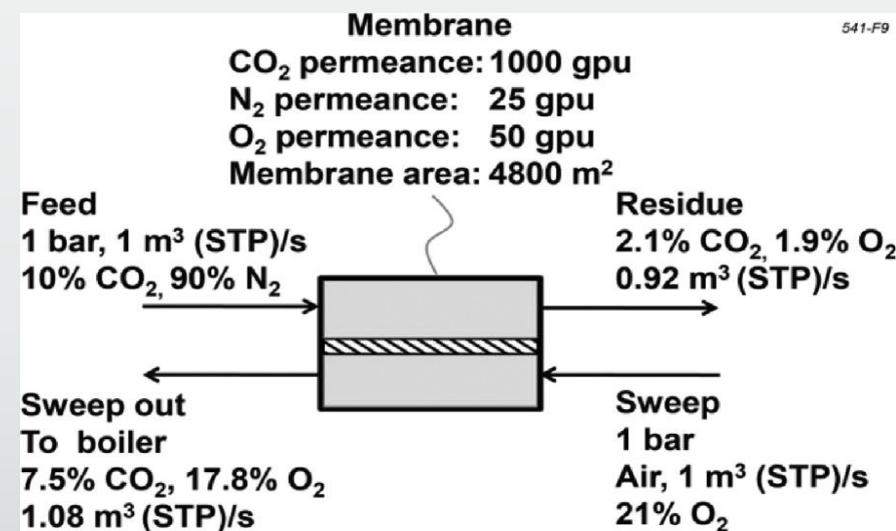
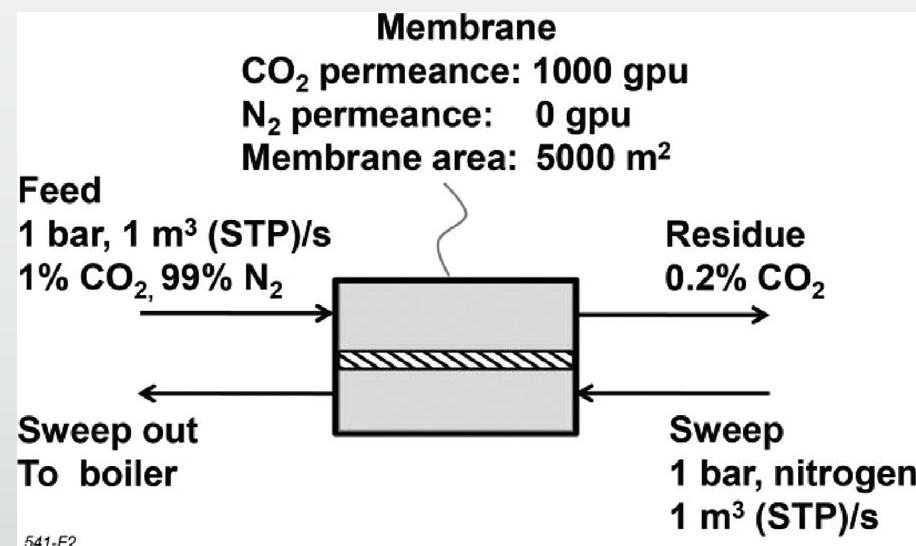
Gas/gas membrane contactors – An emerging membrane unit operation

Pingjiao Hao*, J.G. Wijmans, Jay Kniep, Richard W. Baker

Membrane Technology and Research, Inc., 39630 Eureka Drive, Newark, CA 94560, USA



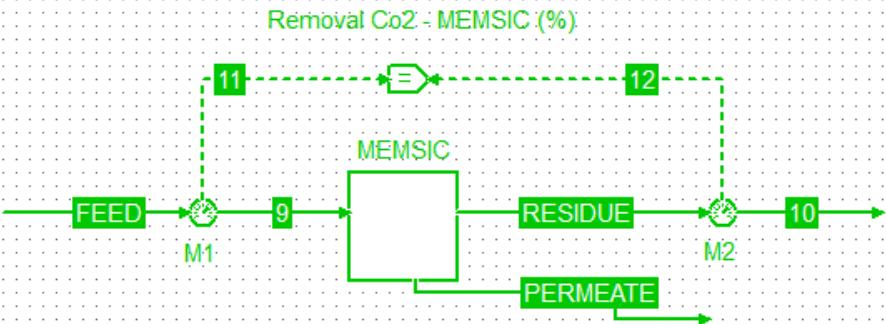
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$$\text{Sweep ratio} = \frac{\text{Inlet sweep flow rate (m}^3\text{(STP)/s)}}{\text{Inlet feed flow rate (m}^3\text{(STP)/s)}}$$

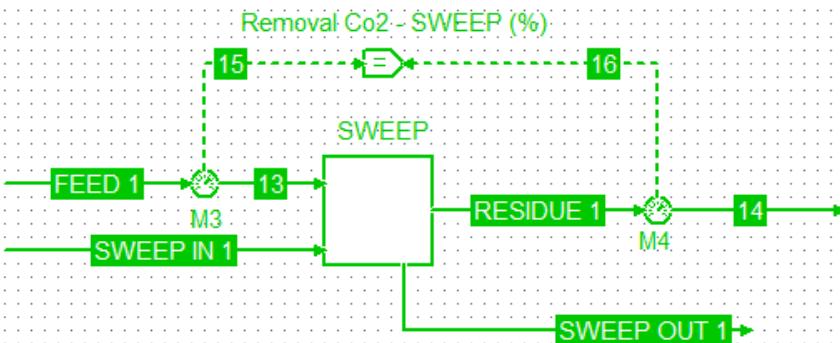
Interesting when a compound has a high permeability value compared to the other compounds

