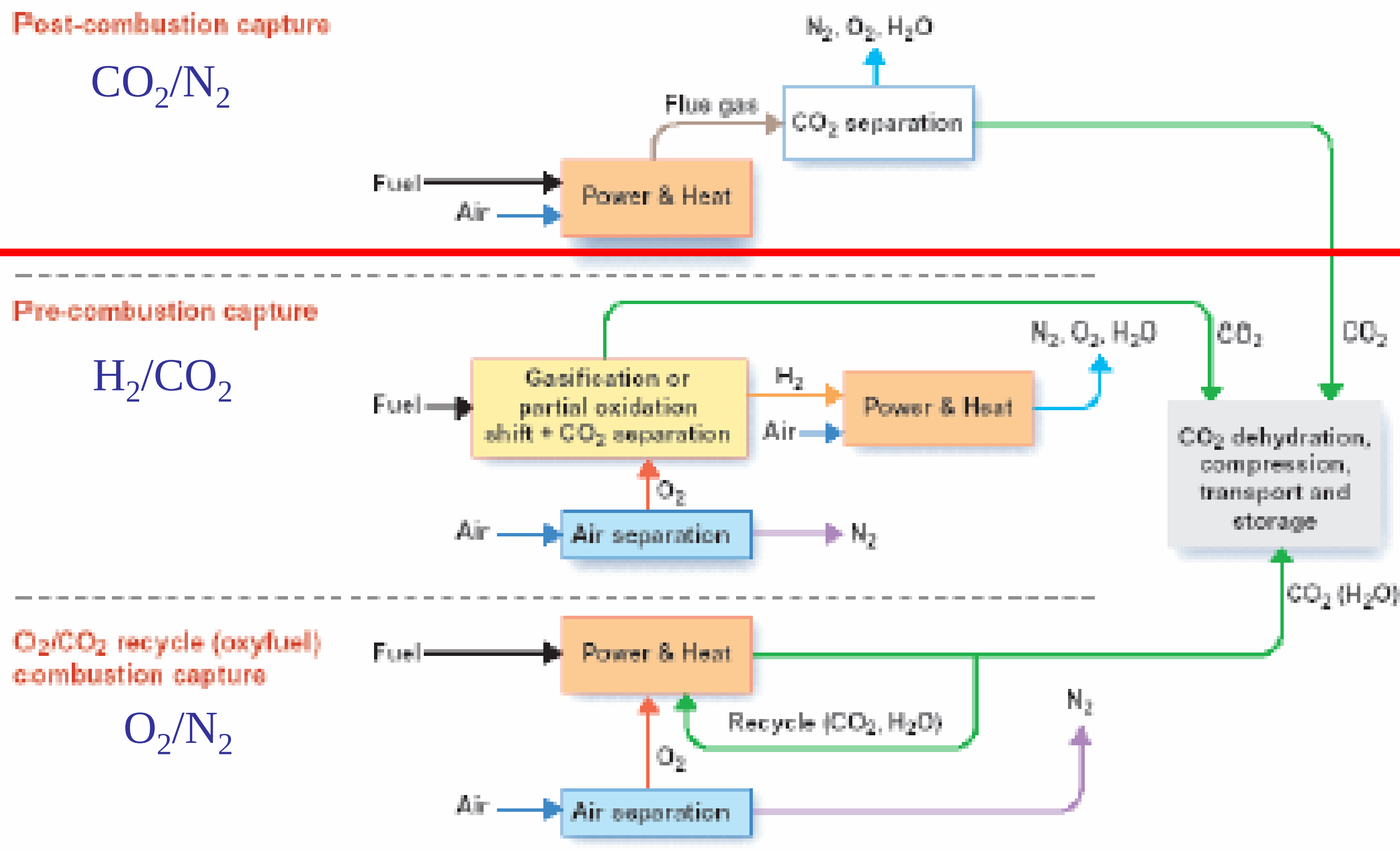
Projets PHYCAP (PE) & COCASE (PR)

LSGC

Eric FAVRE

CO_2 *capture: synopsis*

BAT



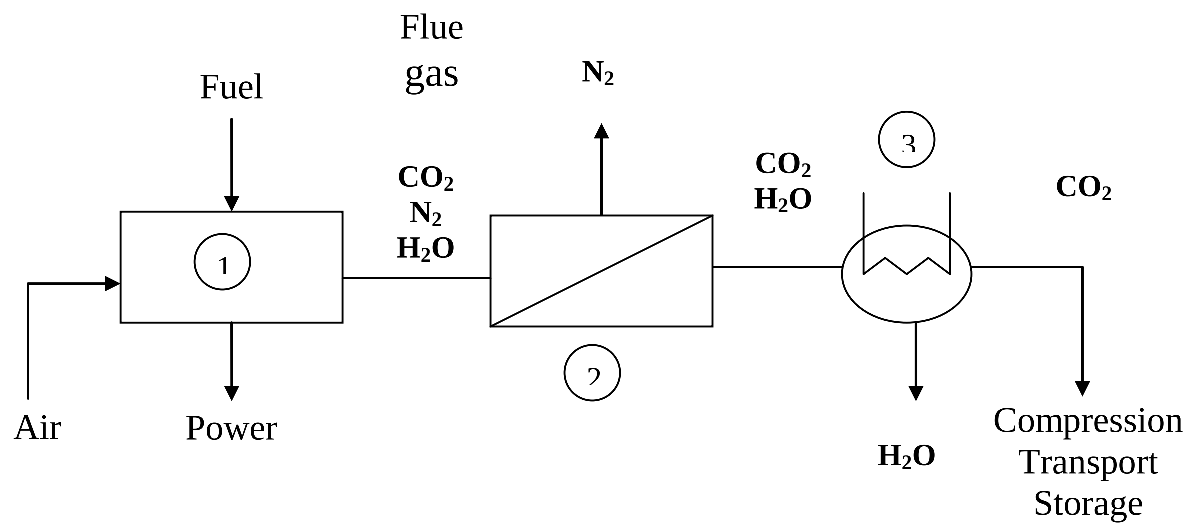
Absorption (chemical)

Absorption (physical)

