Diploma thesis presentation

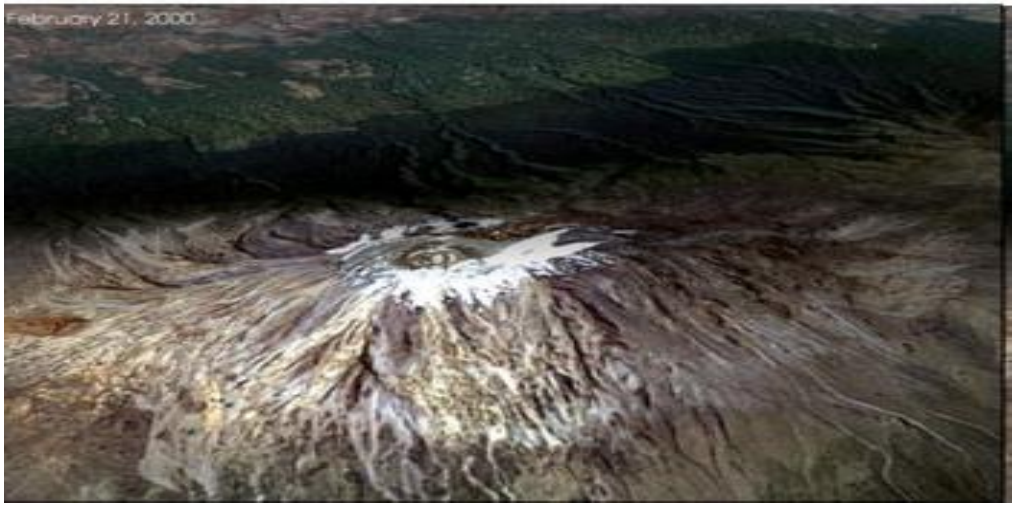
Modeling of a pilot installation for the CO_2-reactive absorption with amine solvent for power plant flue gases

Grégoire Léonard

Global warming context

February 1993

February 2000



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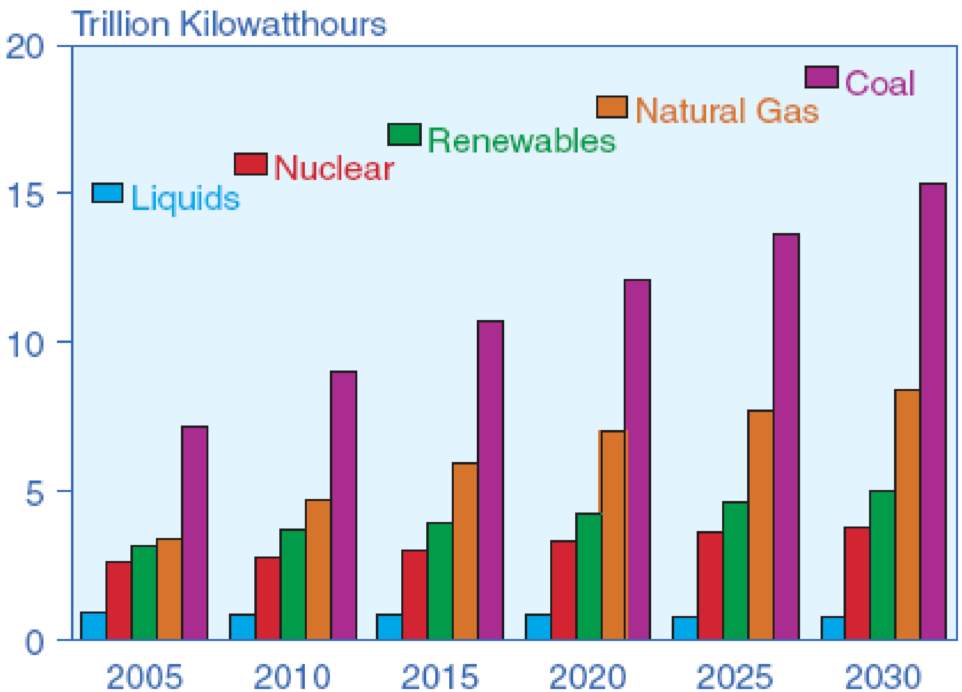
1. Introduction

- Importance of coal for electricity generation in the near-future

- Environmental concerns

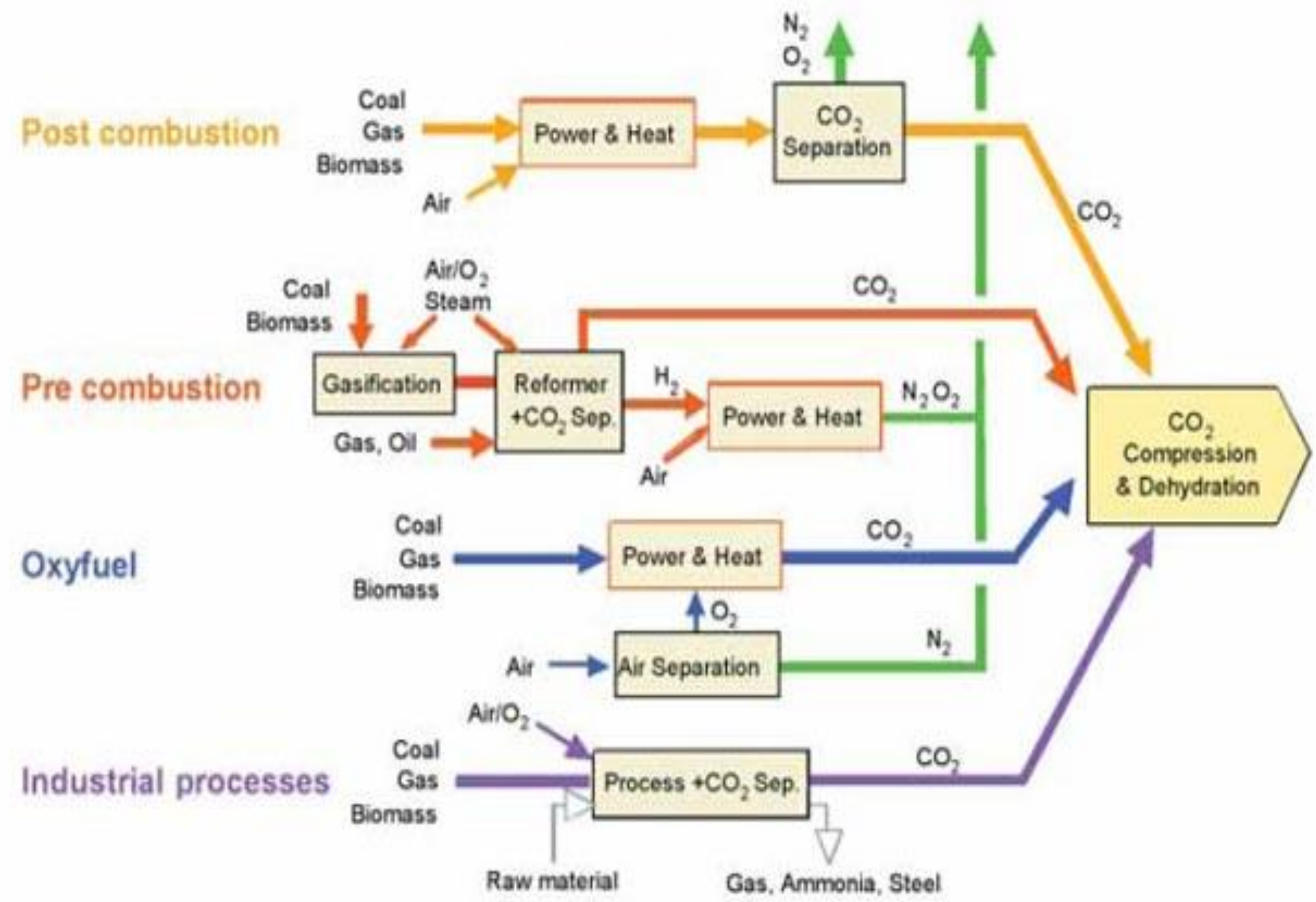
=> Energy efficiency
=> biomass
=> Carbon Capture and Storage (CCS)