MEMSIC		
Parameter	Value	Unit
Area	4800	m ²
Oxygen Permeability	50	
Nitrogen Permeability	25	



Stream	FEED	RESIDUE	PERMEATE	Unit
Pressure	1.1	1.1	1.01325	bar
Temperature	30	30	30	°C
Flow rate	4525	4483.28	41.7157	kg / h
Mole frac Carbon dioxide	0.1	0.0999231	0.1083	
Mole frac Nitrogen	0.9	0.900077	0.891699	
Mole frac Oxygen	0	9.99666e-09	1.036e-08	

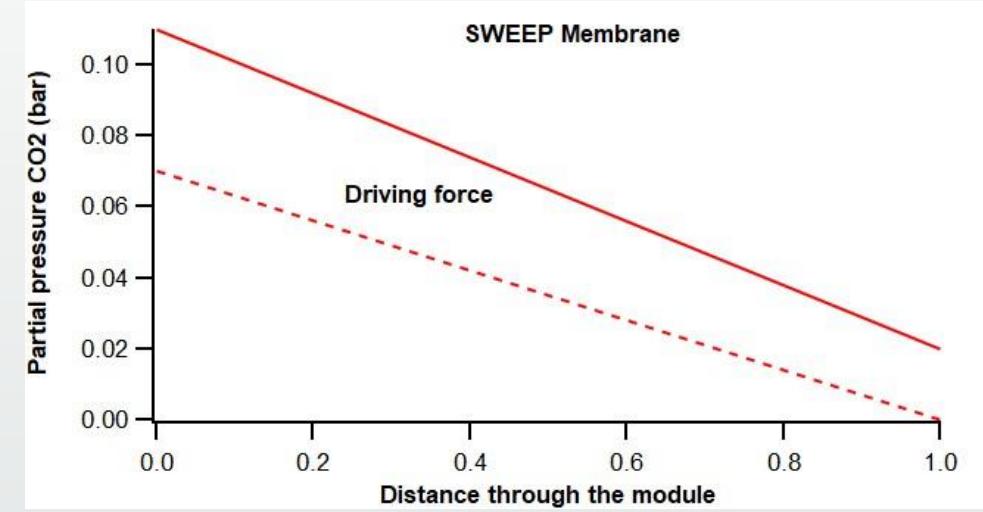
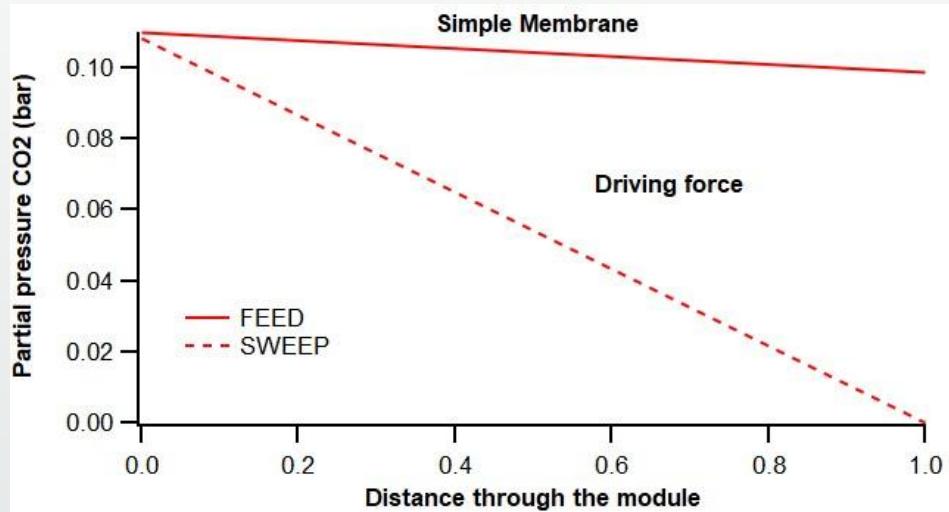
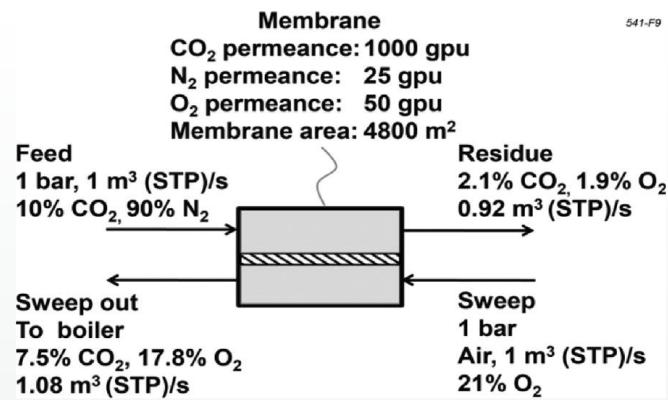
SWEEP		
Parameter	Value	Unit
Area	4800	m ²
A0 Carbon dioxide	1000	
A0 Nitrogen	25	



Stream	FEED 1	SWEEP IN 1	RESIDUE 1	SWEEP OUT 1	Unit
Pressure	1	1	1	0.9999	bar
Temperature	30	30	30	30	°C
Flow rate	4525	4499	3985.91	5038.09	kg / h
Mole frac Carbon dioxide	0.1	0	0.0201455	0.0720547	
Mole frac Nitrogen	0.9	1	0.979854	0.927945	
Mole frac Oxygen	0	0	1.07229e-10	9.41129e-11	

UO	Parameter	Value	Unit
Removal Co2 - MEMSIC (%)	REMOVAL	0.993959	
Removal Co2 - SWEEP (%)	REMOVAL	81.4546	