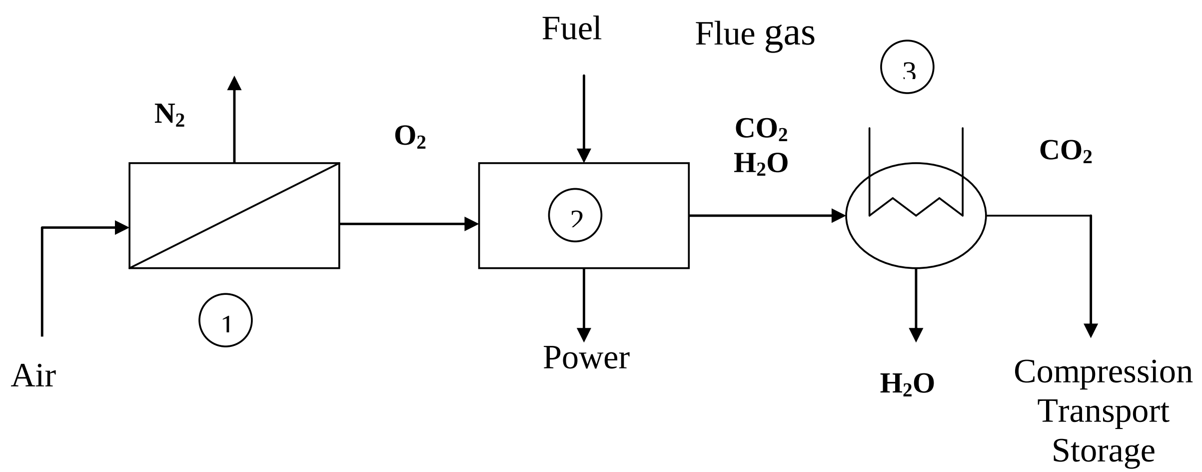
Cryogeny

CCS strategies: post combustion vs oxycombustion

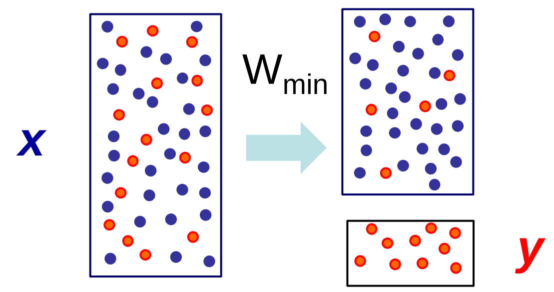
Post combustion capture



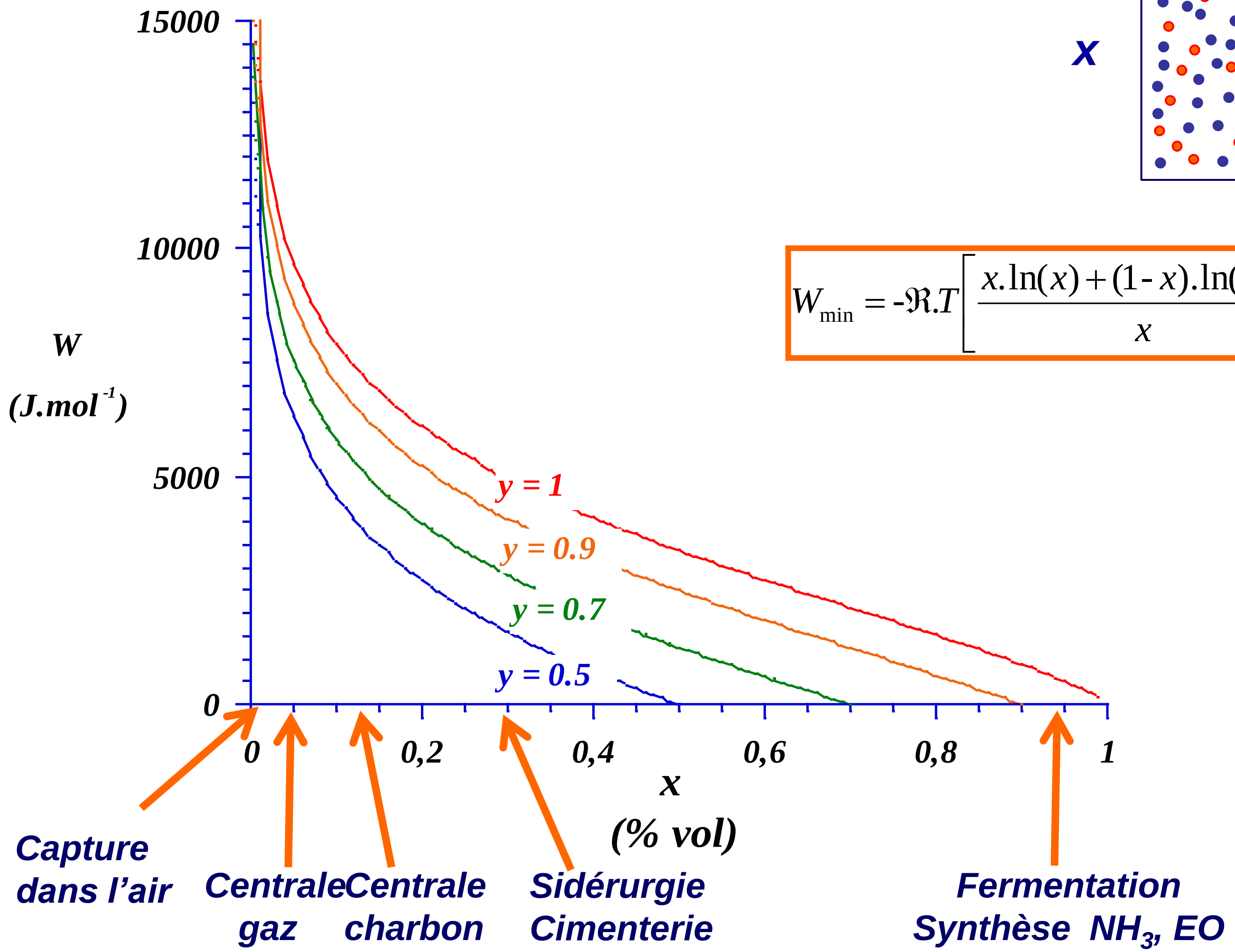
Oxycombustion



Notion de travail minimal théorique de séparation

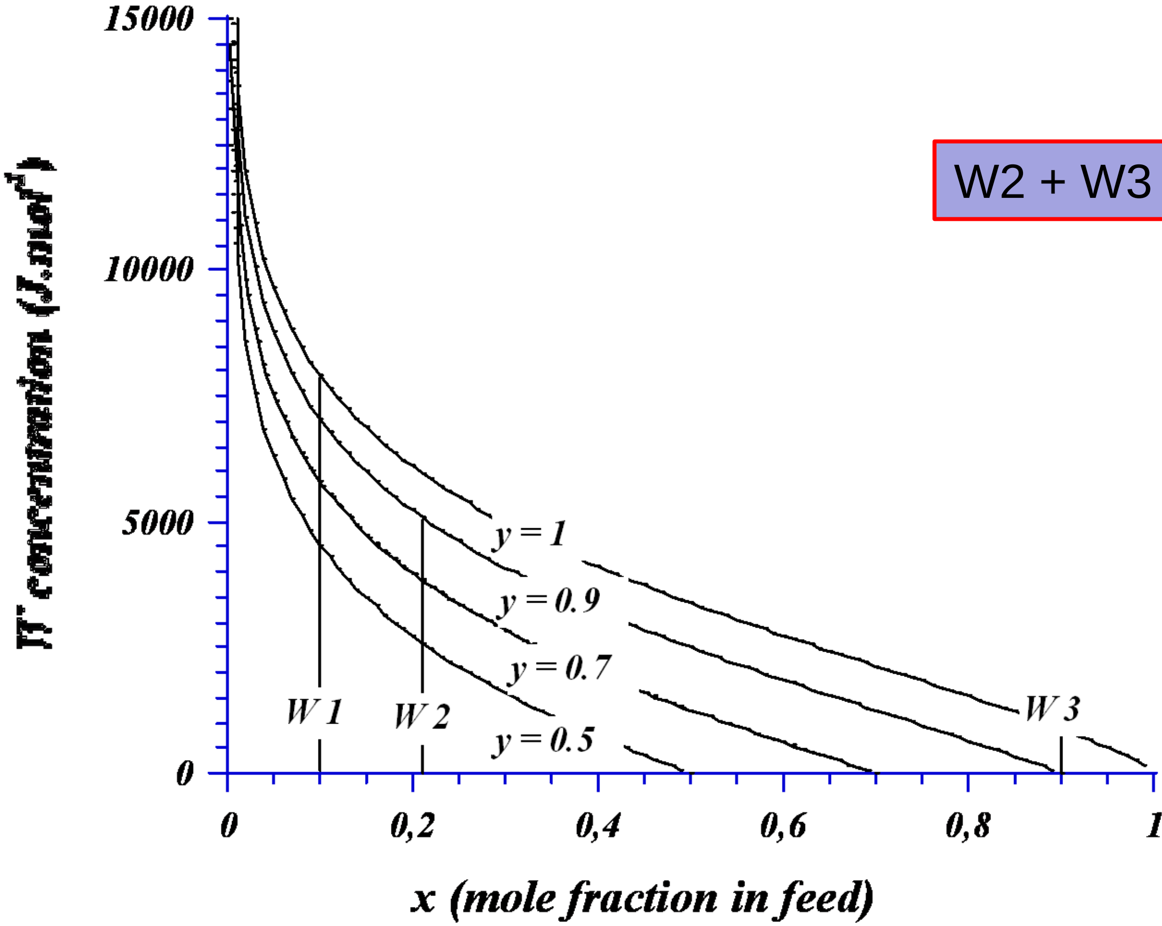


$$W_{\min} = -\Re.T\left[\frac{x.\ln(x)+(1-x).\ln(1-x)}{x} - \frac{y.\ln(y)+(1-y).\ln(1-y)}{y}\right]$$



$$\eta = \frac{W_{\min}}{W_{réel}}$$

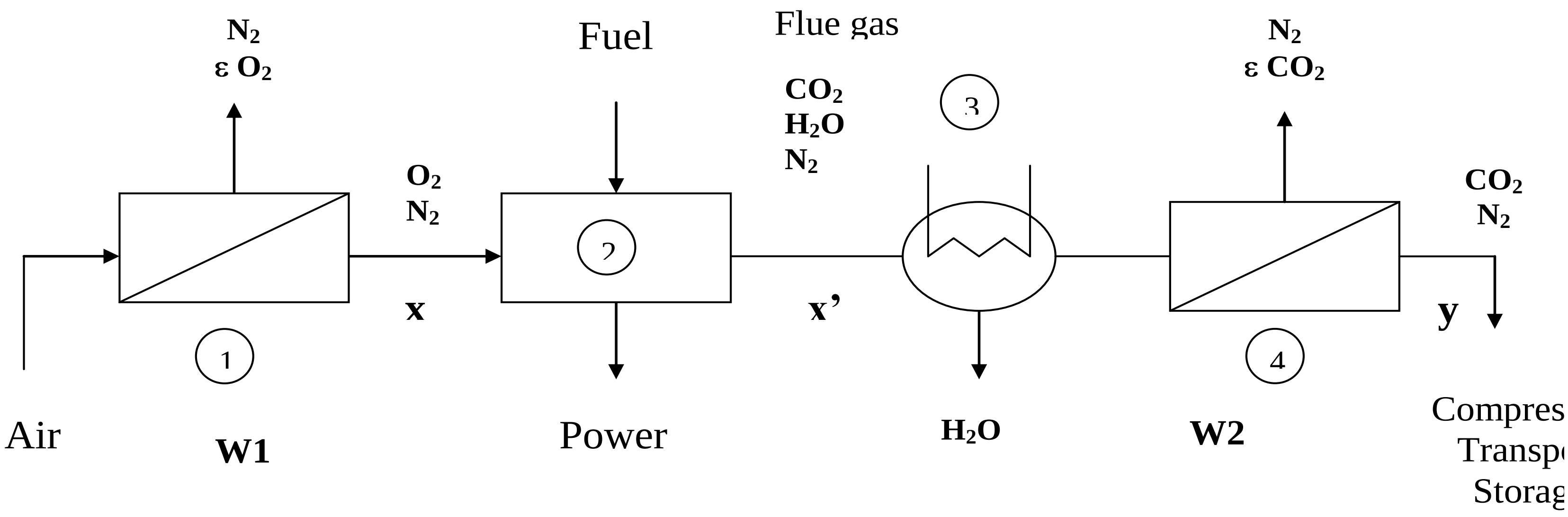
Concept clé du projet exploratoire Phycap



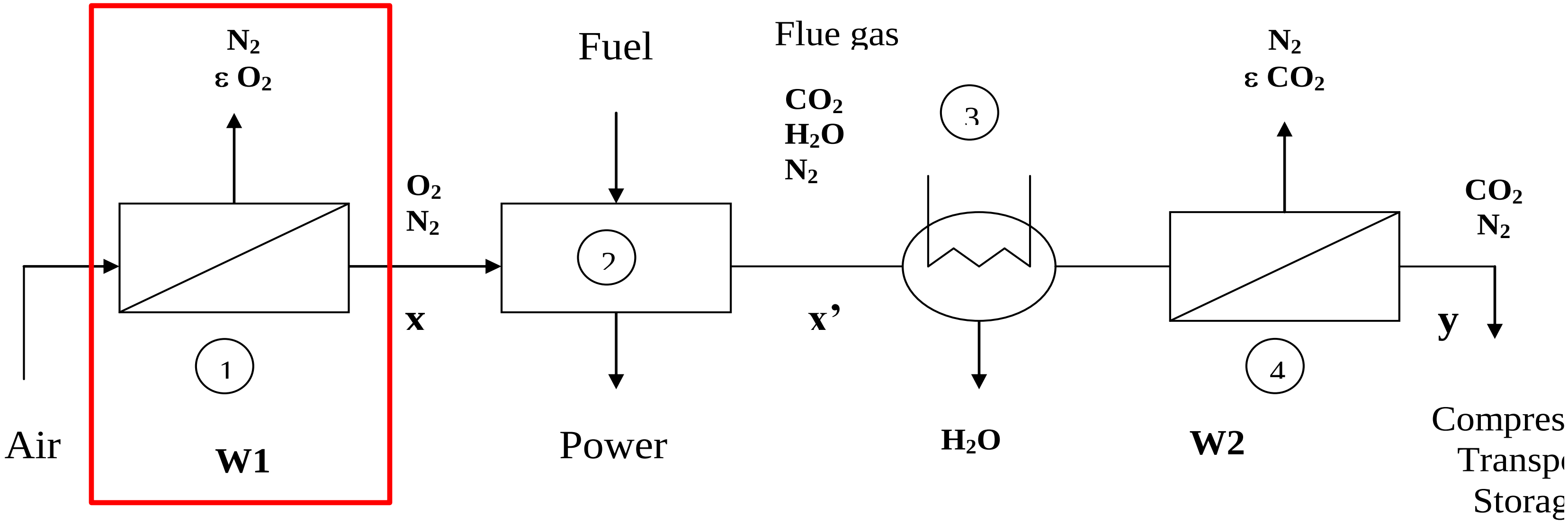
W2 + W3 ><? W1

$$W''_{min} = -R.T \frac{x.\ln(x) + (1-x).\ln(1-x)}{x} + R.T \frac{y.\ln(y) + (1-y).\ln(1-y)}{y}$$