World Electricity Generation by Fuel, 2005-2030

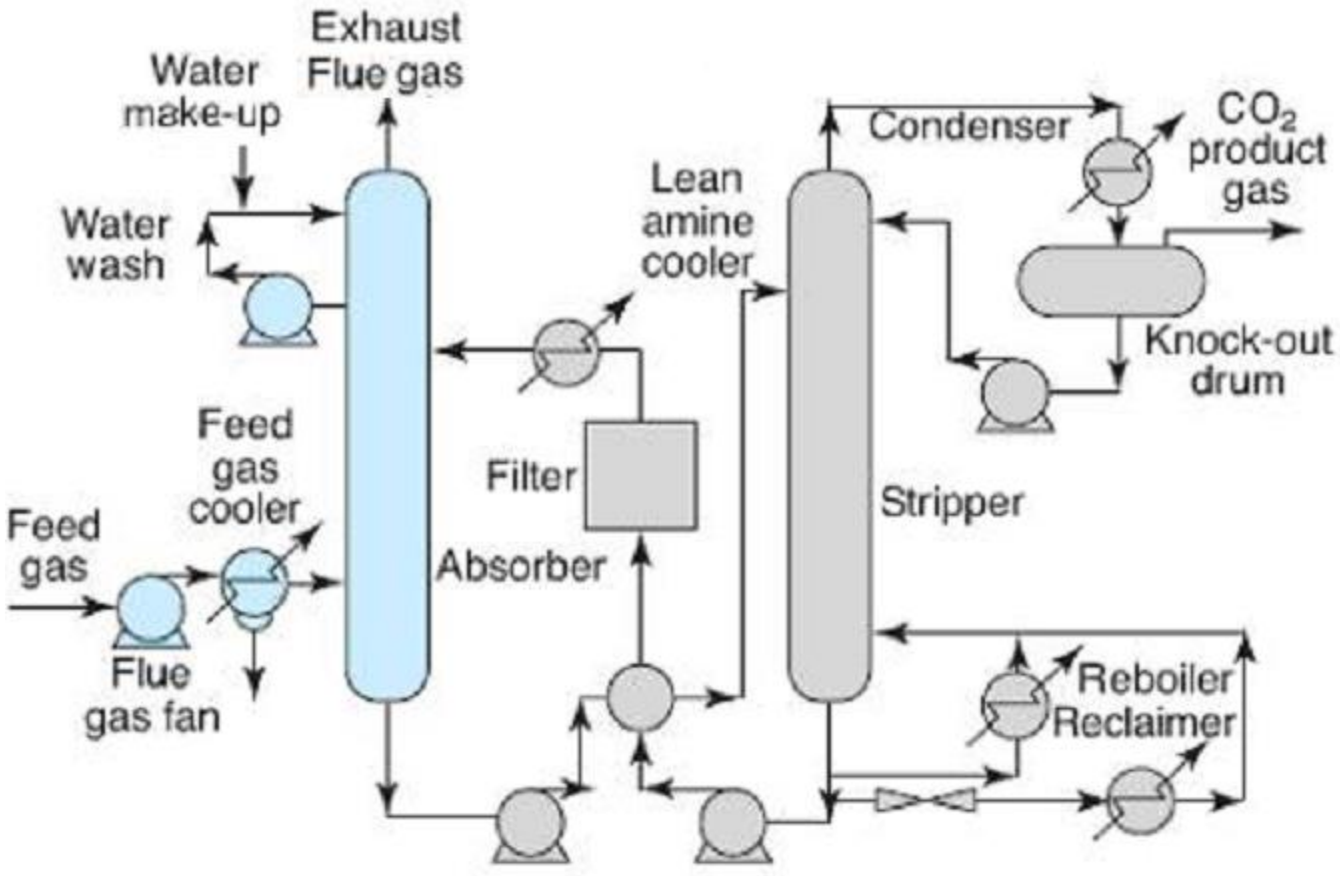


International Energy Outlook 2008

CO_2-Capture methods



Post-combustion capture



2. Objectives

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Background: Pilot installation

- Post-combustion capture for an existing coal-fired power-plant
- 5000 Nm^3 flue gas per hour / 1 ton CO_2 per hour
- Two operation trains
- Different amine solvents

2. Objectives

Objectives:

- Development of a simulation model for the pilot capture installation
- Identification of clue parameters
- Optimization of the developed model
- Simulation of process improvements

3. Modeling basis

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Thermodynamical equilibrium model

=> No mass transfer limitations

=> No reaction kinetics limitations

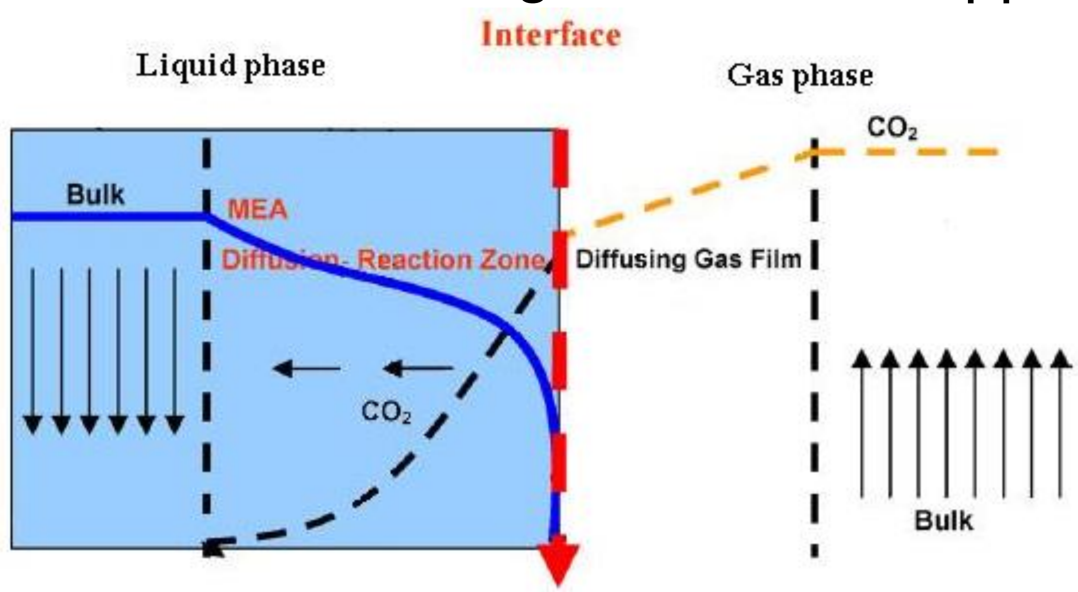
In the practice:

- mass transfer limitations occur
- packing efficiency can be calculated
- packing efficiency reaches about 15 %

3. Modeling basis

Reaction kinetics with MEA

- Pseudo-first order reaction with fast kinetics
- Reaction only occurs in the liquid film
- Kinetic limitations can be neglected in first approximation



4. Model description

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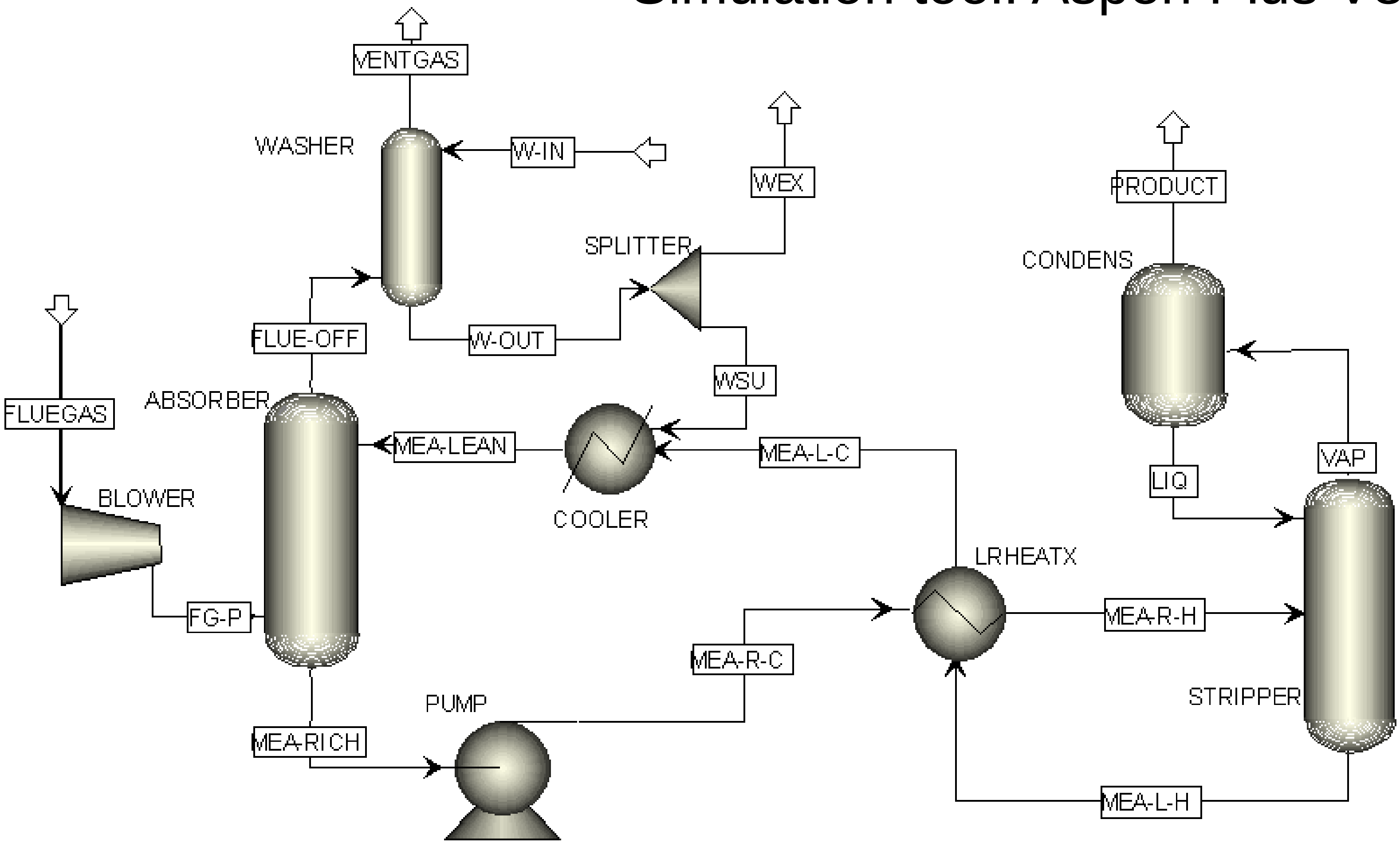
Simulation tool: Aspen Plus V8.0