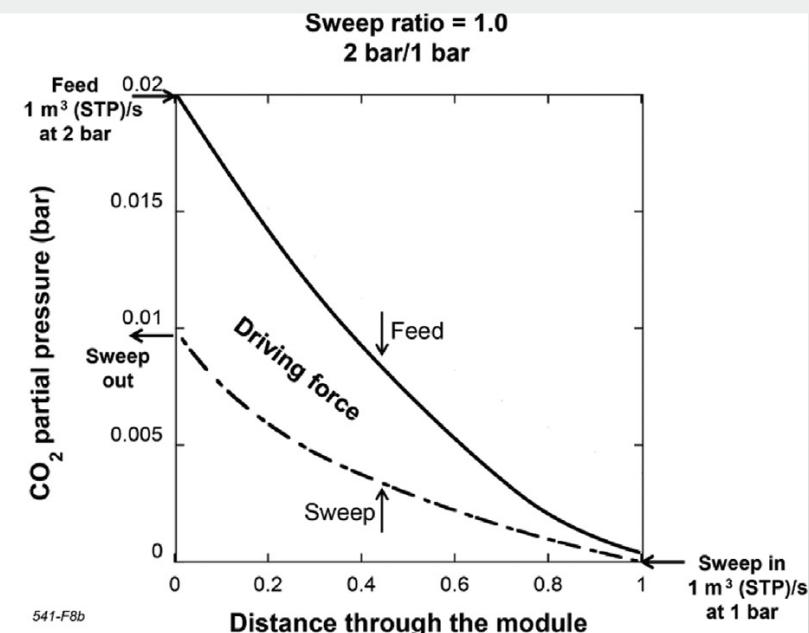
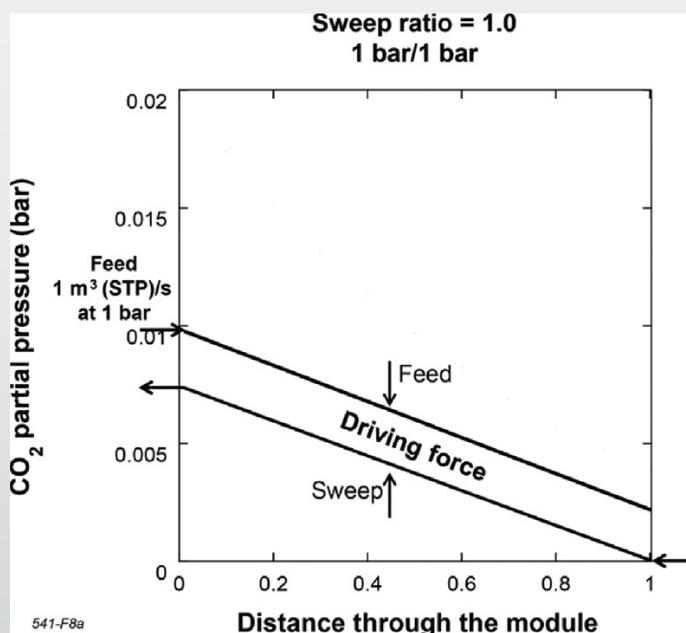
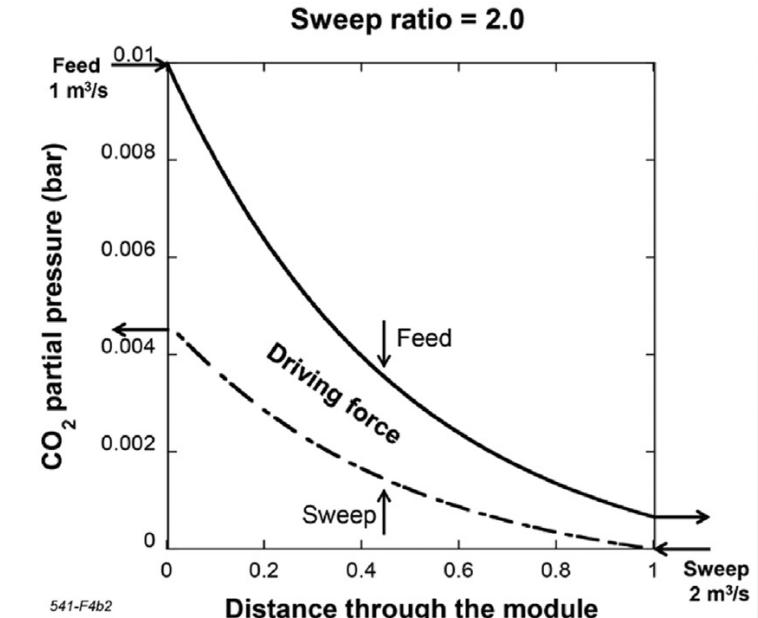
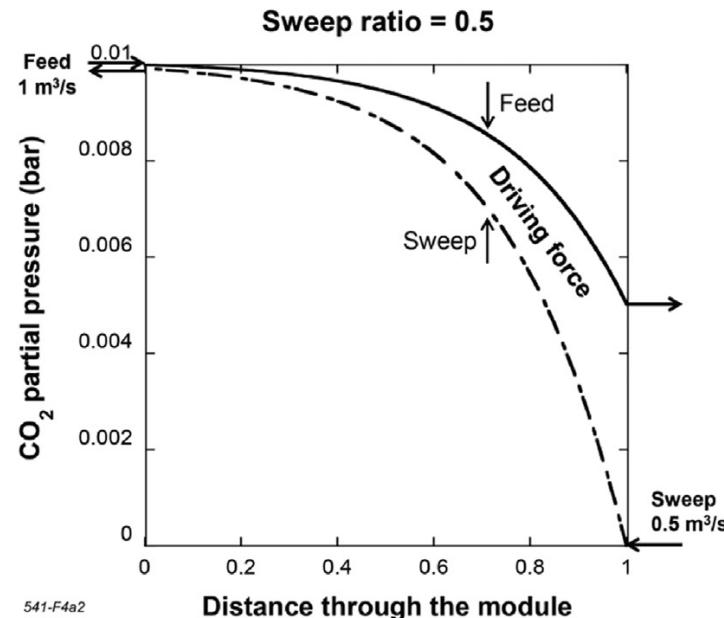
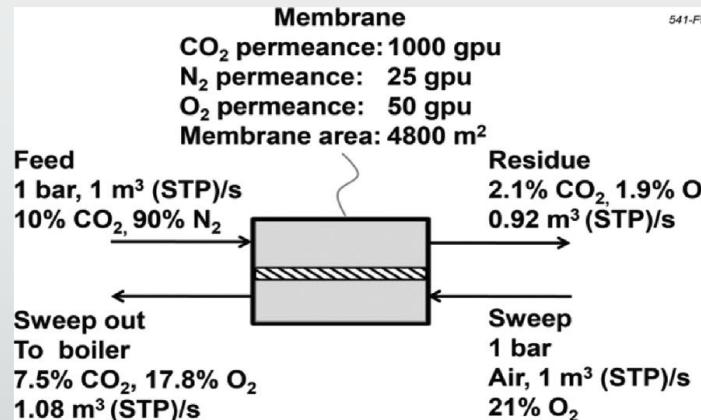
$$CO_2 \text{ Removal} = 1 - \left(\frac{x_{\text{residue}} \cdot Q_{\text{residue}}}{x_{\text{in}} \cdot \text{FEED}} \right)_{co2}$$