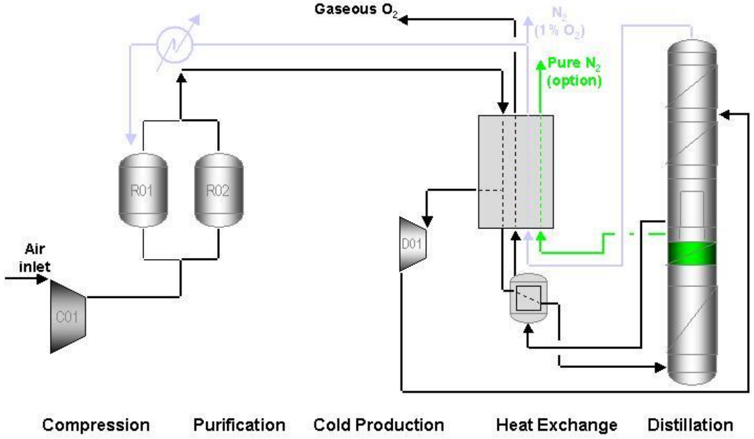
Projet PHYCAP: Schéma de principe

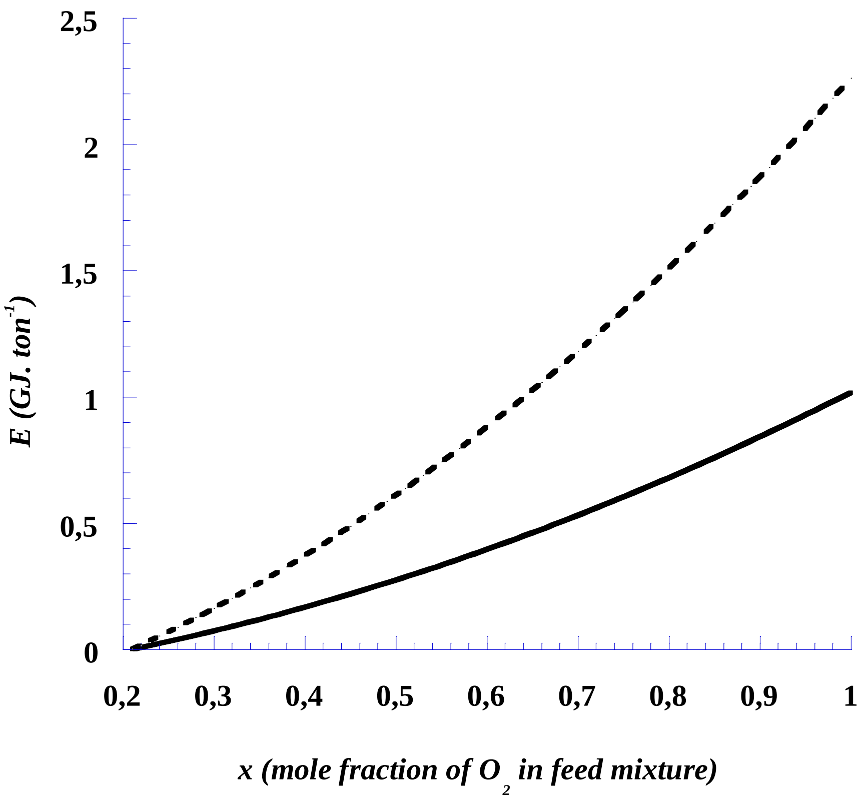


Projet COCASE: Schéma de principe



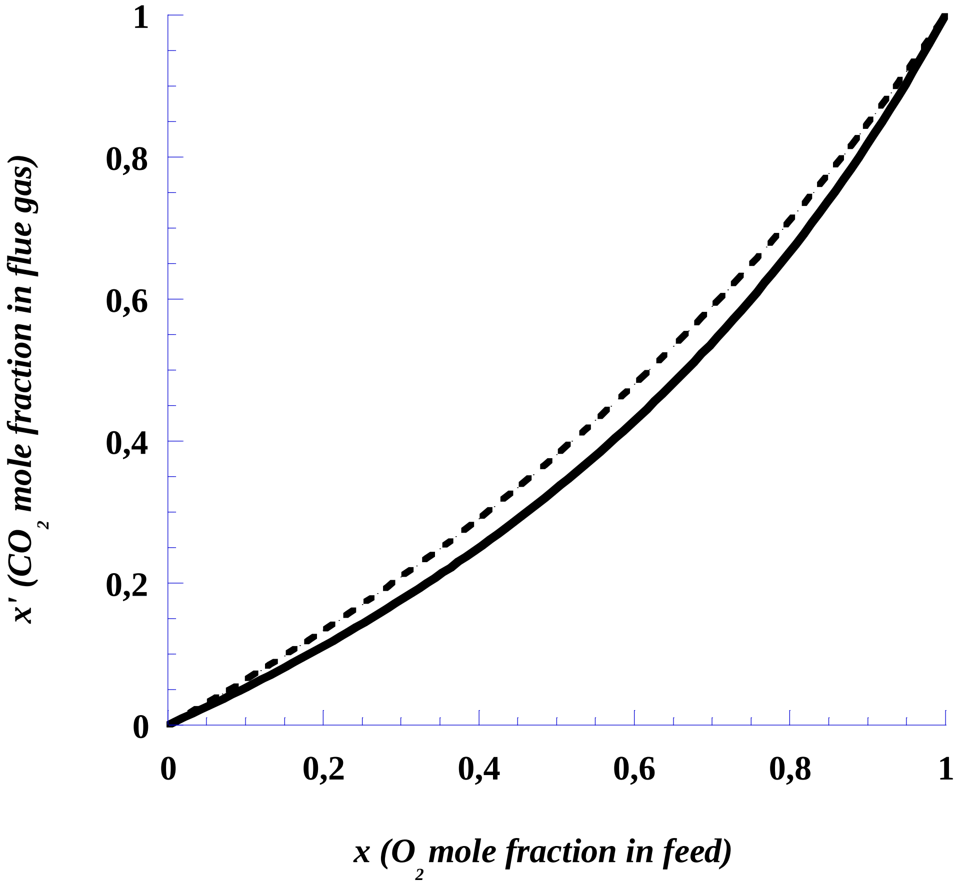
Procédé de production d'oxygène: Cryogénie





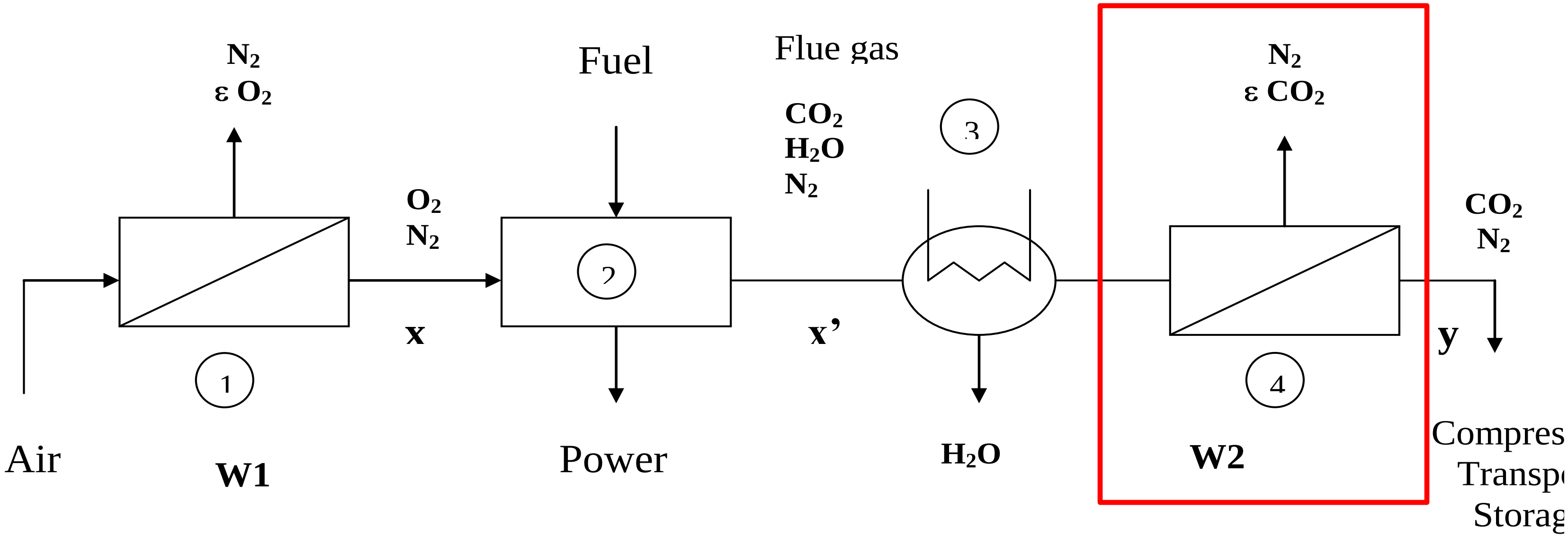
Relation teneur en CO_2 / pureté en O_2

$$x' = \left[\frac{2n.x/(3n+1)}{(2n.x/(3n+1)) + 1 - x} \right]$$

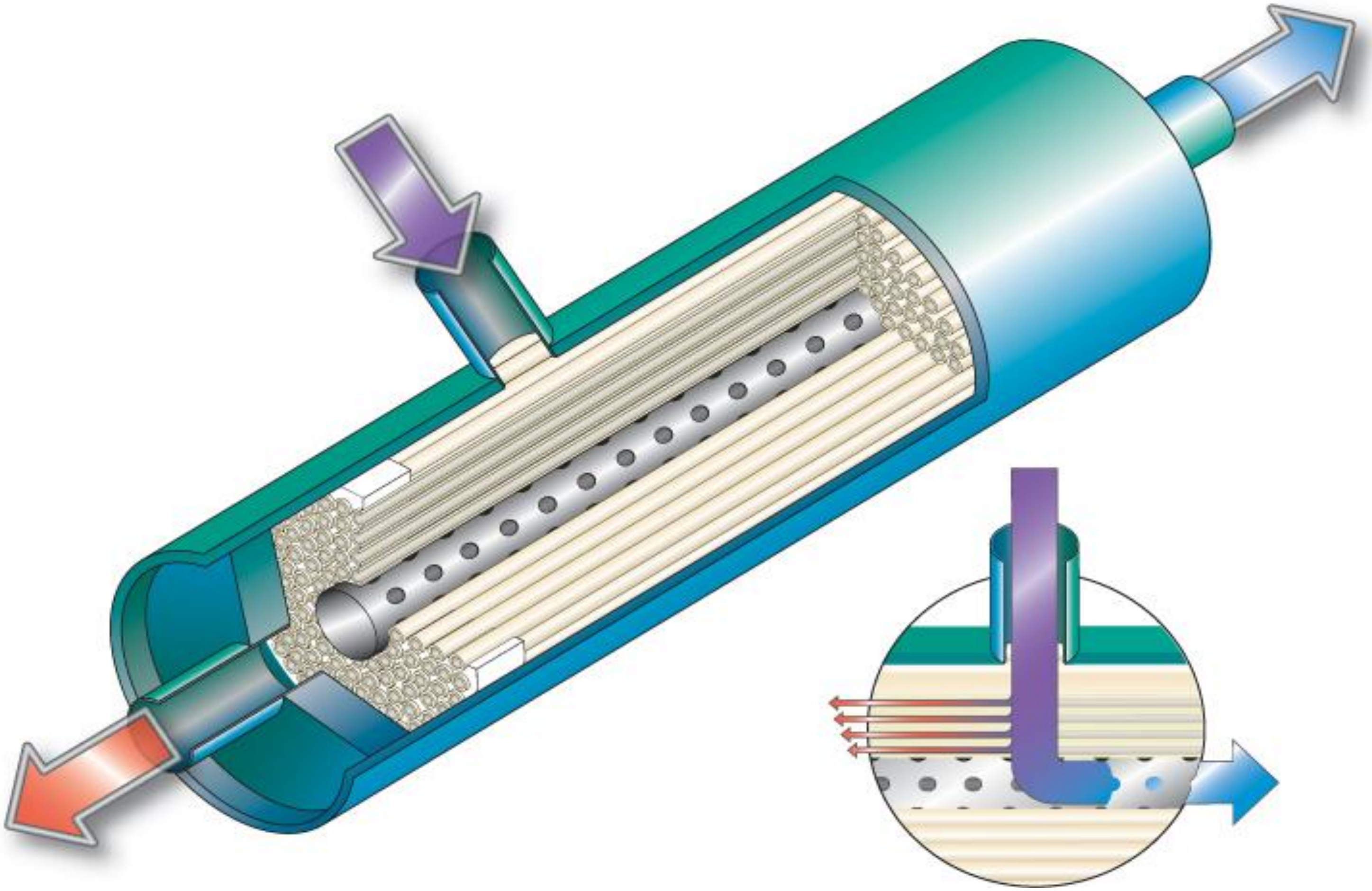


$$C_nH_{2n+2} \;+\; (1.5n+0.5)\,O_2 \;\rightarrow\; n\,CO_2 \;+\; (n+1)\,H_2O$$

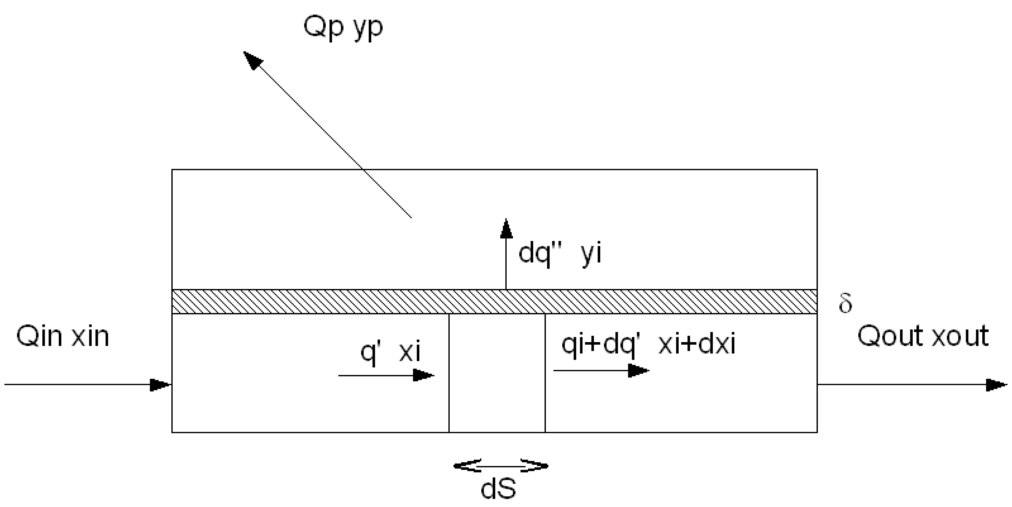
Projet COCASE: Schéma de principe



Module à fibres creuses (perméation gazeuse)