4. Model description

Model main characteristics

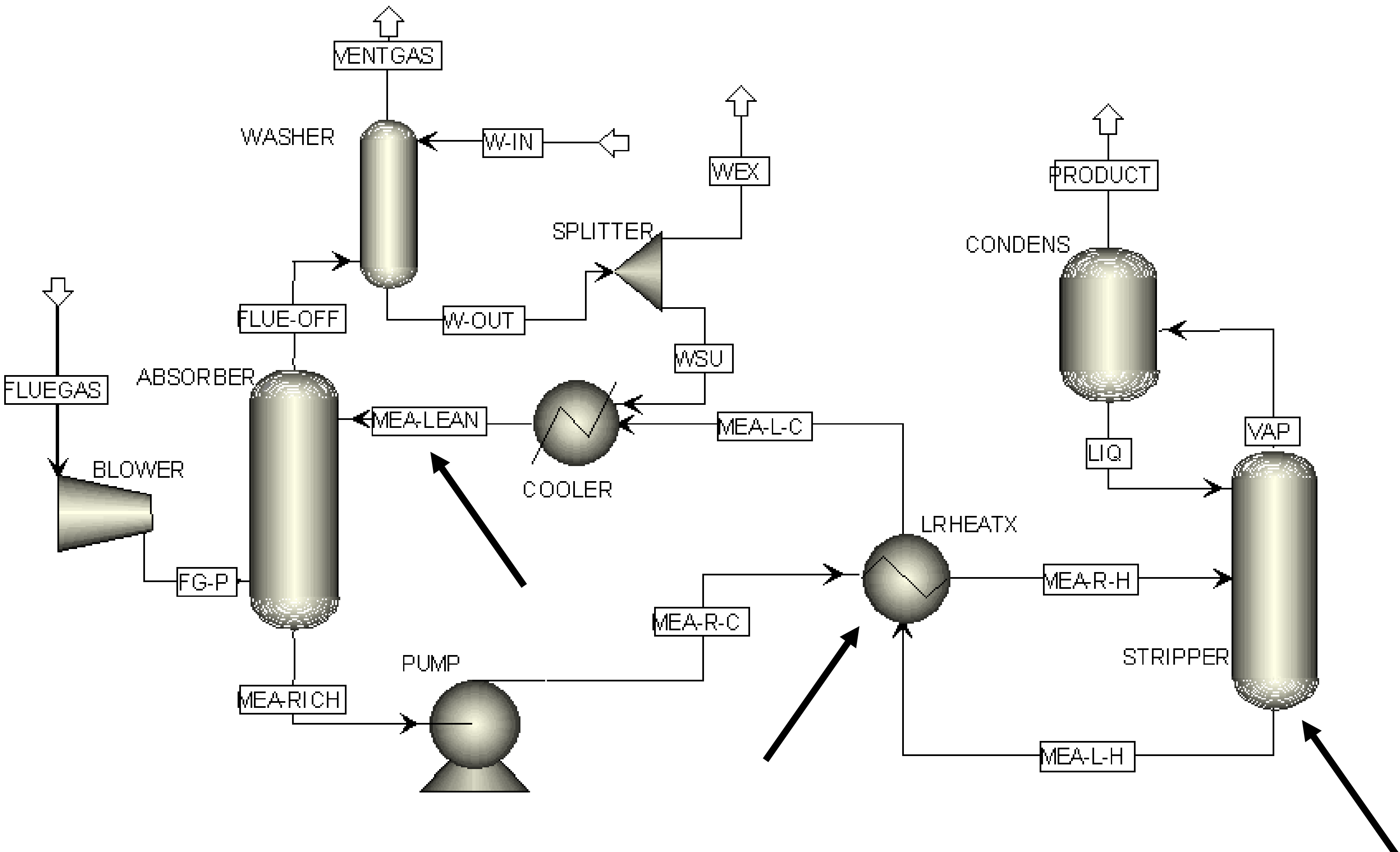
- Flue gas flow: 2500 Nm³/h
- 90% CO_2-recovery rate
- captured CO_2: 566 kg/h
- MEA solvent, concentration = 30 wt-%

5. Simulation results

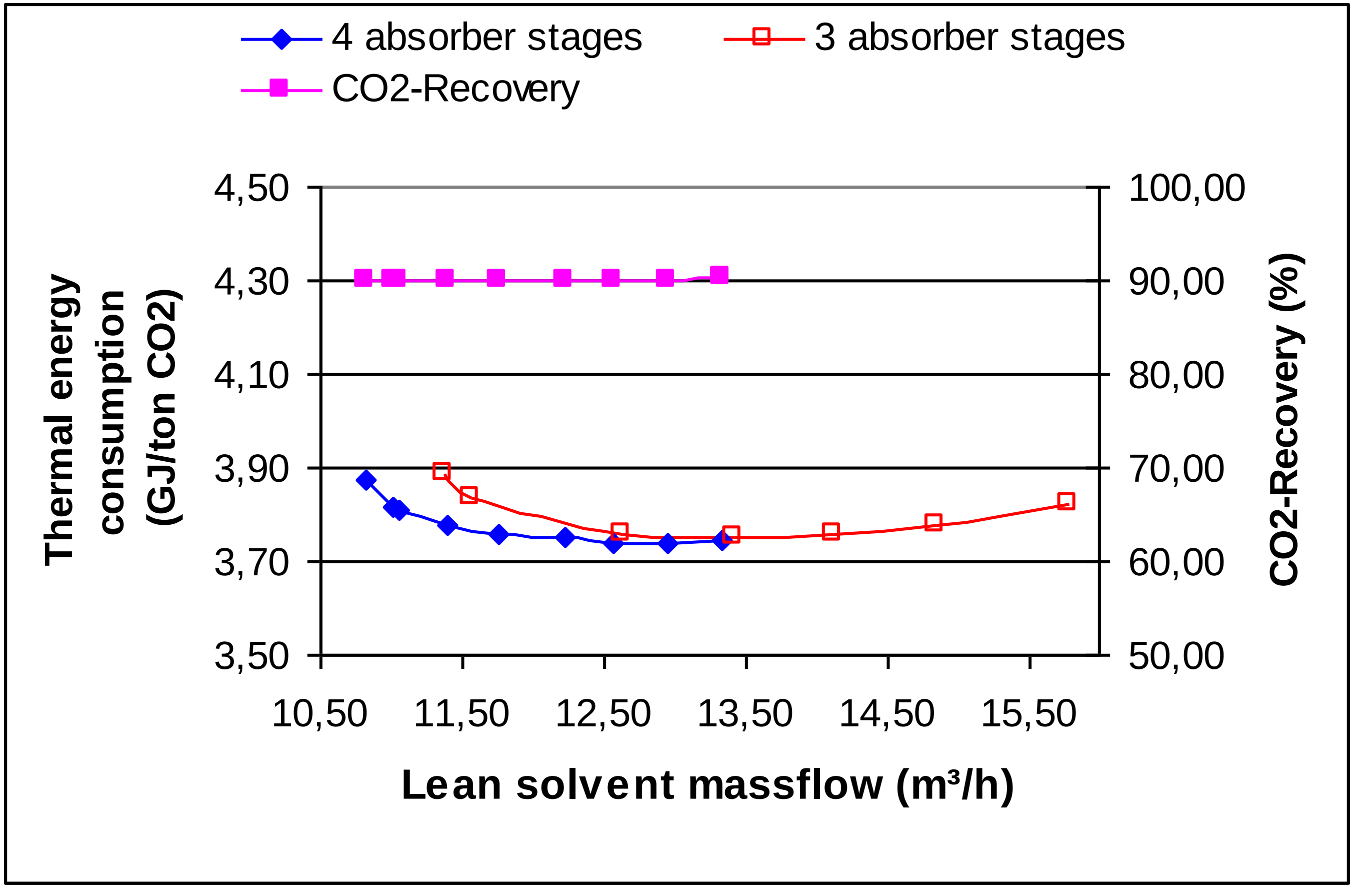
Optimization of the base case

- 5.1 Lean solvent flow
- 5.2 Lean solvent concentration
- 5.3 Lean solvent inlet temperature in the absorber
- 5.4 Stripper pressure
- 5.5 Temperature approach at the lean-rich heat exchanger

5. Simulation results



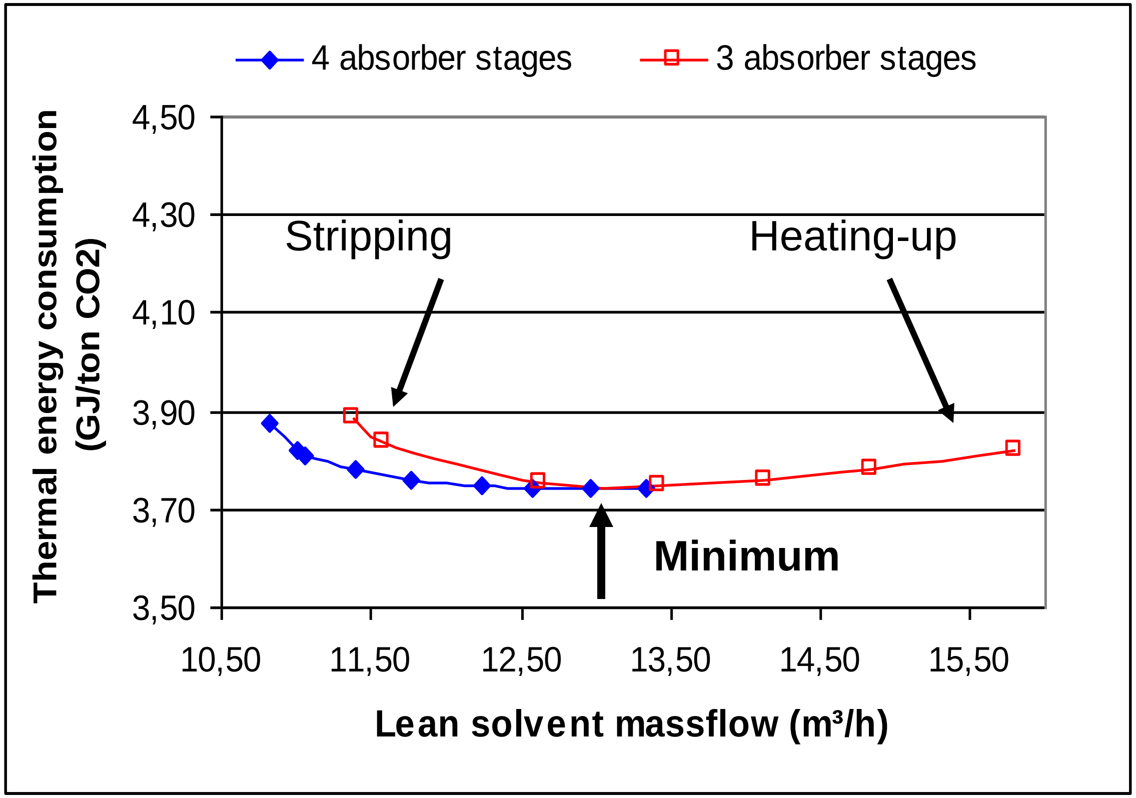
5.1 Optimization of the lean solvent flow