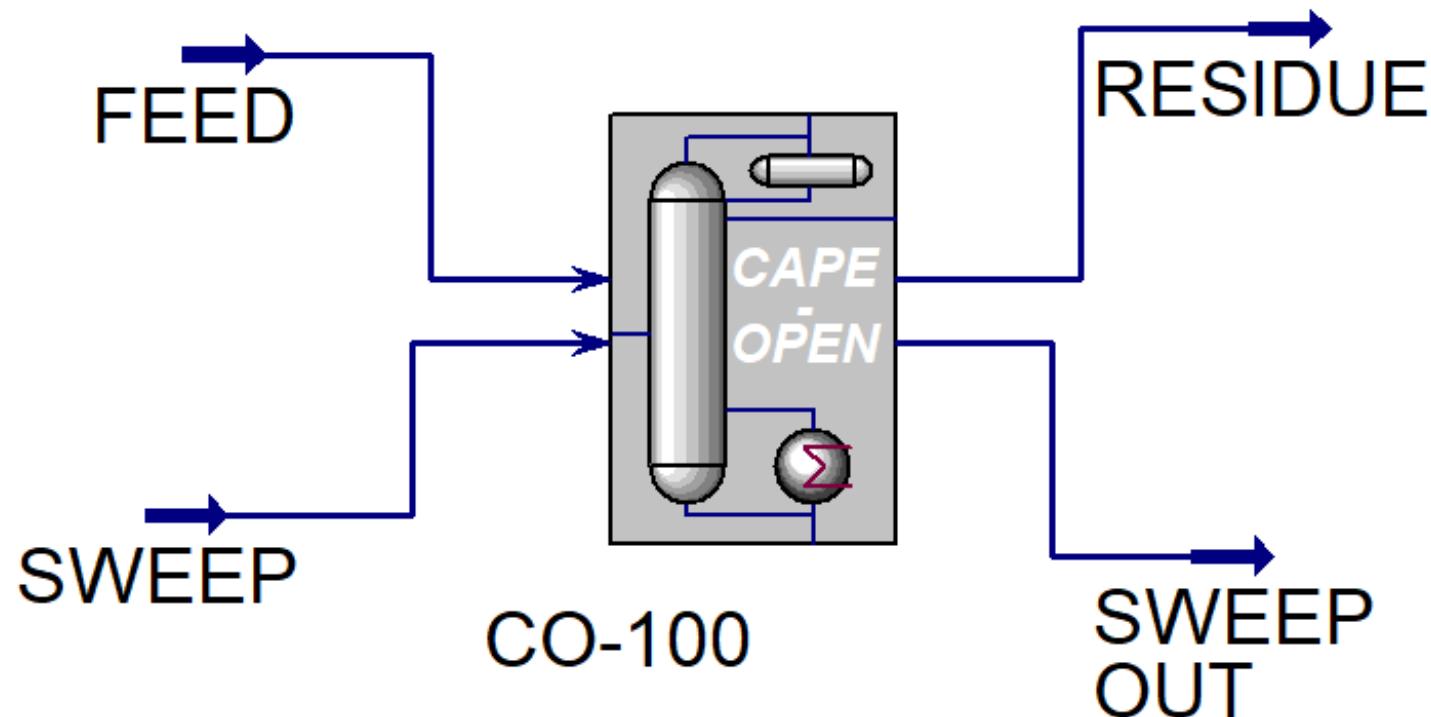


We keep an important driving force along the entire length of the membrane

Effect of sweep ratio
 R_{CO_2} : from 40 to 90%

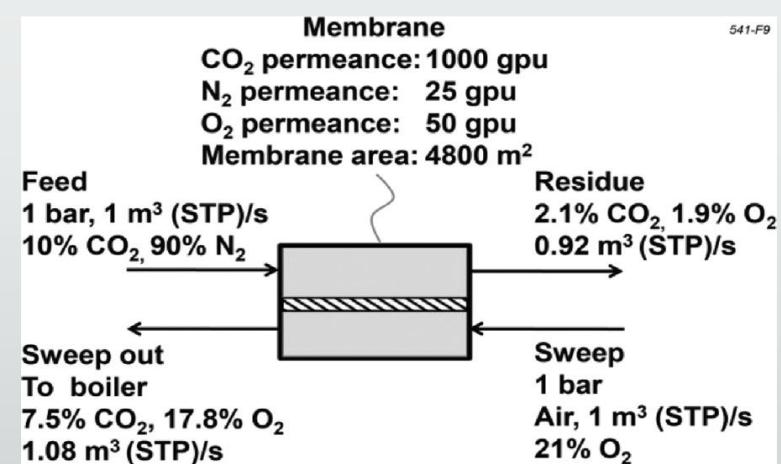