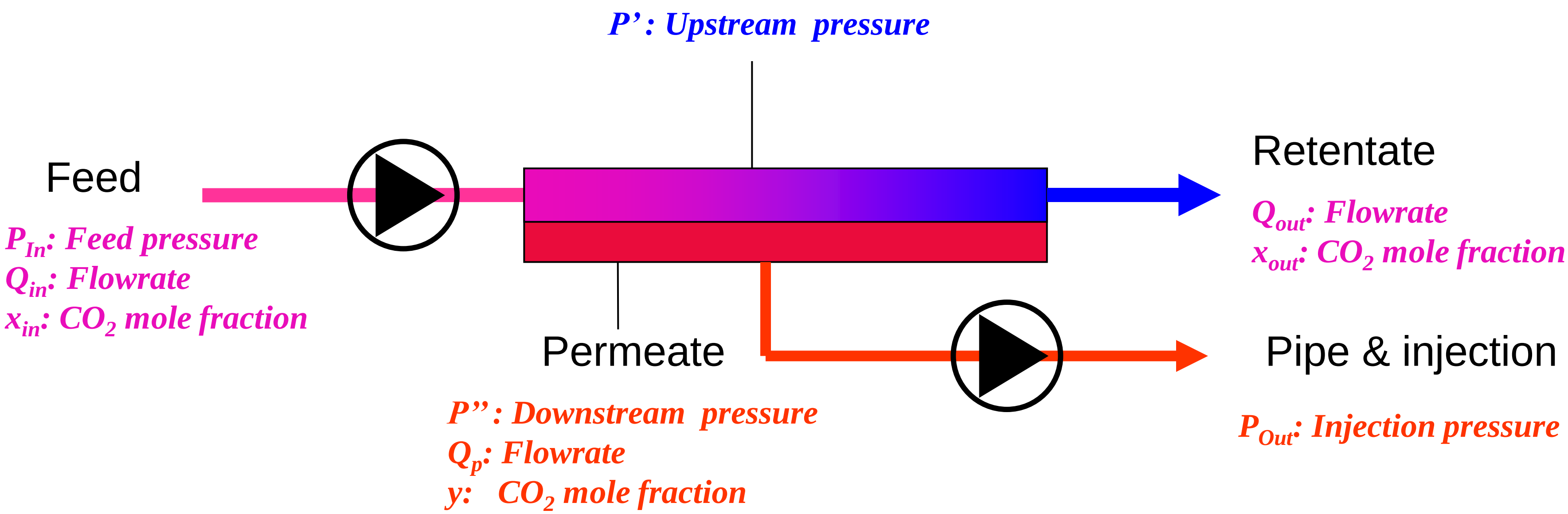
Simulation du procédé: Hypothèses de base



Hypothèses:

- **Conditions isothermes**
- **Perméabilité constante indépendante de la pression**
- **Membrane seule résistance au transfert : absence de polarisation de concentration**
- **Perte de charge négligée dans chaque compartiment**

Procédé de capture: Module à membranes



Key variables

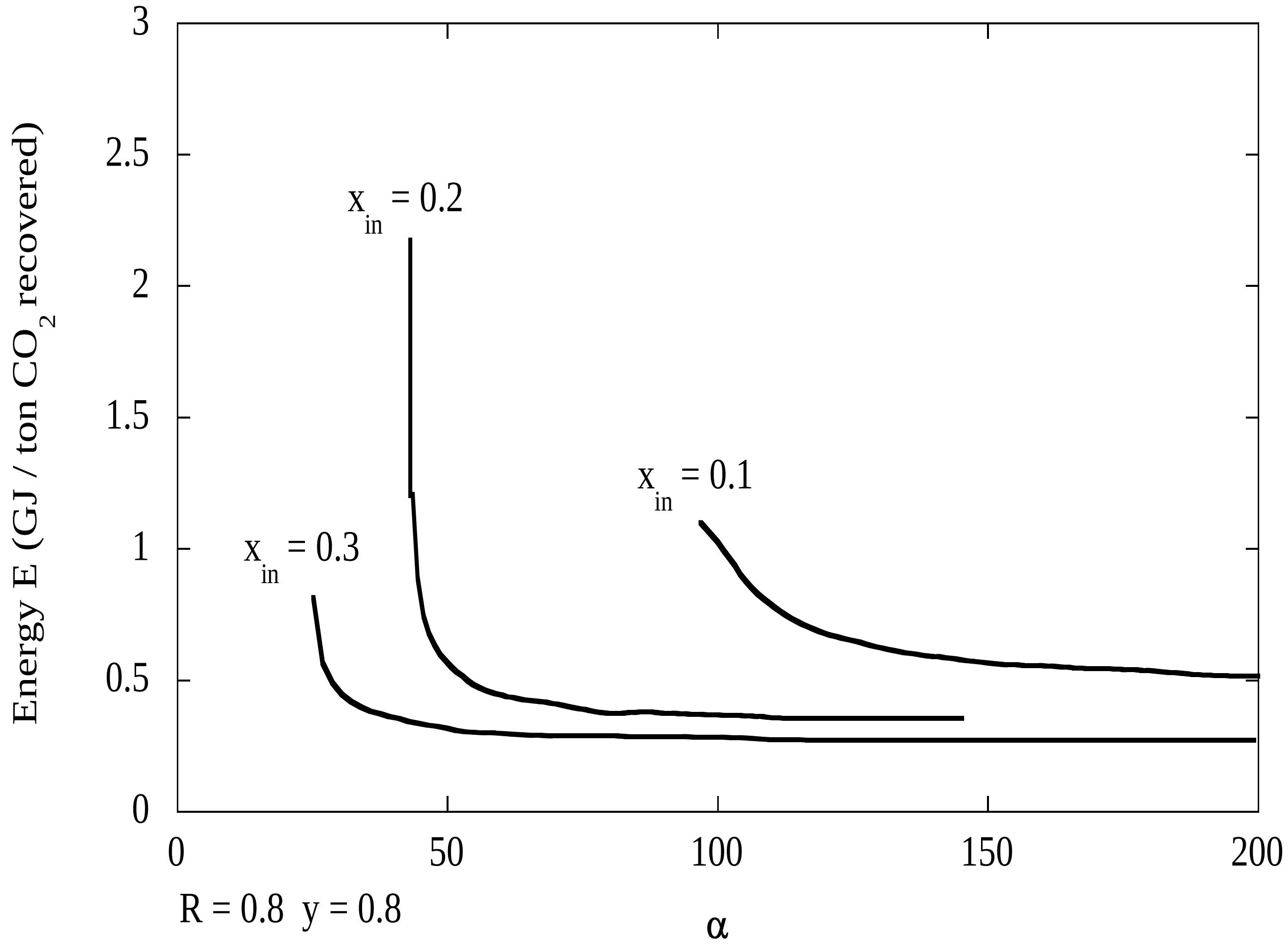
Separation factor $\alpha^* = \frac{\Pi_{CO2}}{\Pi_{N2}}$

Pressure ratio $\psi = \frac{P''}{P'}$

Stage cut $\theta = \frac{Q_p}{Q_{in}}$

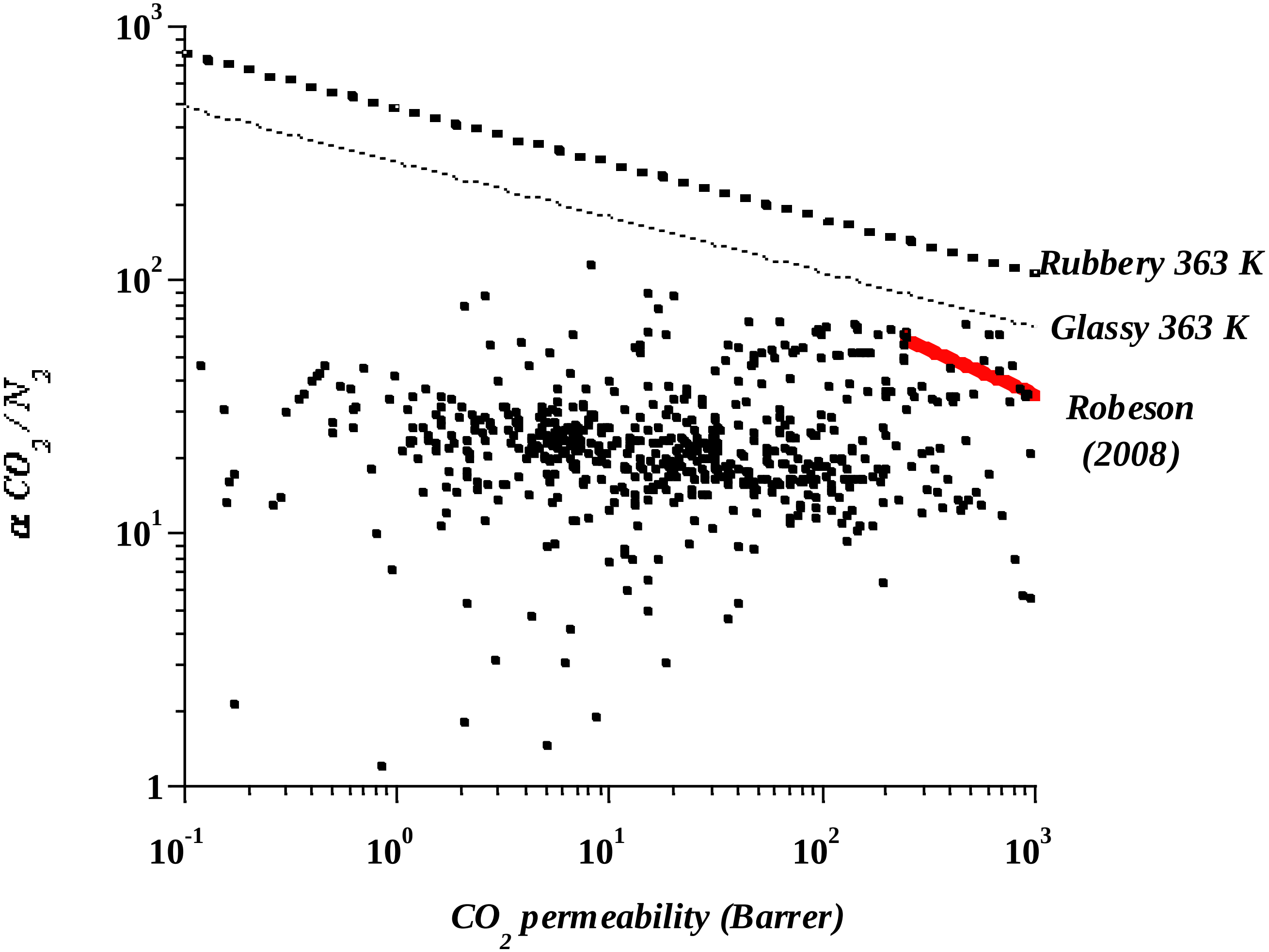
Simulation performed based on cross plug flow model (Hwang & Kammermeyer)