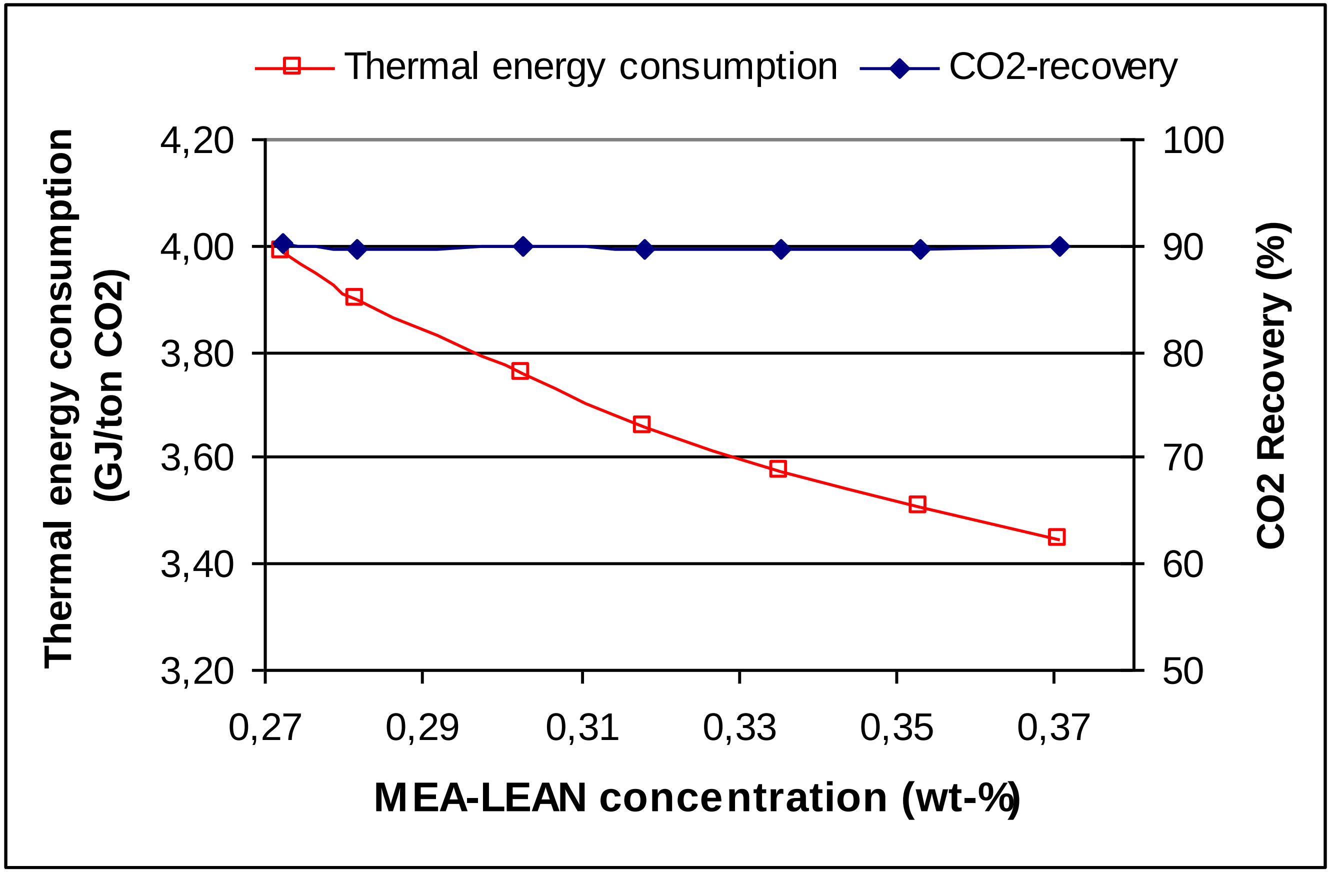
5. Simulation results

3 contributions to the thermal energy consumption :