Effect of pressure ratio
 R_{CO_2} : from 80 to 95%

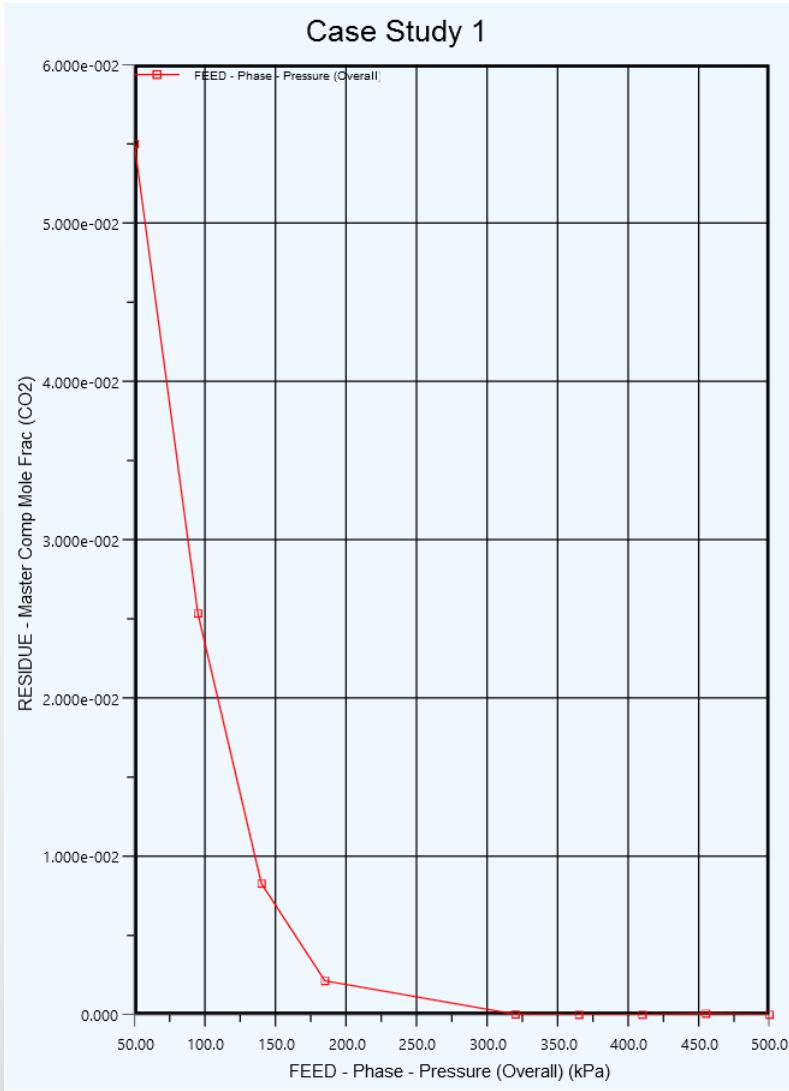




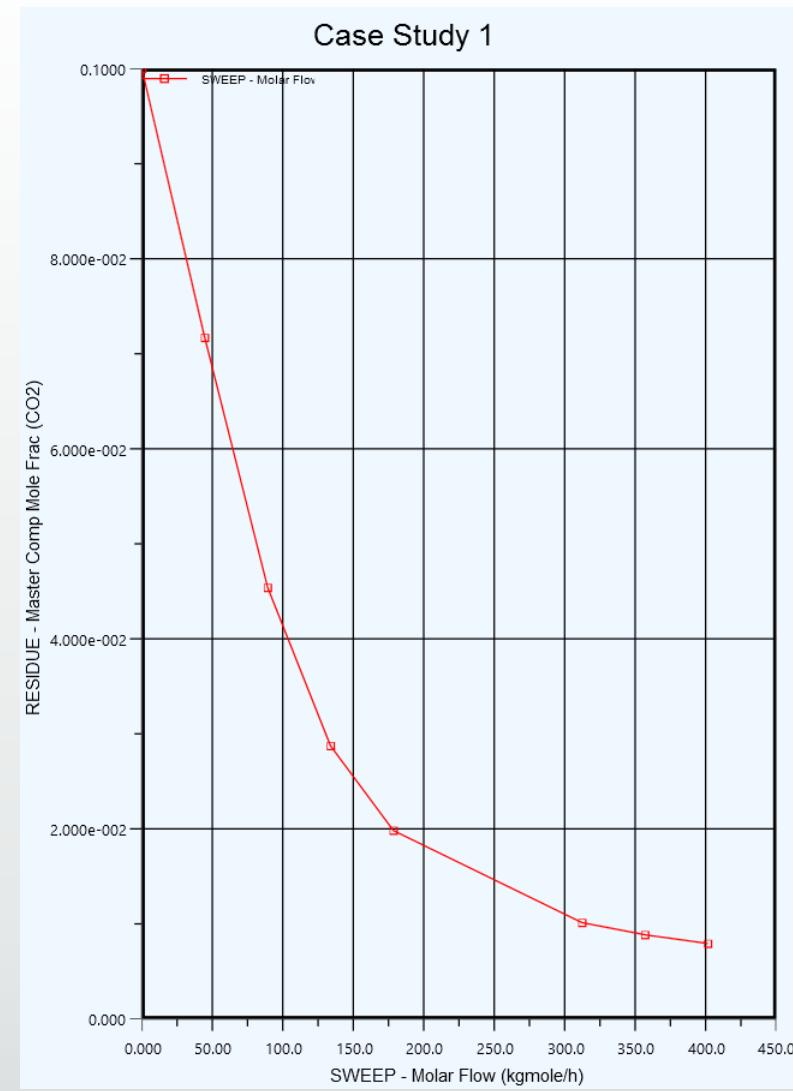
$$3380 \text{ Nm}^3/\text{h} = 0.94 \text{ Nm}^3/\text{s}$$