Parametric study results: Vacuum pumping

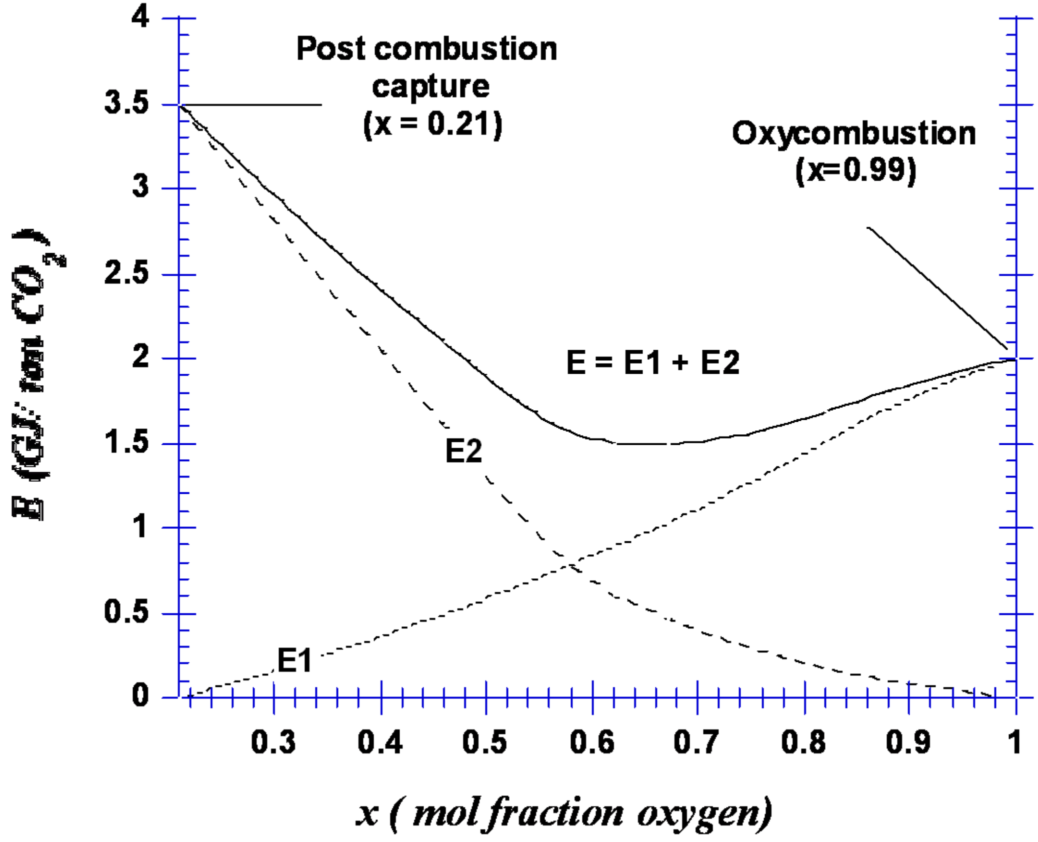


1. *E below 0.5 GJ per ton can be achieved*
2. *For a 20% CO_2, content the required membrane selectivity for E = 0.5 GJ per ton is around 60, i.e. a realistic figure*

Recherche bibliographique sur les données de perméation: CO_2/N_2

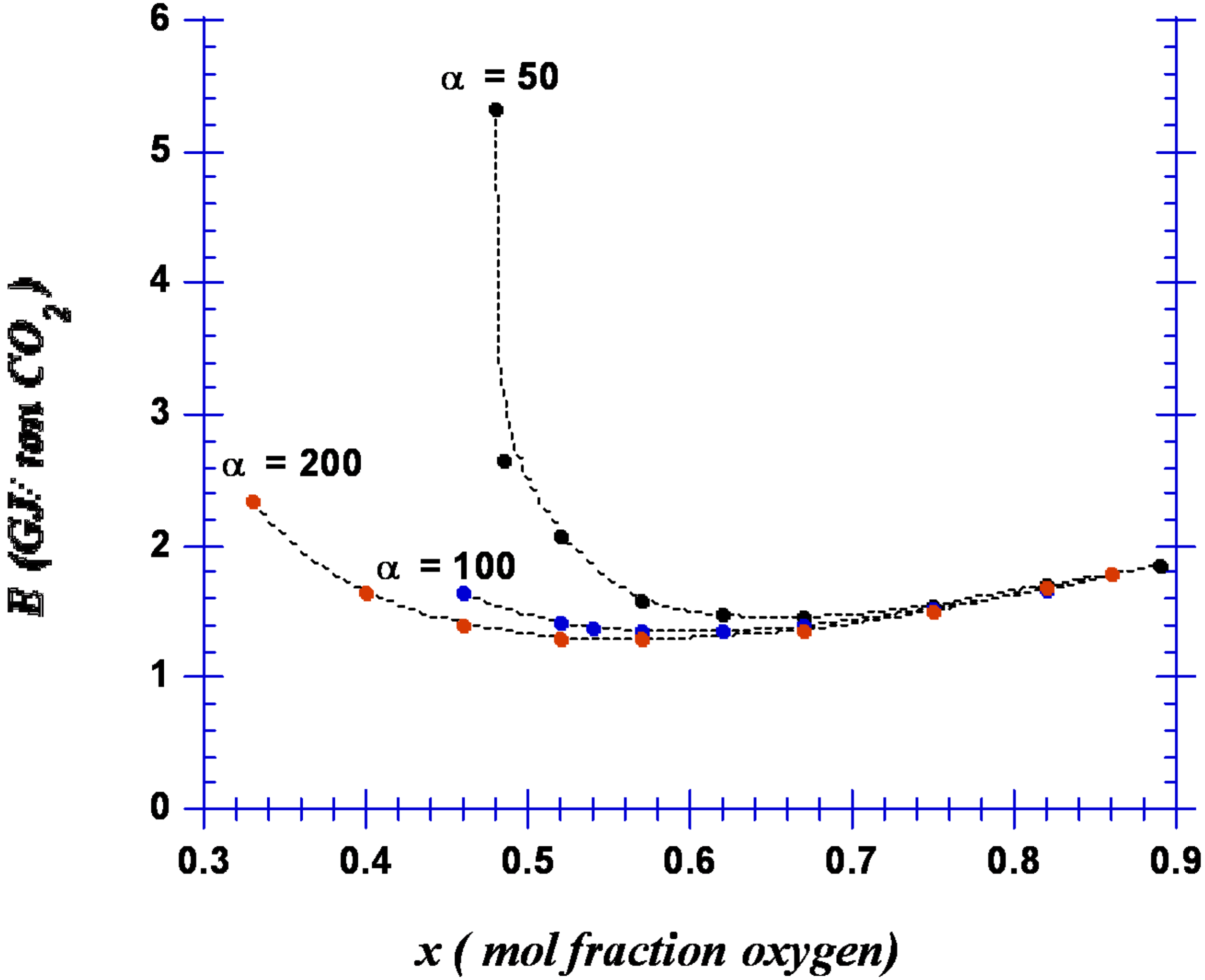


Simulation PHYCAP: Schéma de principe

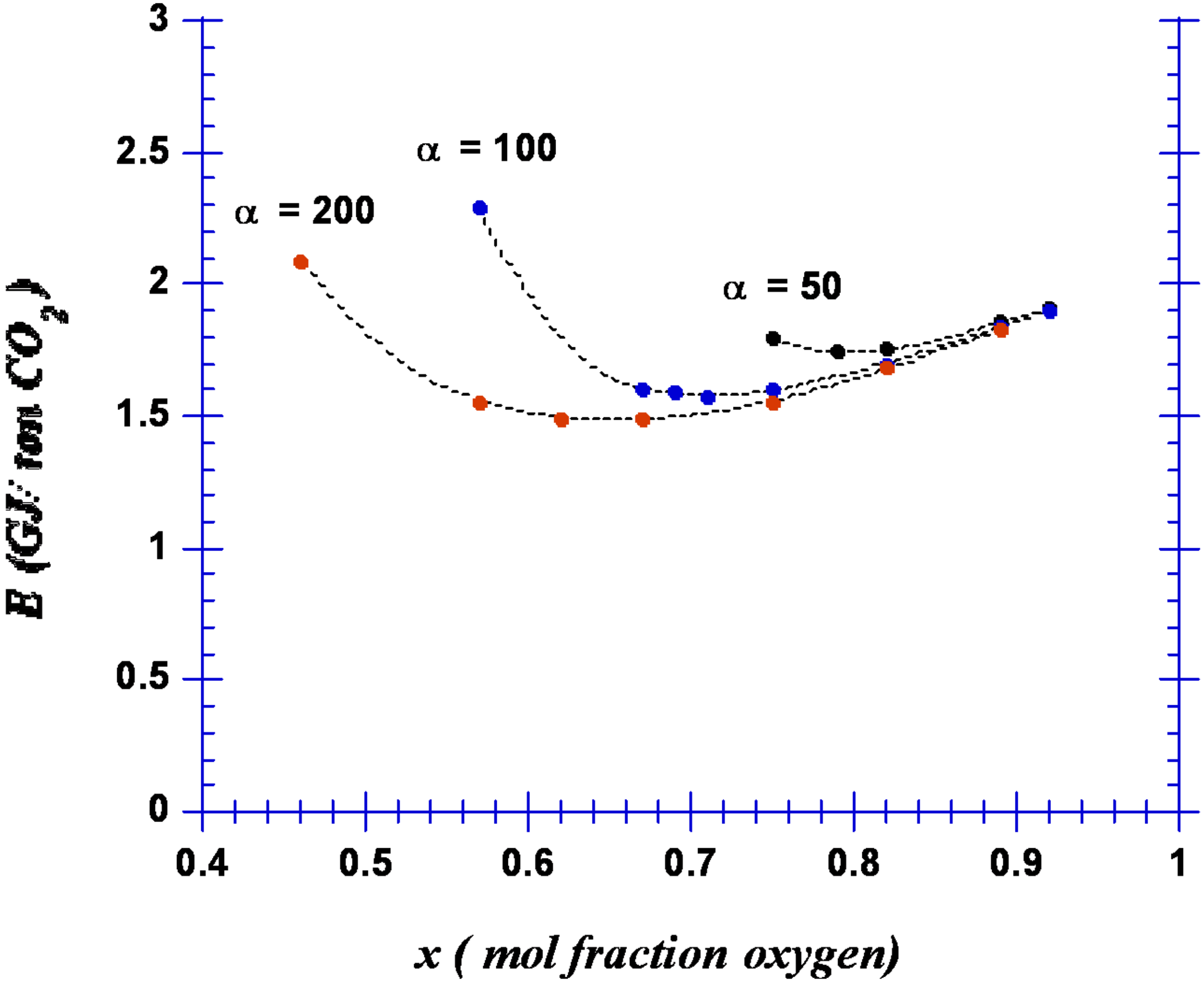


$$E = E1 + E2 = \frac{E_{O2}}{R} \cdot \frac{3n+1}{2n} + \frac{\gamma}{\gamma - 1} \cdot \frac{RT}{\eta} \cdot \left[\left(\frac{P'}{P''} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \cdot \frac{10^{-3}}{R.x'.44}$$

Résultats simulation: n=1, R = 0.9, y = 0.9



Résultats simulation: n=1, R = 0.95, y = 0.95



Projet PHYCAP: Poursuite

1) Concept validé…par simulation uniquement!