- Solvent heating-up
- Desorption enthalpy
- Stripping steam



5.2 Optimization of the lean solvent concentration



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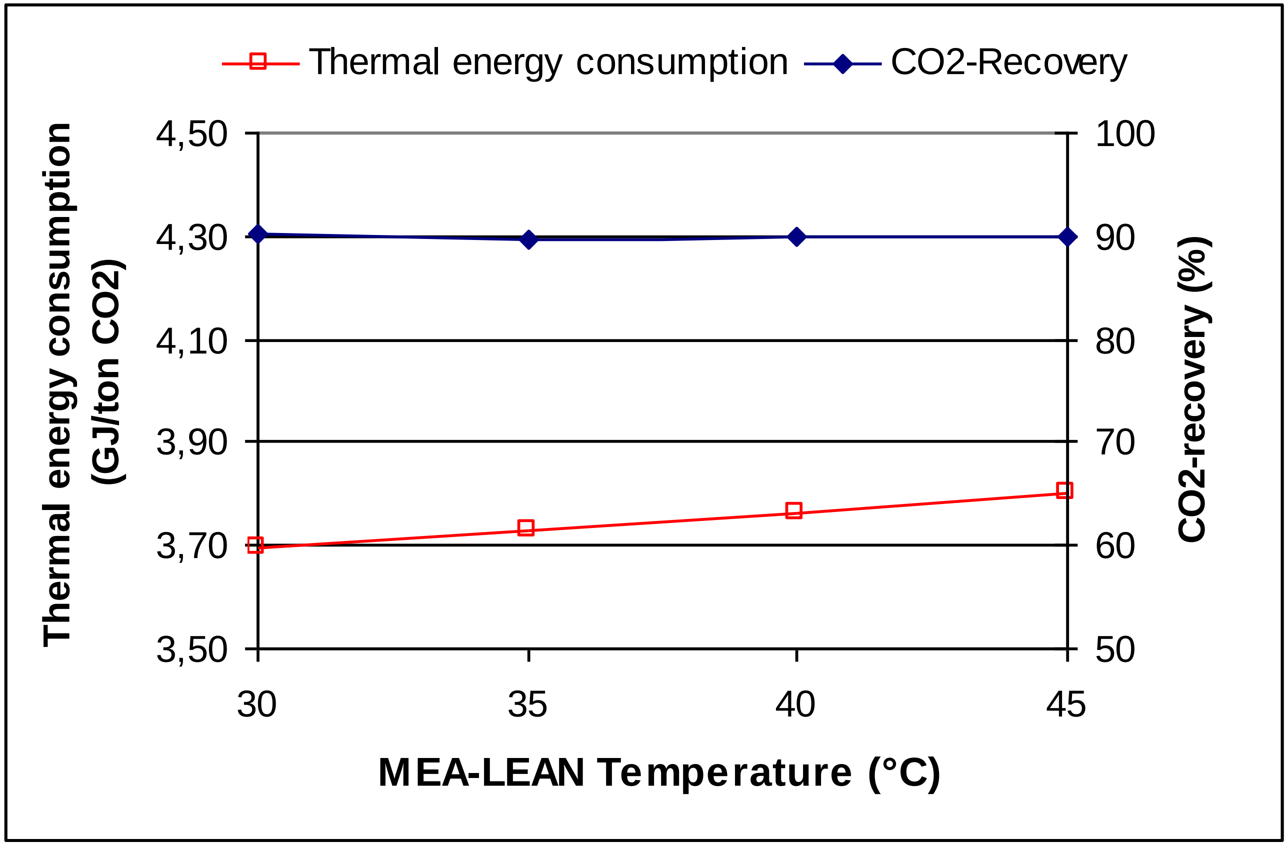
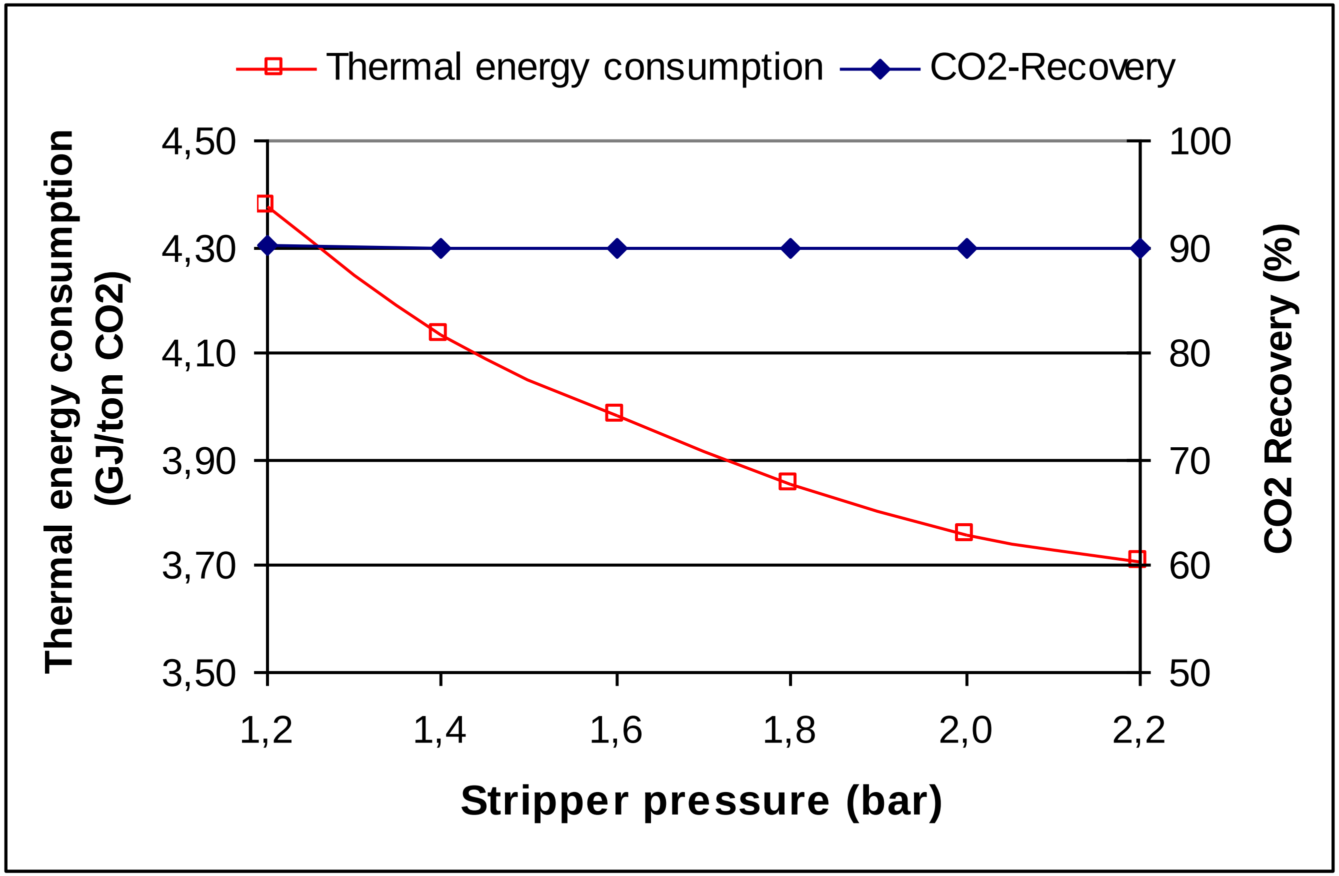
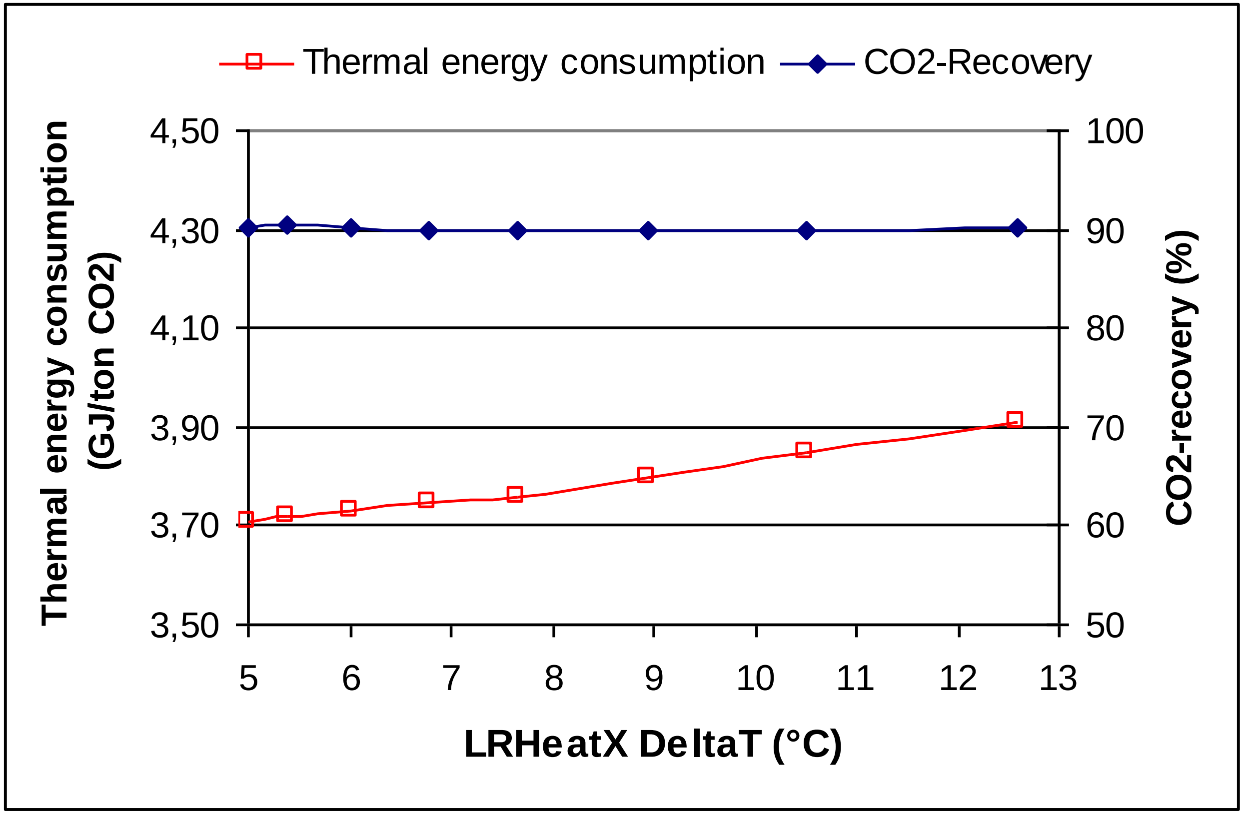
5.3 Optimization of the lean-solvent inlet temperature in the absorber



5.4 Optimization of the stripper pressure



5.5 Optimization of the temperature approach at the lean-rich heat exchanger



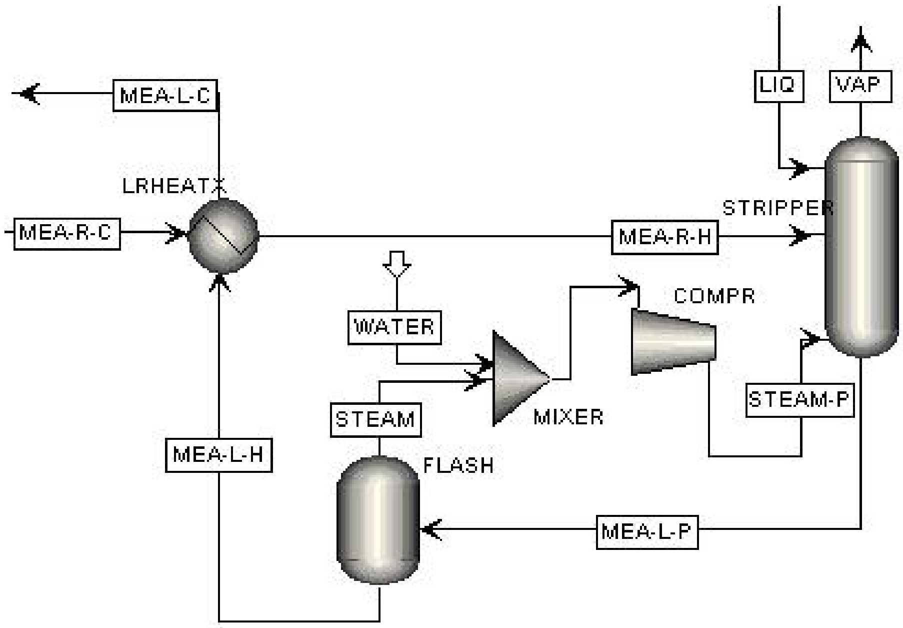
5. Simulation results

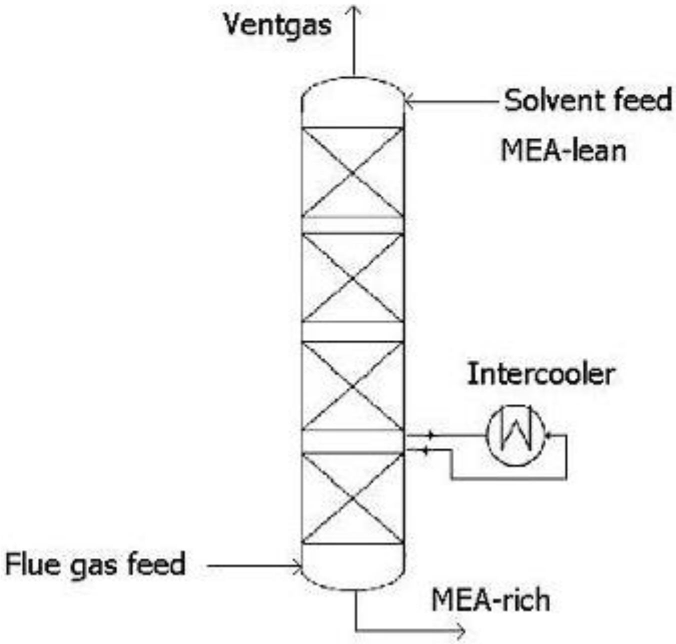
Parameter	Best-case value	Reduction of the thermal energy consumption	Disadvantage
MEA inlet flow	11,725 m³/h	- 3%	not experimentally confirmed yet
MEA inlet concentration	40 wt-%	- 12,5%	Corrosive behavior
MEA inlet temperature	30 °C	-2,5%	Increase of the cooling water requirement
Stripper pressure	2,2 bar	- 16%	Possibility of solvent degradation
Temp. approach at the L-R heat exchanger	5 °K	- 5%	Increase of the equipment costs