$$3820 \text{ Nm}^3/\text{h} = 1.06 \text{ Nm}^3/\text{s}$$





Effect of pressure ratio
 R_{CO_2} : from 80 to 95%



Effect of sweep ratio
 R_{CO_2} : from 40 to 90%

Case 3

An industrial case

DRYPOINT® M PLUS membrane dryer



Dryer and filter in one

Compact, reliable, without electricity: The **DRYPOINT M Plus** membrane dryer dries the compressed air by means of highly selective membranes. Pressure dew points between +15 and -40 °C can therefore be achieved - one reason for the diverse range of applications even under changing operating conditions. An additional bonus: the integrated nanofilter, which fulfils all the requirements for efficient filtration and thereby also protects the membranes.

[Read more...](#)

Real membrane from Beko (<https://www.beko-technologies.com/>)

Evaluation of the possibility of "special sweep-based membrane" to dry a air gas respect to different constraints

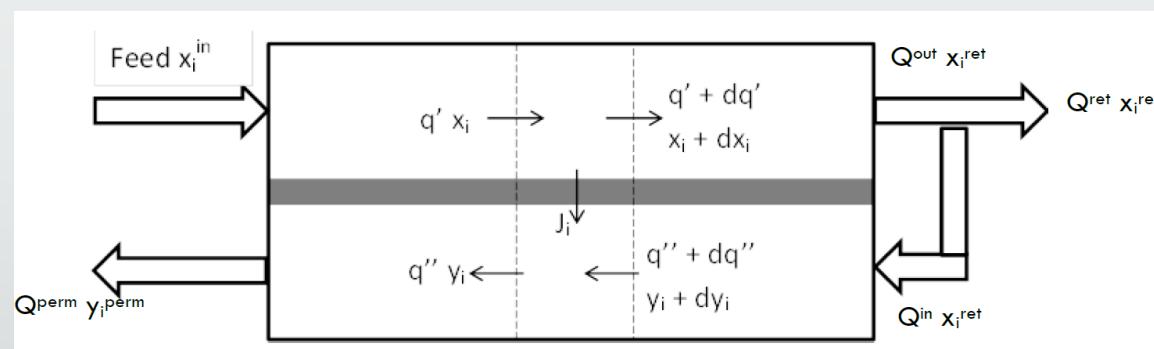
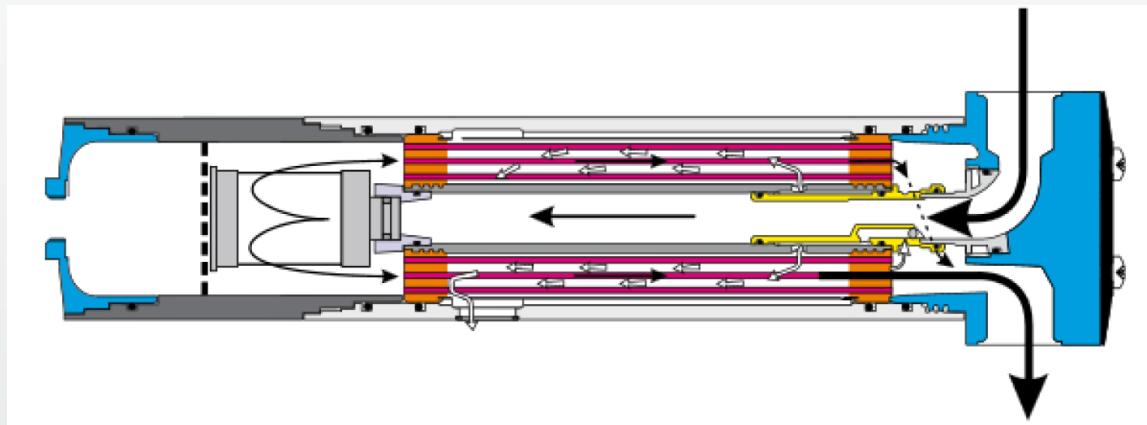
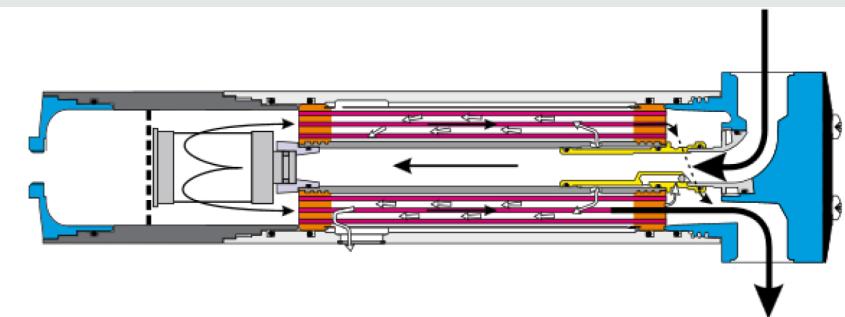
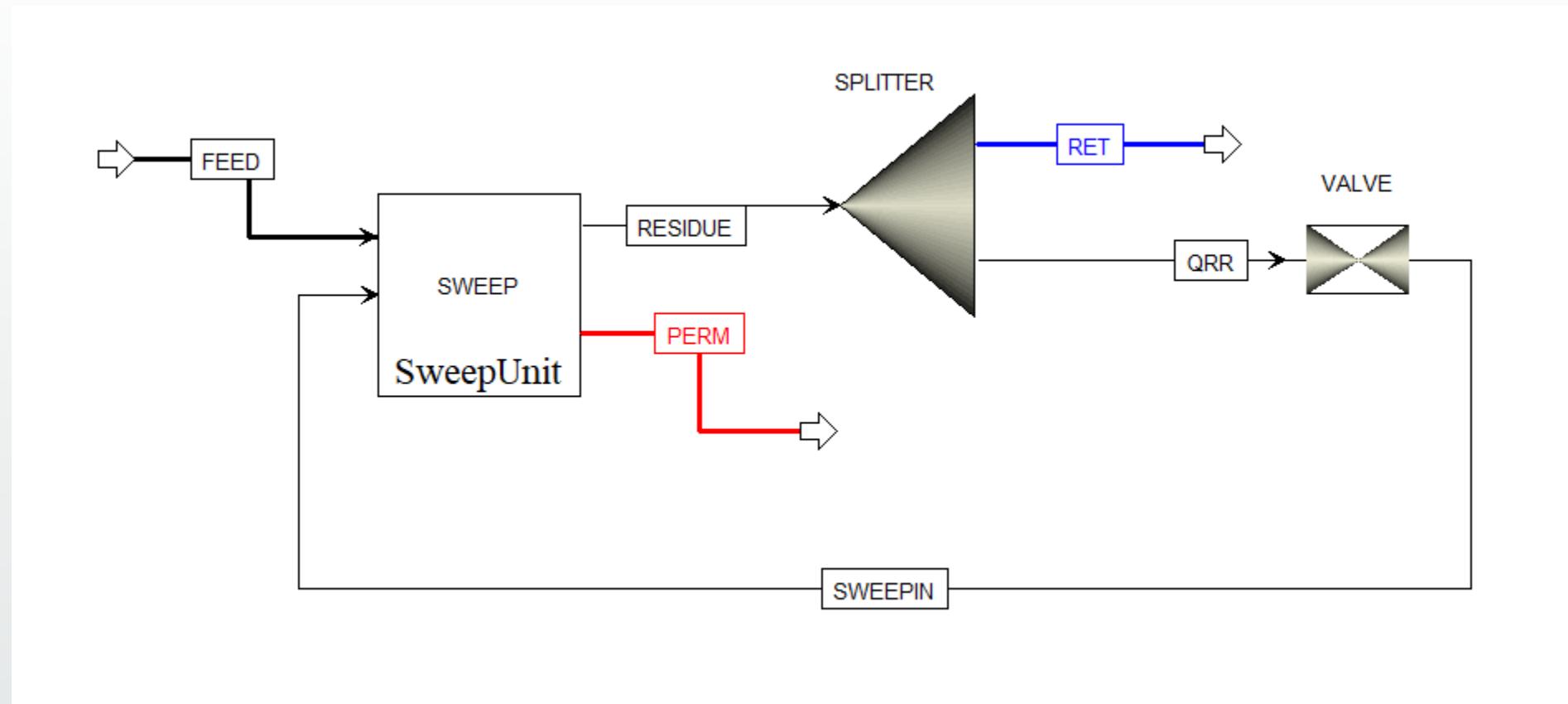