2) Prise en compte d'une stoechiométrie de combustion plus réaliste NOx, Ar…

3) Température de flamme et recyclage CO_2

4) Efficacité et intégration énergétique

…….

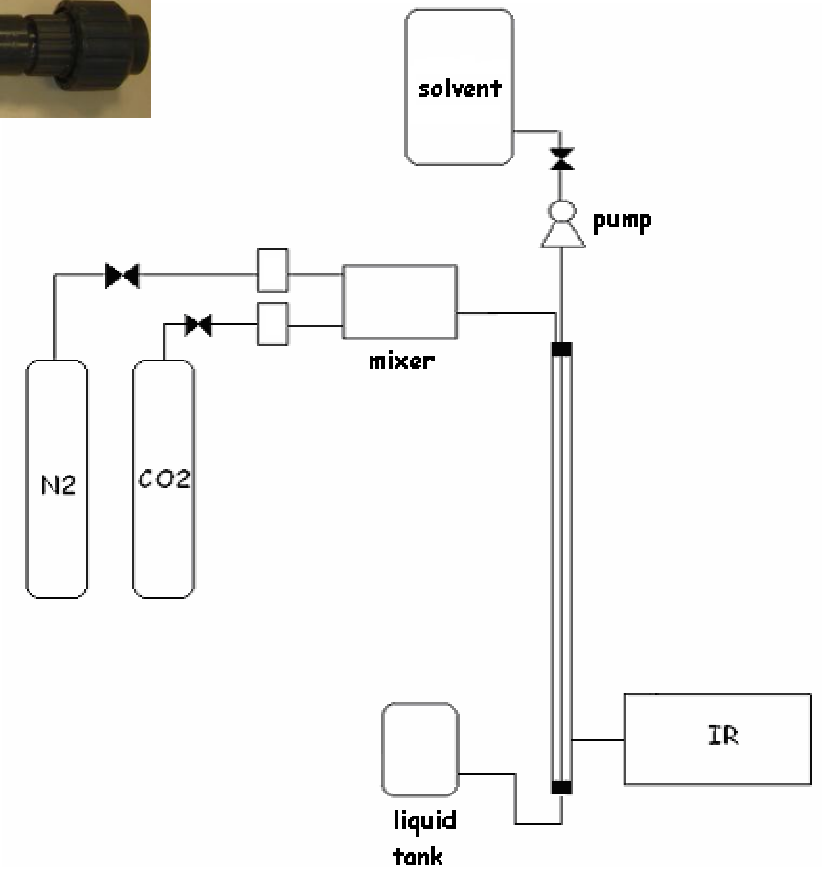
Projet COCASE: Planning prévisionnel

Démarrage: Avril 2008
Rapport intermédiaire: Septembre 2009
Rapport final: Avril 2011

Etape & Durée	*LCD*	*CORIA*	*ICARE*	*LSGC*
Année 1	Séminaire de démarrage Synthèse bibliographique			
	Mise au point de l'installation de combustion	Mise au point de l'installation (turbine)	Simulations des conditions de combustion	Simulations des performances de capture (logiciel M3Pro)
Année 2	Séminaire de présentation et confrontation des résultats Programmation des essais complémentaires			
	Expérimentations (simulation de la recirculation interne des produits de combustion)	Expérimentations (turbine)	Etude de la structure de flamme laminaire	Conception du pilote de capture
	Comparaison simulation / expérimentation Recherche des paramètres opératoires optimaux Séminaire : Choix des conditions de fonctionnement pour l'ensemble du dispositif			
Année 3	Essais complémentaires et modélisation	Essais complémentaires et modélisation	Simulation essais complémentaires	Mesures capture sur pilote
	Etude de sensibilité paramétrique Analyse énergétique globale Séminaire de clôture Rédaction du rapport final & valorisation			

Montage pilote

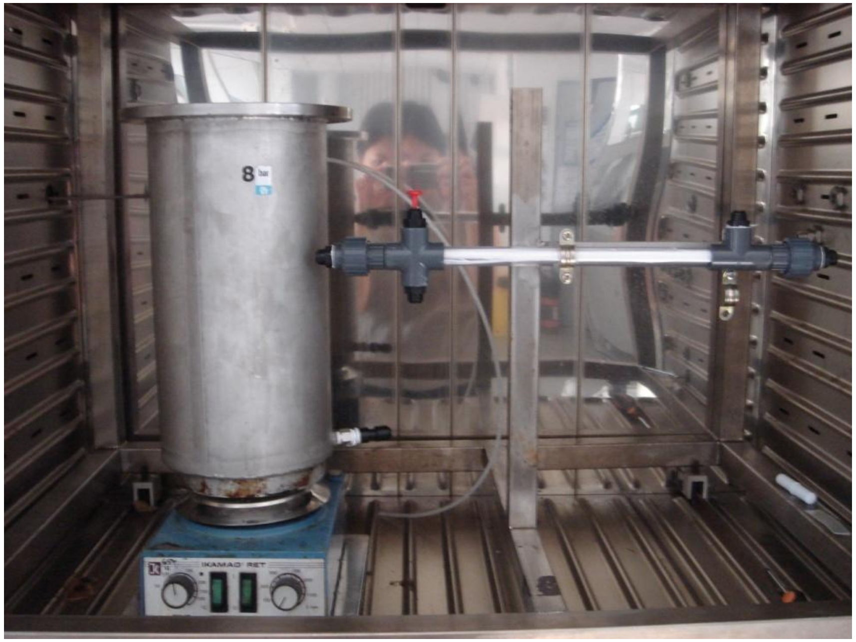
Etude perméation gazeuse de mélanges contenant CO_2, N_2, O_2, H_20, NO_x, SO_x…



Montage pilote

Banc de mesure avec alimentation de mélanges gazeux et détection de CO_2, O_2, NO_x

Etape suivante: obtention de modules industriels de séparation membranaire



Poursuite: simulation de performances de séparation pour mélanges multicomposants

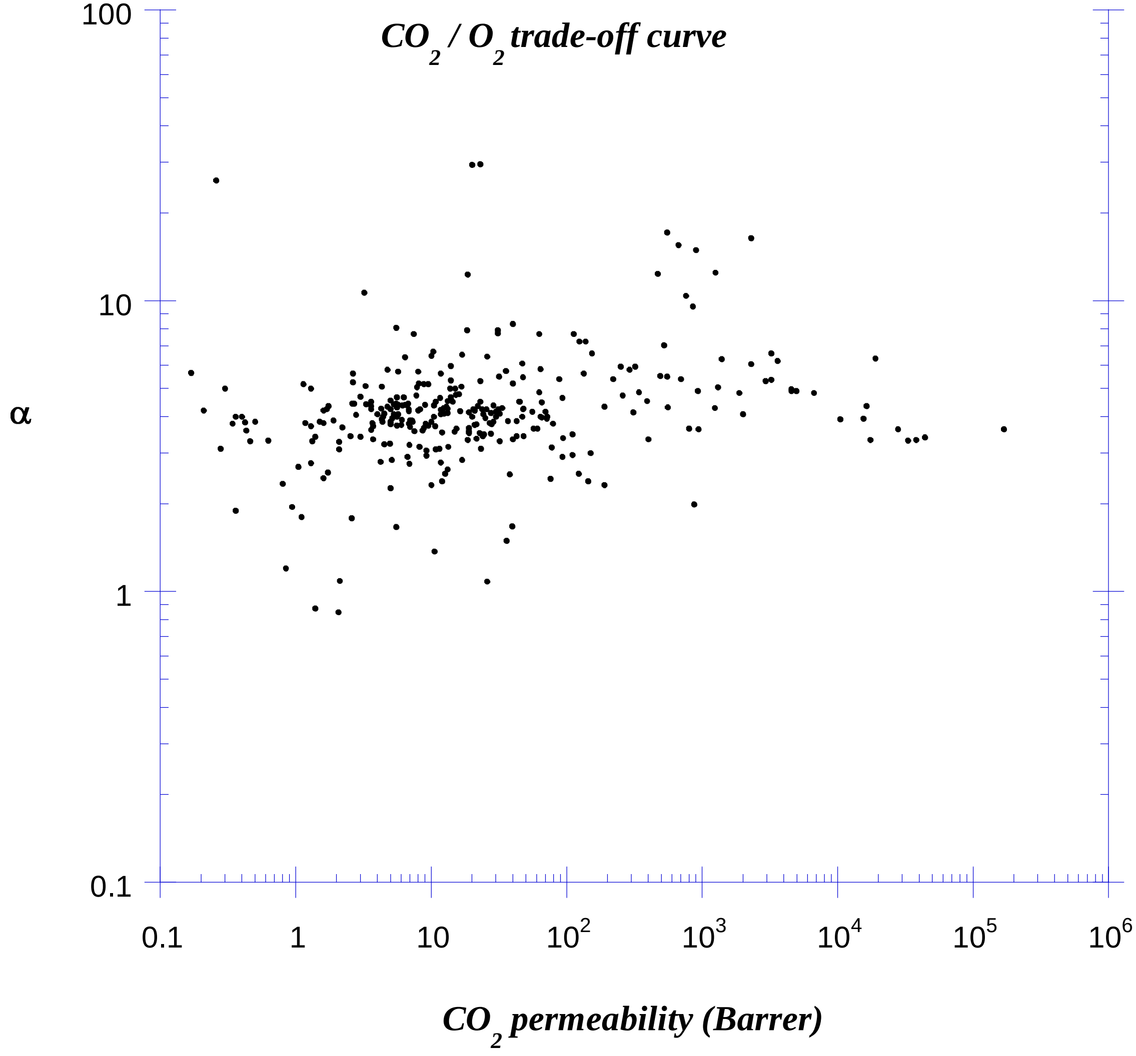
INTERNATIONAL JOURNAL OF GREENHOUSE GAS CONTROL 1 (2007) 343–354 347

Table 1 – Gas quality (mol%) and pressure and temperature from the various capture processes