6. Process modifications

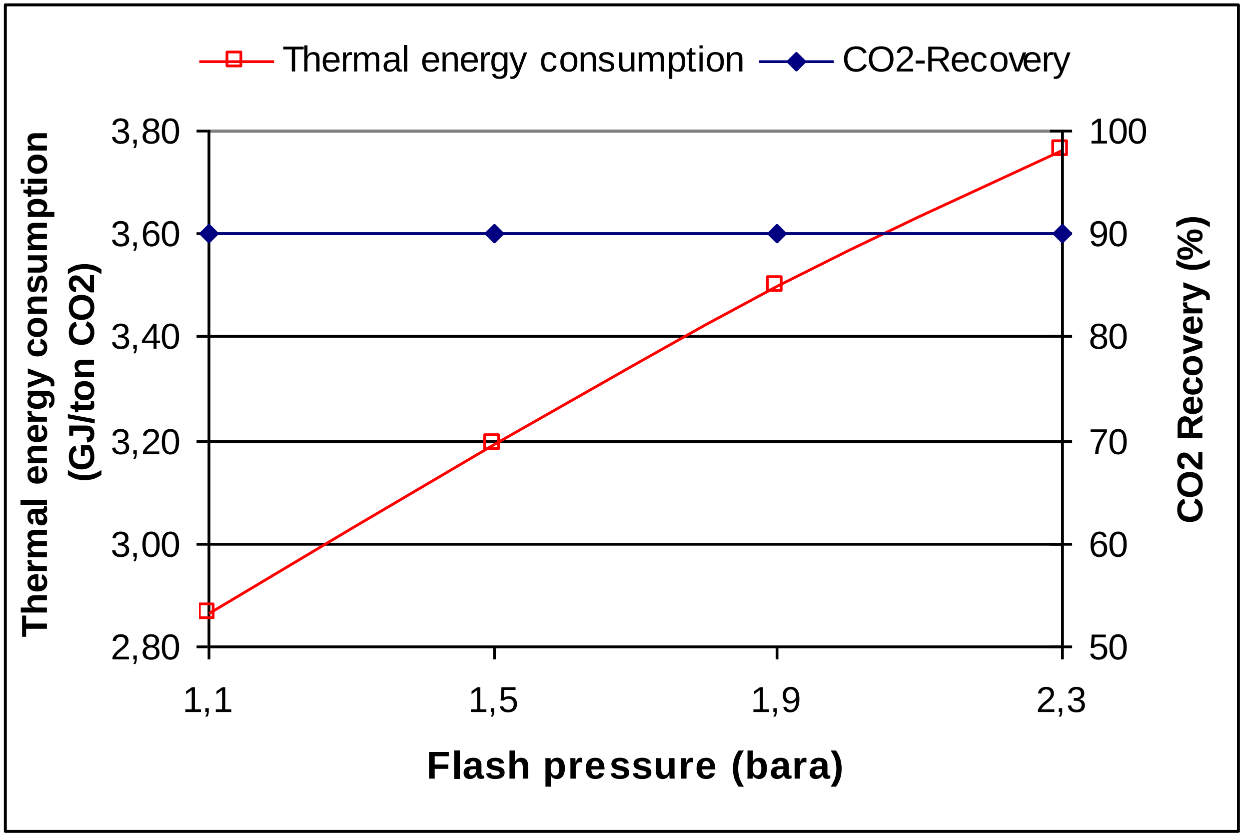
6. Process modifications

- **6.1 Lean vapor compression**
- **6.2 Absorber intercooling**





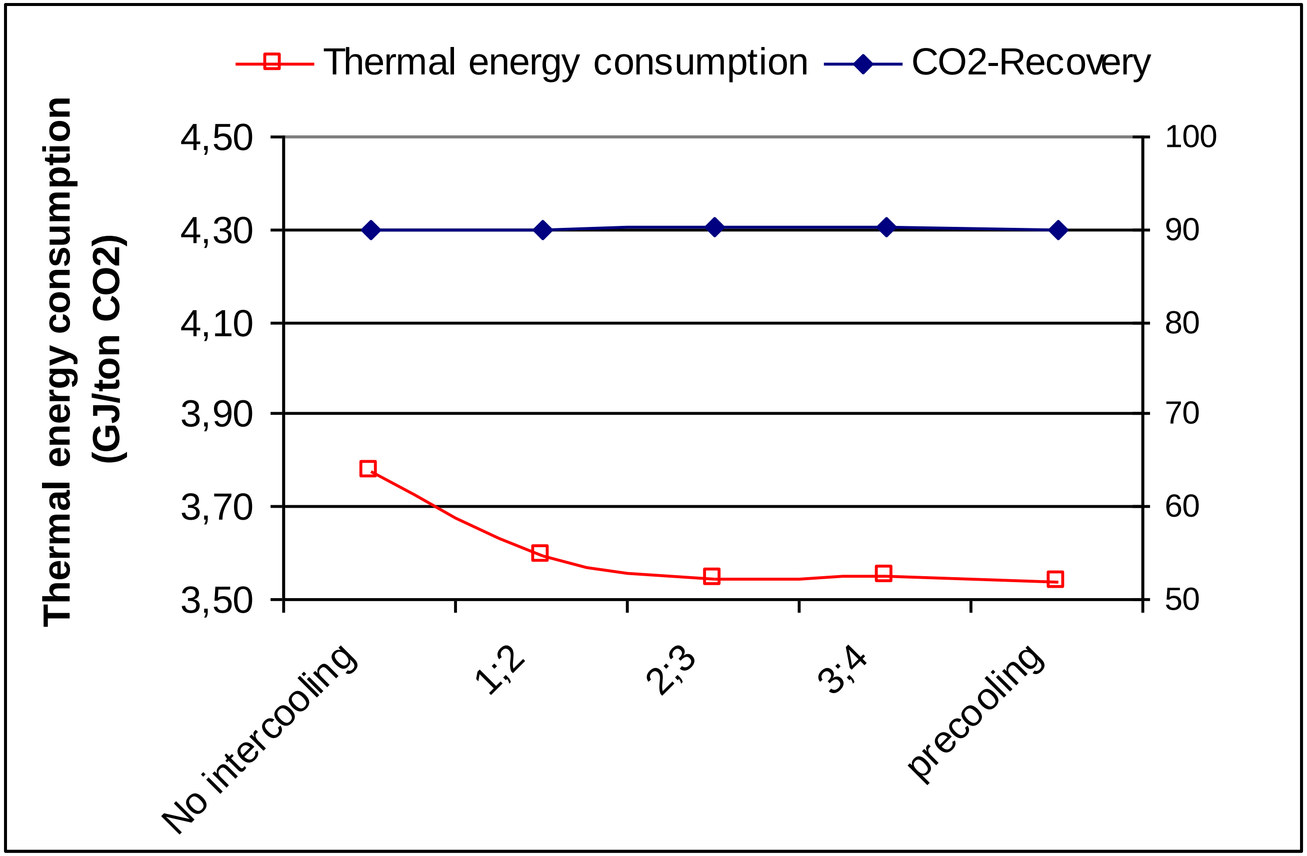
6.1 Influence of the flash pressure by the LVC



- 25 % Thermal energy consumption

- 18 % Exergy consumption

6.2 Influence of intercooler position



- 6 % Thermal energy consumption

7. Conclusion and perspectives

7. Conclusion and perspectives

- Simulation model => coherent results in comparison with the experiments on the Castor pilot
- Reduction of the thermal energy consumption by 29% achievable (IC + LVC)
- Reduction of the process exergy consumption reaches 19,5%

7. Perspectives: PhD Thesis

- The subject is subdivided into 2 main subjects:

1. Modeling and optimal conception of the CO_2 capture process

2. Study of the solvent degradation phenomena

The final purpose is to propose optimal operating conditions for the CO_2 capture process.

7. Perspectives: PhD Thesis

Objectives of the Modeling:

- Optimisation of the existing process
- Proposition of new process improvements
- Test of those process improvements thanks to the simulation and selection of the best ones
- Utilization of the model in parallel with test campains on the CO_2 capture pilot plant

7. Perspectives: PhD Thesis

Objectives of the degradation study:

- Construction of a test installation for the study of solvent degradation phenomena
- Study of classical solvents
- Study of newly developed solvents and of degradation inhibitors
- Optimal conditions in order to avoid degradation

7. Perspectives: PhD Thesis

Degradation consequences:

- Process operating cost:
  - Solvent make-up
  - Removal and disposal of degradation products
  - 4-10% of the total operating costs!