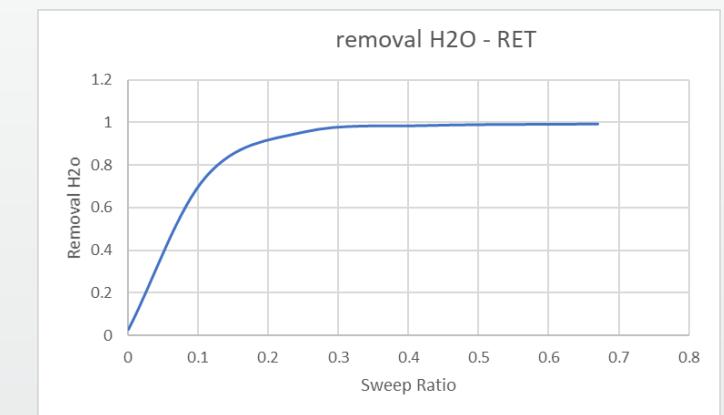
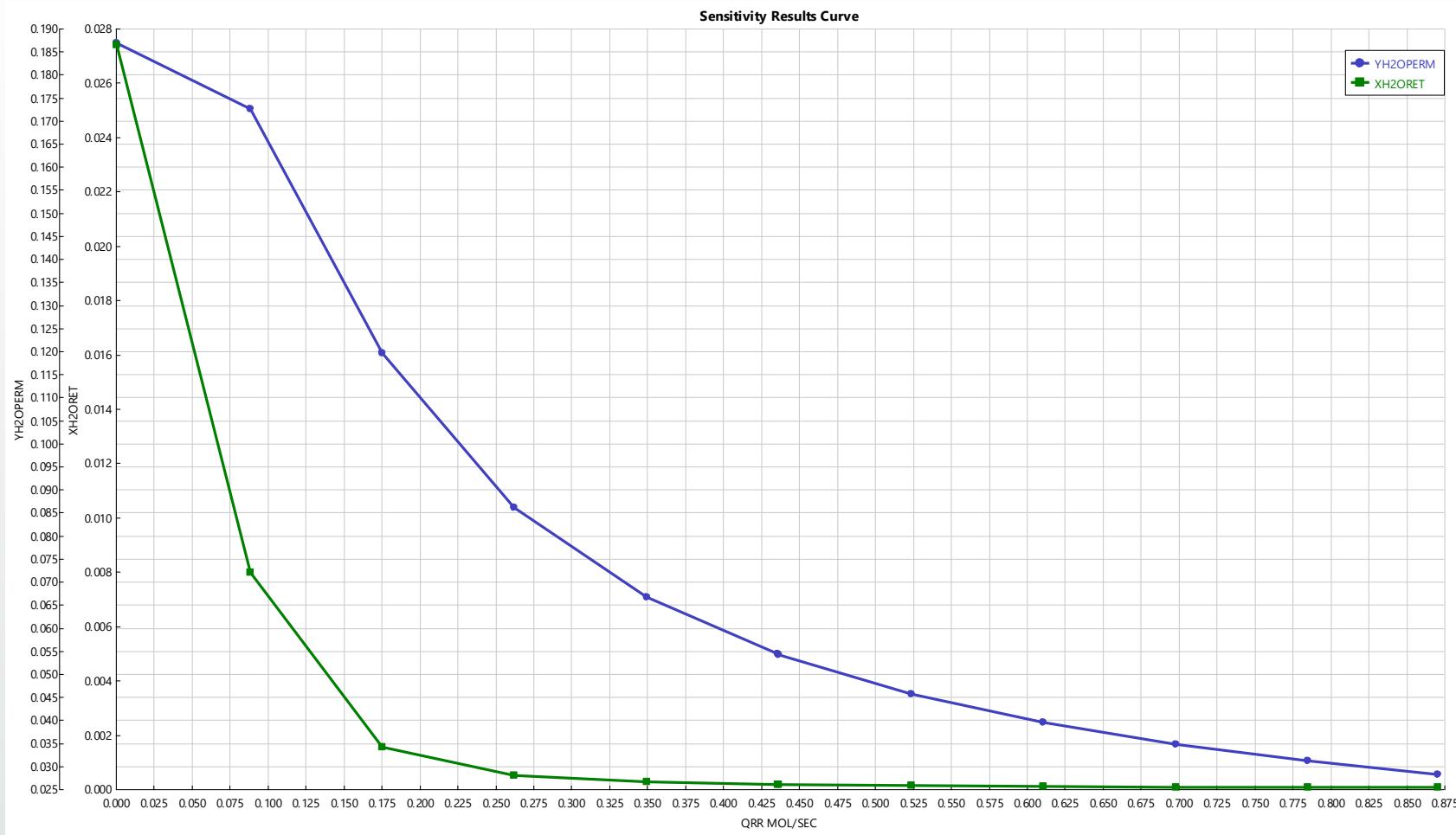
TABLE 1 : VALEURS DES PERMEABILITES SUIVANT LE MATERIAUX ET A DIFFERENTES TEMPERATURES

Perméabilité [barrier]	H ₂ O			N ₂			O ₂		
Température [°C]	30	70	210	30	70	210	30	70	210
Membrane/Matériaux									
PES	2.71E+03	3.05E+03	3.93E+03	1.29E-01			5.99E+00		

TABLE 2 : SPECIFICATIONS ENTREE/SORTIE

	ENTREE	SORTIE
Charge en eau [g/kg air sec]	19	7
Fraction molaire		
Oxygène - O ₂	0.2038	0.2077
Azote - N ₂	0.7666	0.7812
Eau - H ₂ O	0.0297	0.0111





Sweep mode : removal fraction increase with the sweep ratio

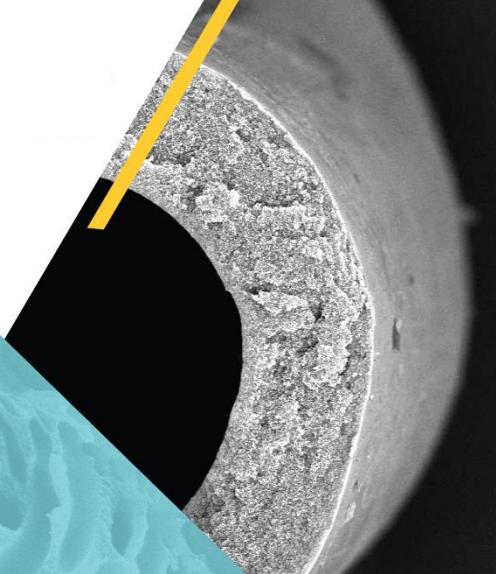
Conclusion

Conclusion

- 1) An important advantage of using sweep gas is to generate a driving force for membrane separation without an extra compression machine
- 2) Nevertheless, it has the inherent feature of diluting the permeate
- 3) Interesting when a compound has a high permeability value compared to the other compounds
- 4) The development of numerical tools, such as MEMSIC or SWEEP, as CAPE-OPEN unit operations it's a real asset for engineers who want to do:
 - 1) Optimization
 - 2) Revamping
 - 3) Process synthesis
 - 4) ...
- 5) Future development: equivalent tools for G/L or L/L separation



MEMSIC



LRGP
LABORATOIRE
RÉACTIONS
ET GÉNIE
DES PROCÉDÉS



UNIVERSITÉ
DE LORRAINE



Thank you for your attention

<http://memsic.tech/>

Contact: roda.bounaceur@univ-Lorraine.fr