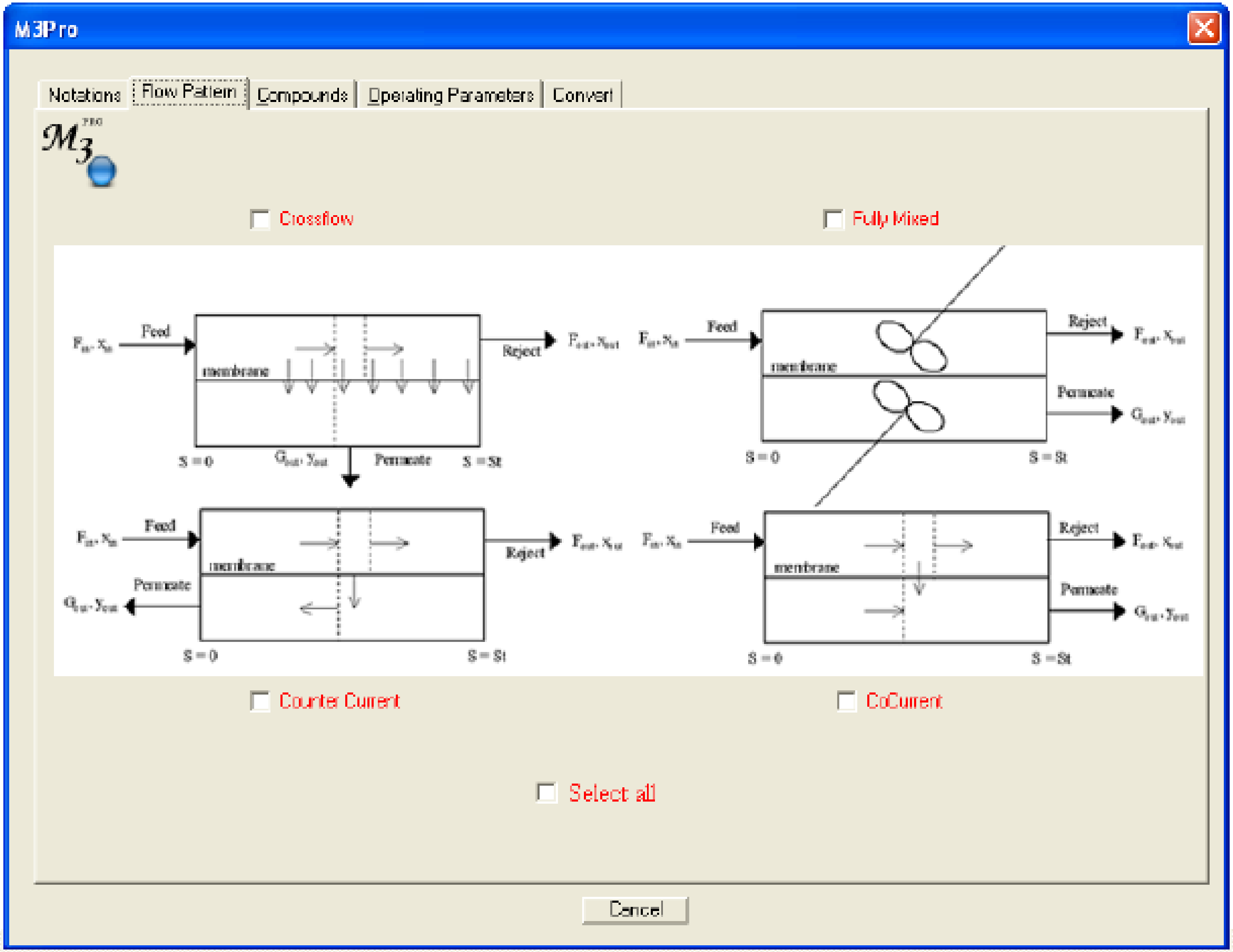
	CO_2	H_2O	H_2	CO	N_2	O_2	CH_4	Ar	P (bar)	T (°C)
Amine (post-combustion)	94.39	5.61	0	0	0	Traces	0	0	1.01	35
ATR (pre-combustion with amine)	98.21	1.79	0	0	0	0	0	0	1.01	16
Water cycle (WC)	59.74	32.84	0	0.01	2.81	1.00	0	3.59	0.045	13
S-Graz	61.65	30.90	0	0	2.91	0.85	0	3.69	1.01	337
Oxyfuel CC	93.82	4.16	0	0	0.28	1.38	0	0.35	1.01	30
SOFC + GT	35.90	63.84	0	0	0.26	0	0	0	1.01	439
AZEP HP	35.90	63.84	0	0	0.26	0	0	0	15.38	248
AZEP LP	35.90	63.84	0	0	0.26	0	0	0	1.01	111
CLC	34.66	65.06	0	0	0.28	0	0	0	1.01	415
MSR-H2 HP	62.44	35.49	0.92	0.57	0.45	0	0.12	0	63.94	578
MSR-H2 LP	62.44	35.49	0.92	0.57	0.45	0	0.12	0	1.04	98

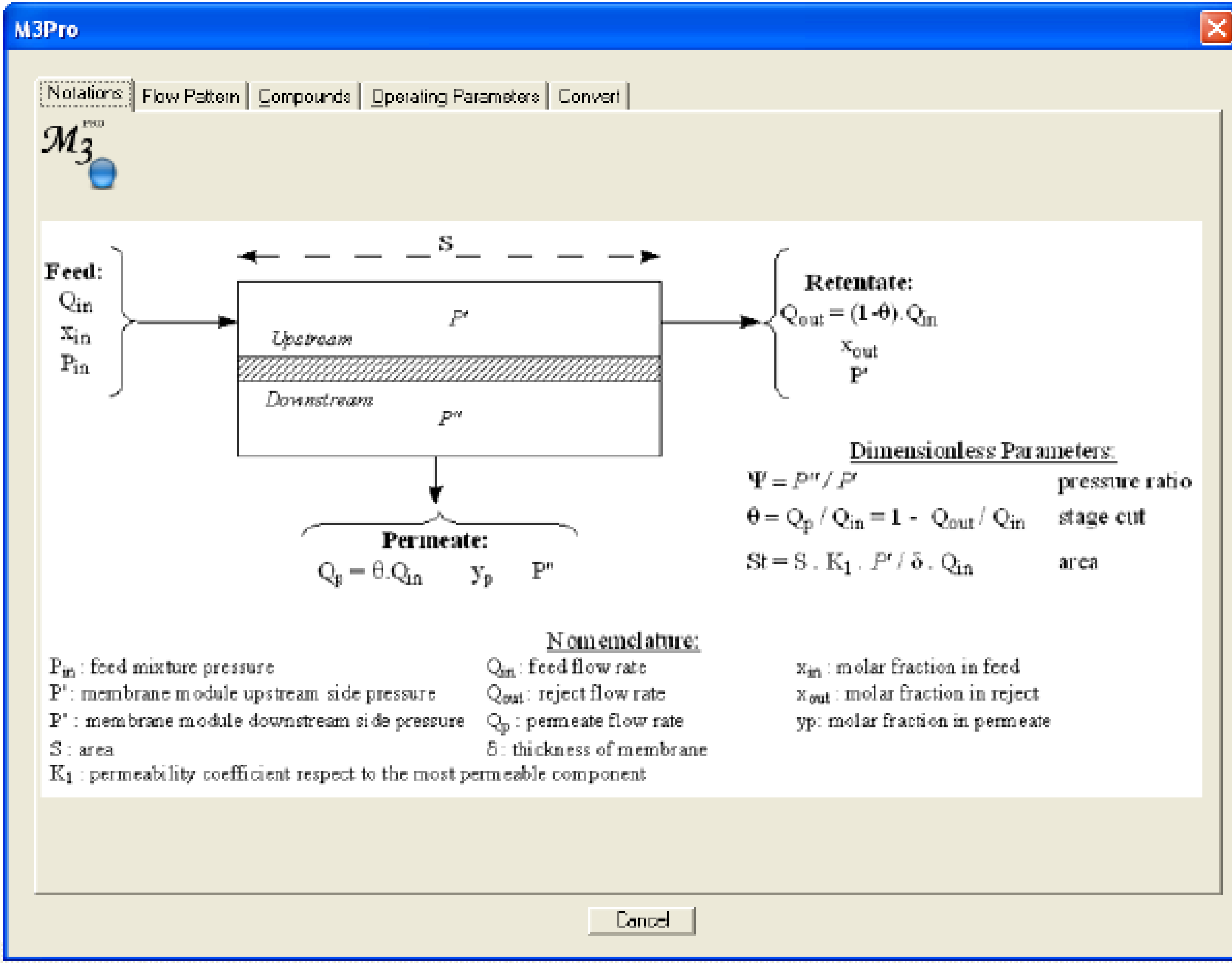
Important: Evaluer la compatibilité des mélanges obtenus dans le flux de CO_2 concentré avec les contraintes de transport (O_2, NOx, SOx…)