- Process performances
  - Solvent loading capacity decreases
  - Viscosity increases

- Capital cost
  - Corrosion

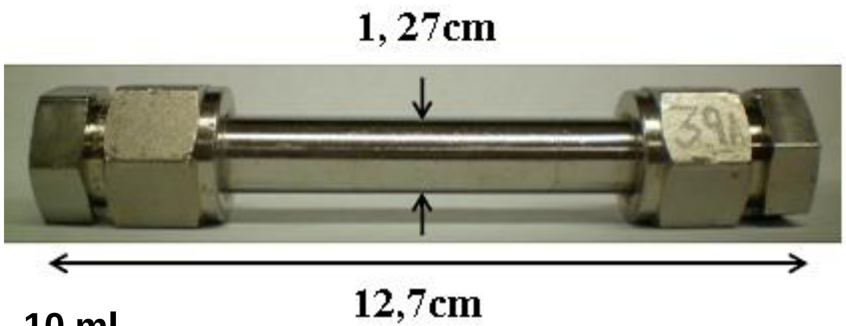
7. Perspectives: PhD Thesis

Importance of testing solvents on small scale installations before using them in larger scale pilots!

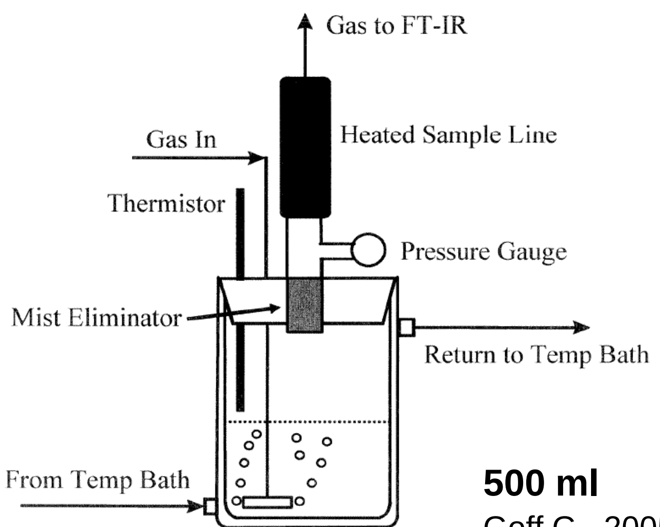
- Toxicity of the degradation products
- Viscosity, foaming, fouling,…
- Solvent make-up rate
- Removal and disposal of the degradation products
- Corrosion

7. Perspectives: PhD Thesis

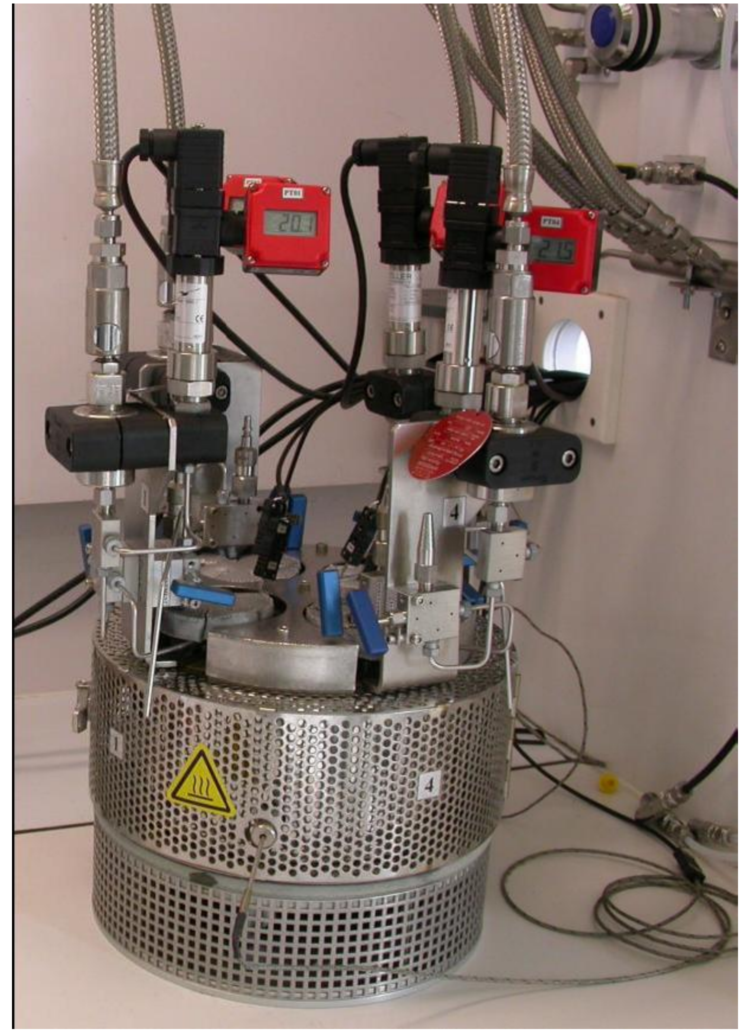
Different reactor types



10 ml
Davis et al., 2005



500 ml
Goff G., 2005

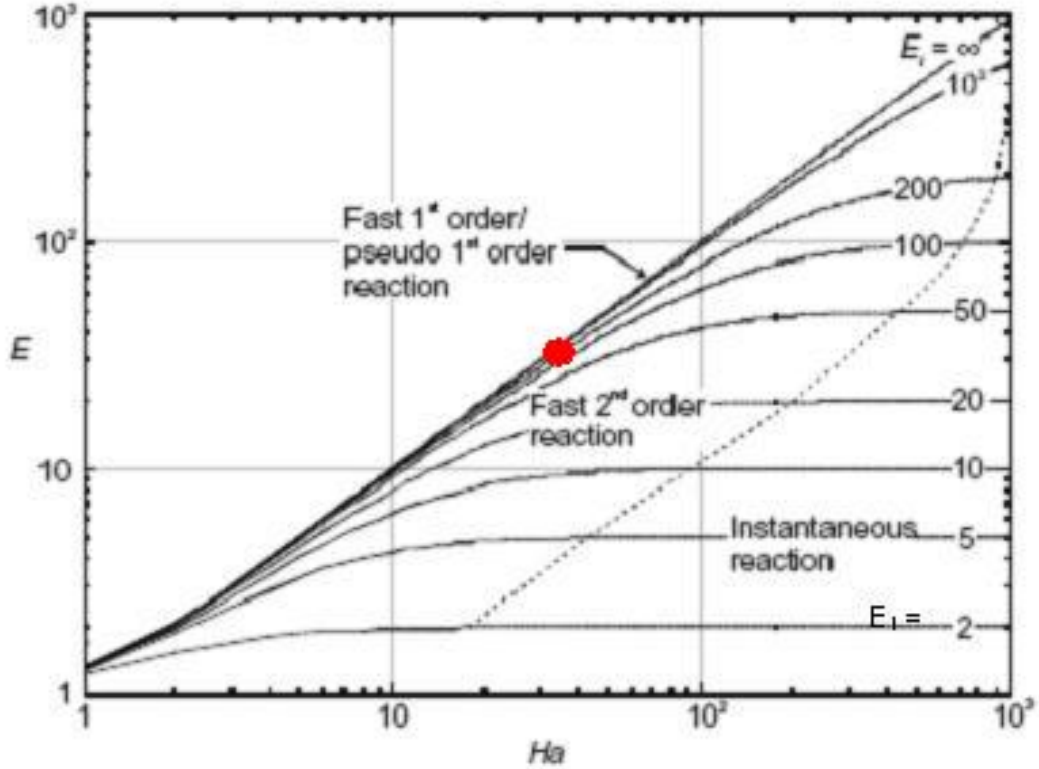


4 x 100 ml
Lepaumier H., 2008

Thank you for your attention !

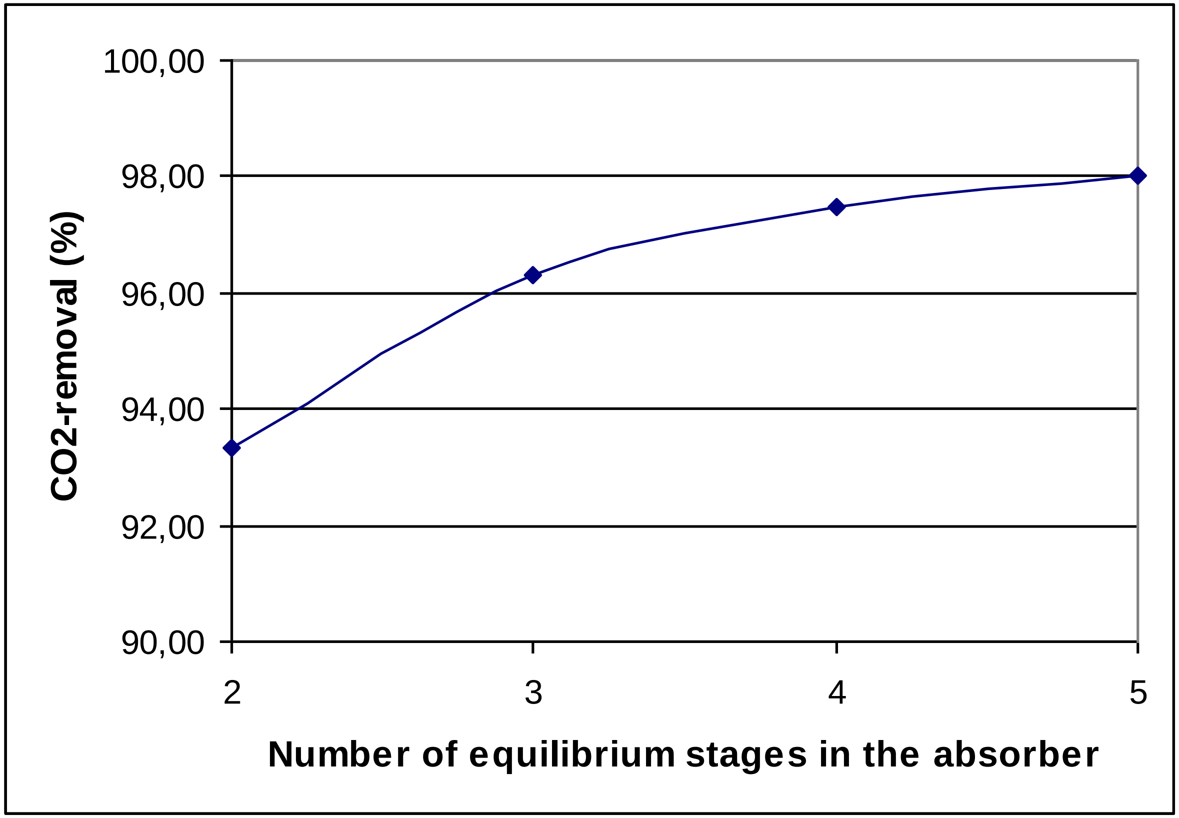
Back-up slides

- Reaction kinetics is fast and neglectible in comparizon to mass transfer limitations