Recherche bibliographique sur les données de perméation: CO_2/O_2

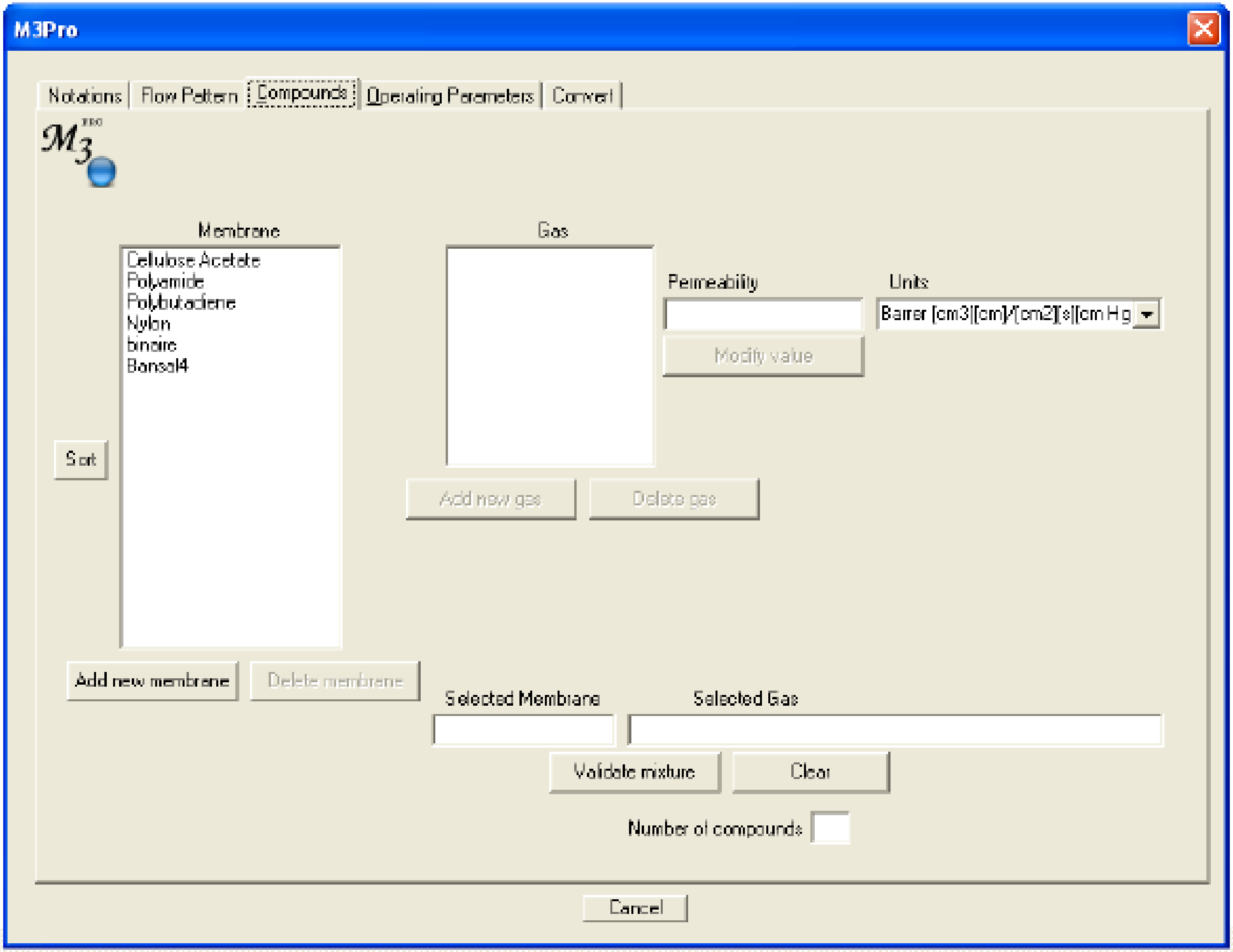


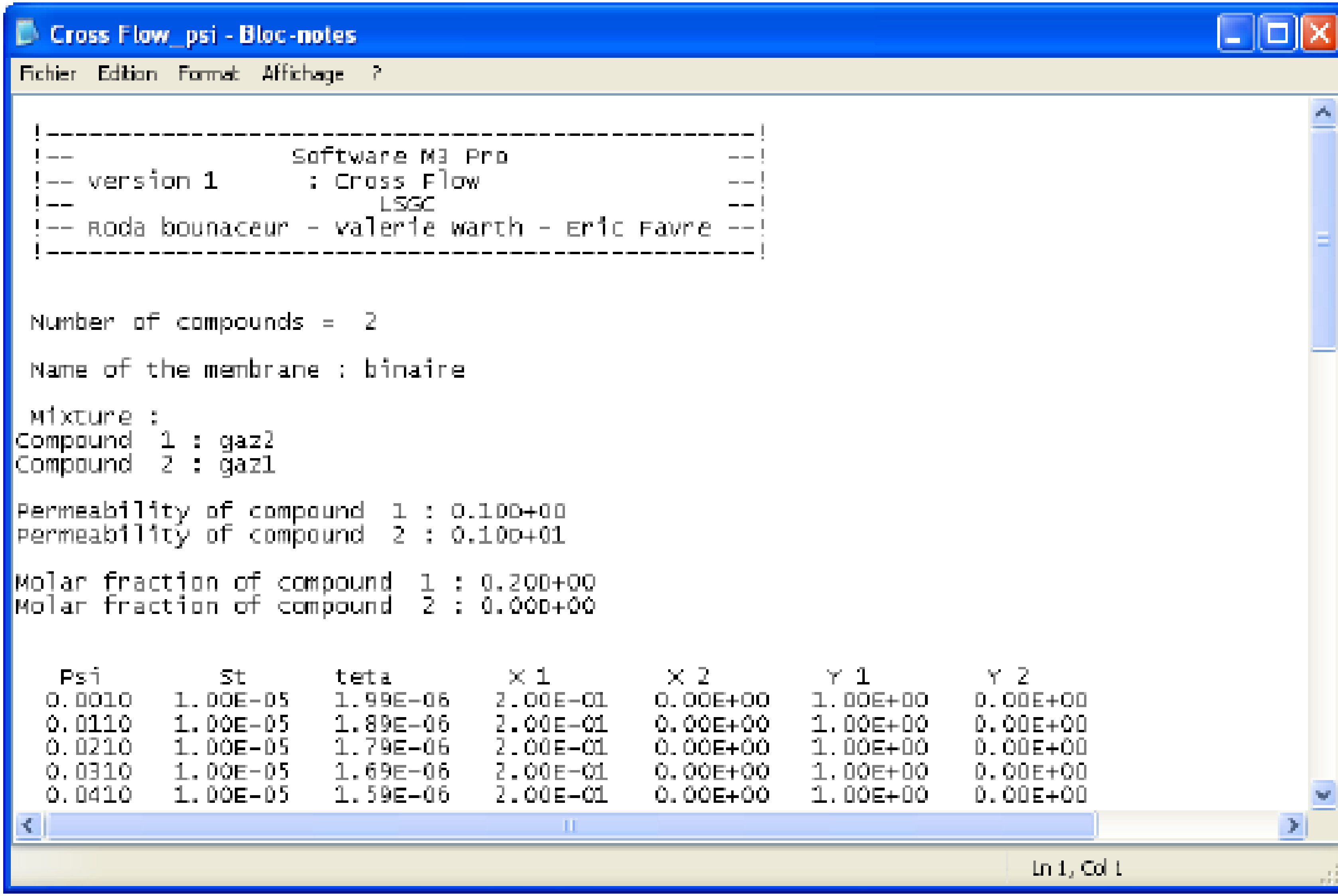
Simulation du procédé de perméation gazeuse pour des mélanges multicomposants: Extension du logiciel M3Pro (LSGC)





M3Pro
Notations
Flow Pattern
Compounds
Operating Parameters
Convert
S
Feed:
Qin
xin
Pin
P'
Upstream
Downstream
P''
Retentate:
Qout = (1-θ).Qin
xout
P'
Permeate:
Qp = θ.Qin
yp
P''
Dimensionless Parameters:
Ψ = P'' / P'
pressure ratio
θ = Qp / Qin = 1 - Qout / Qin
stage cut
St = S . K1 . P' / δ . Qin
area
Nomenclature:
Pin : feed mixture pressure
P' : membrane module upstream side pressure
P'' : membrane module downstream side pressure
S : area
K1 : permeability coefficient respect to the most permeable component
Qin : feed flow rate
Qout : reject flow rate
Qp : permeate flow rate
δ : thickness of membrane
xin : molar fraction in feed
xout : molar fraction in reject
yp: molar fraction in permeate
Cancel


M3Pro
Notations
Flow Pattern
Compounds
Operating Parameters
Convert
Membrane
Cellulose Acetate
Polyamide
Polybutadiene
Nylon
binaire
Bansal4
Sort
Add new membrane
Delete membrane
Gas
Add new gas
Delete gas
Permeability
Modify value
Units
Barrer [cm3][cm]/[cm2][s][cm Hg
Selected Membrane
Selected Gas
Validate mixture
Clear
Number of compounds
Cancel


Cross Flow_psi - Bloc-notes

Fichier Edition Format Affichage ?

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!-------------------------------------------------!
!--                  Software M3 Pro            --!
!-- version 1        : Cross Flow               --!
!--                       LSGC                  --!
!-- Roda bounaceur - valerie warth - Eric Favre --!
!-------------------------------------------------!


 Number of compounds =  2

 Name of the membrane : binaire

 Mixture :
Compound  1 : gaz2
Compound  2 : gaz1

Permeability of compound  1 : 0.10D+00
Permeability of compound  2 : 0.10D+01

Molar fraction of compound  1 : 0.20D+00
Molar fraction of compound  2 : 0.00D+00
```

Psi	St	teta	X 1	X 2	Y 1	Y 2
0.0010	1.00E-05	1.99E-06	2.00E-01	0.00E+00	1.00E+00	0.00E+00
0.0110	1.00E-05	1.89E-06	2.00E-01	0.00E+00	1.00E+00	0.00E+00
0.0210	1.00E-05	1.79E-06	2.00E-01	0.00E+00	1.00E+00	0.00E+00
0.0310	1.00E-05	1.69E-06	2.00E-01	0.00E+00	1.00E+00	0.00E+00
0.0410	1.00E-05	1.59E-06	2.00E-01	0.00E+00	1.00E+00	0.00E+00

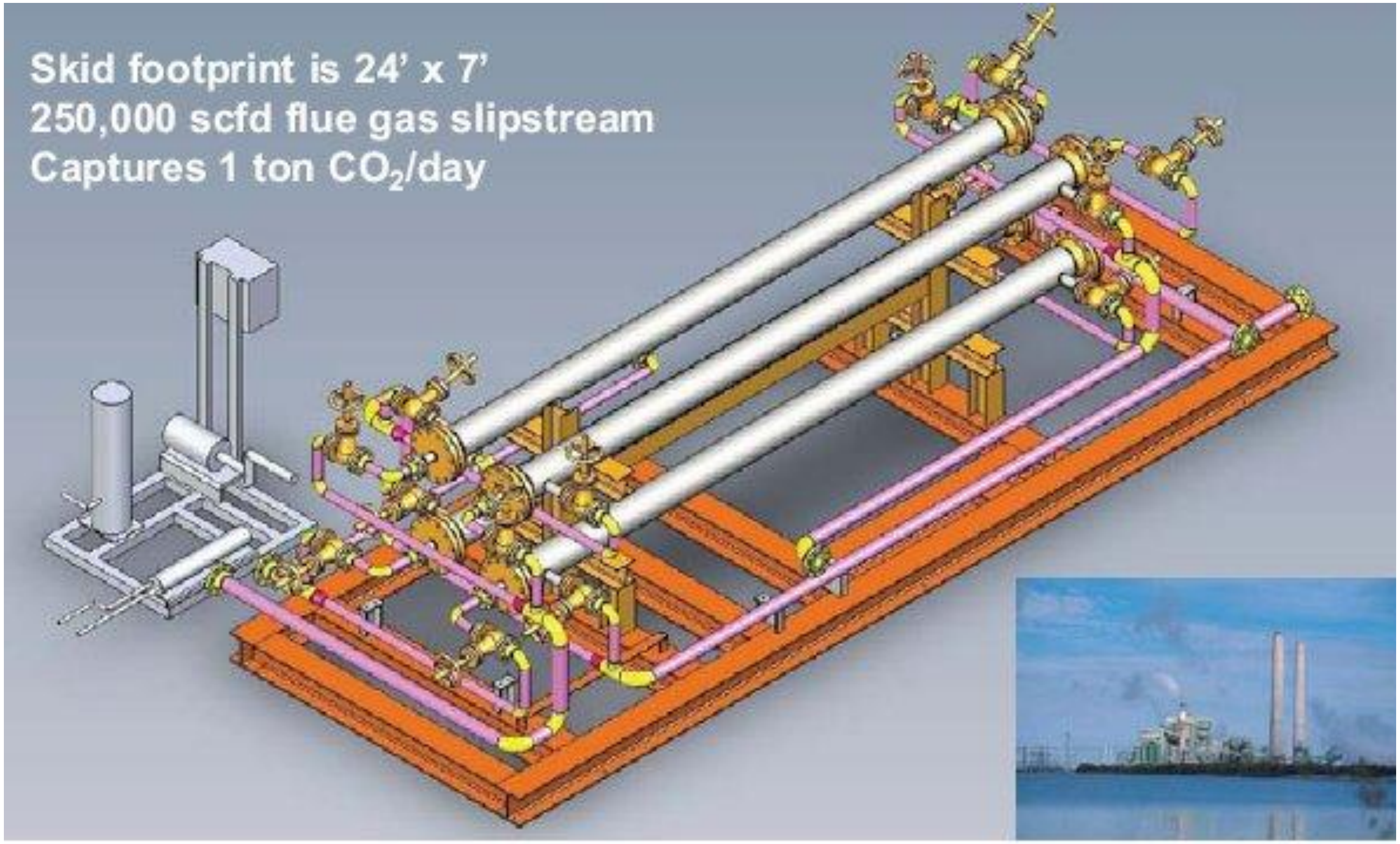
Ln 1, Col 1

Air Products Joins World#s First Full Demonstration of Oxyfuel CO2 Capture and Sequestration at Vattenfall

02.04.2009 - Air Products announced it will play a key role in the world's first full demonstration of oxyfuel carbon capture and sequestration with the signing of an agreement with Vattenfall AB. Air Products will install its proprietary carbon dioxide (CO2) capture, purification and compression system at Vattenfall's research and development facility in Schwarze Pumpe, Germany, which is viewed globally as the preeminent CO2 oxyfuel project. Air Products will focus specifically on the purification and compression of oxyfuel combustion flue gas. The two companies also executed a joint research and development agreement related to the project. Air Products' pilot plant is to be operational at Schwarze Pumpe in December 2010.

"This is the world's first full demonstration of oxyfuel CO2 capture and sequestration, and our unique CO2 purification and compression technology will be validated at pilot scale through this work," said David J. Taylor, vice president - Energy Businesses at Air Products.

At the Schwarze Pumpe facility, Air Products will take flue gas directly off Vattenfall's 30 megawatt (MW) wall-fired boiler at the oxyfuel pilot plant. It will purify and compress the carbon dioxide, a portion of which will ultimately be transported for sequestration. Air Products' proprietary sour compression technology uses a staged compression process to optimize pressure, hold-up, and residence time to allow removal of impurities during the compression process. This allows cost savings in the oxyfuel combustion process and minimizes the concentration of acidic components, important in preventing corrosion during the CO2 sequestering process. This pilot will demonstrate the efficient purification of CO2, and remove inert gases, in particular oxygen. In addition, it will incorporate novel membrane technology, targeting carbon capture rates as high as 98 percent.



The APS Cholla power plant
1 ton/day field test pilot unit