Back-up slide

- Number of absorber stages / Mass transfer limitations



$N_{s,\ real}$ = H/HETP

$\eta_{packing} = N_{s,\ ideal}/N_{s,\ real}$

Castor packing:
H = 17m
HETP ~ 0,55 m

New Pilot plant packing:
H = 9m
HETP ~ 0,3 m

=> $N_{S,\ real}$ ~ 30
=> $\eta_{packing}$ ~ 15-20 %

Back-up slide

- Henry 's law:

  $P_{CO2} = K^{H}_{CO2/Solvent} \cdot x_{CO2}$

- Temperature dependence :

  $CO_2 + MEA <=> CO_{2,\ abs.}$

  $K' = x_{CO2,\ abs.} / P_{CO2} \cdot [MEA]$ $\quad => K = x_{CO2} / P_{CO2}$

  $\Rightarrow K^{H}_{CO2/Solvent} = 1/K$

- Van't Hoff:

  $\Rightarrow d\ln K/dT = \Delta H / RT^2 <=> K(T) / K(T_{ref}) = \Delta H / R * (1/T_{ref} - 1/T)$

Back-up slide

- With $-\Delta H/R = C$ and $H_{CO2/Solvent} = 1/K$

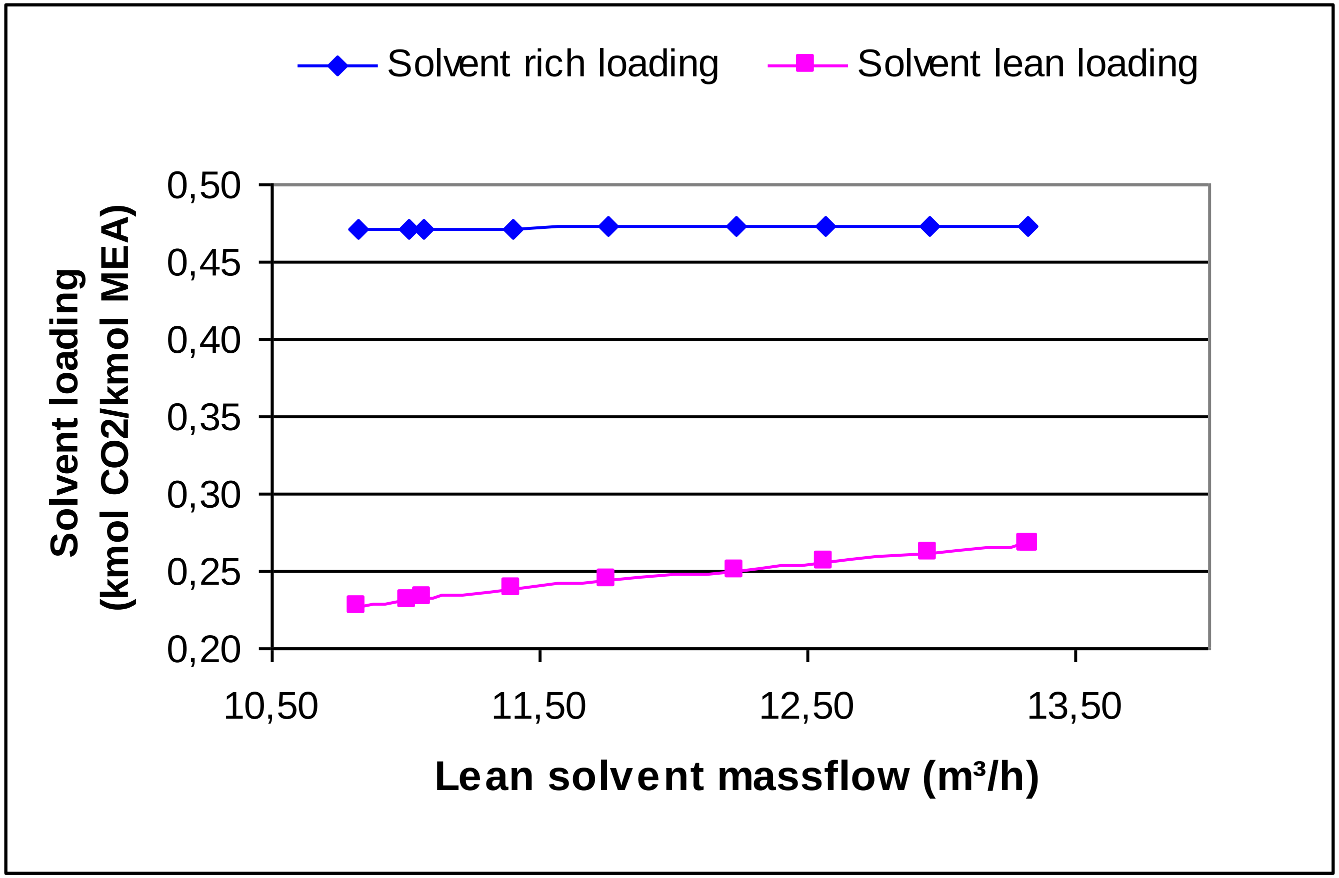
$$k_H(T) = k_H(T_{ref}) \cdot \exp\left[-C \cdot \left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right]$$

- If P increases, then T also increases and K^H increases since Δ H is negative (exothermic absorption)

- => The CO_2 partial pressure increases and the regeneration is easier

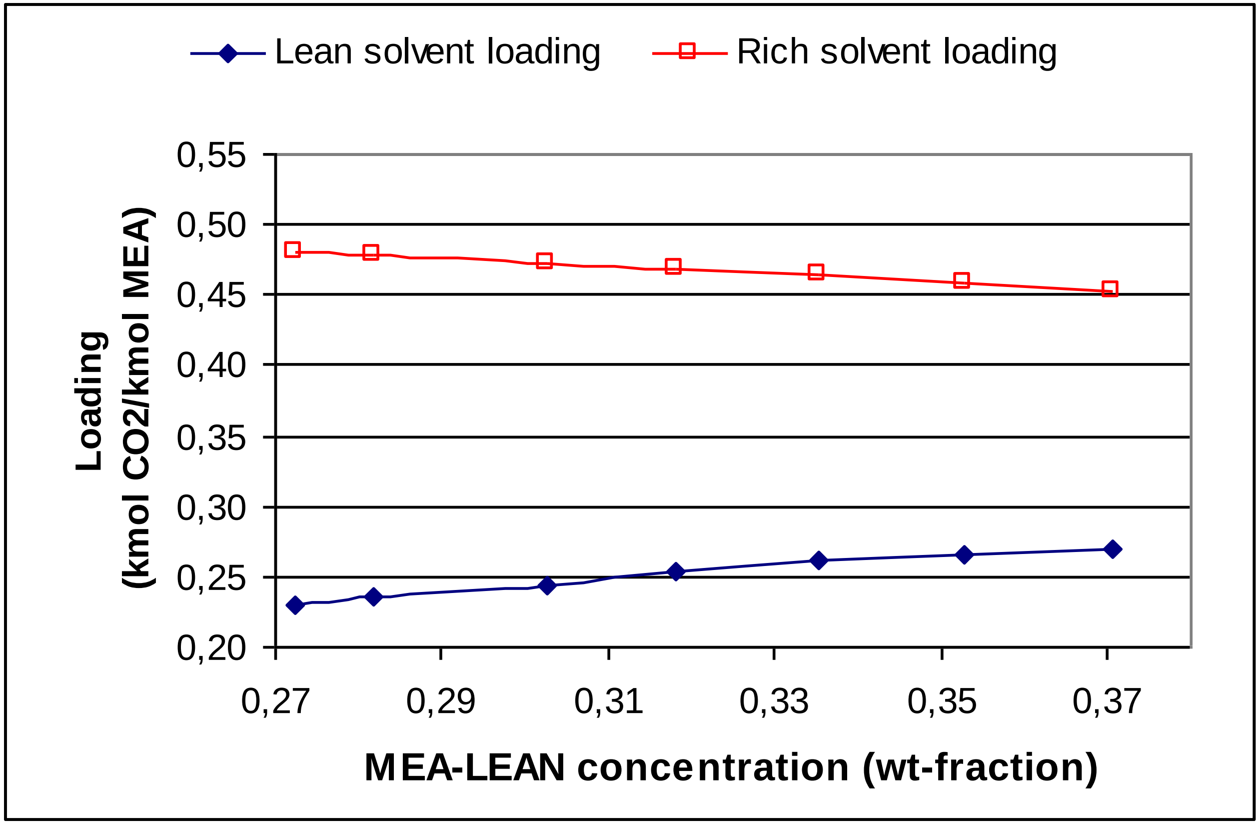
Back-up slide

- Influence of the solvent mass flow



Back-up slide

- Influence of the MEA-concentration



Back-up slide

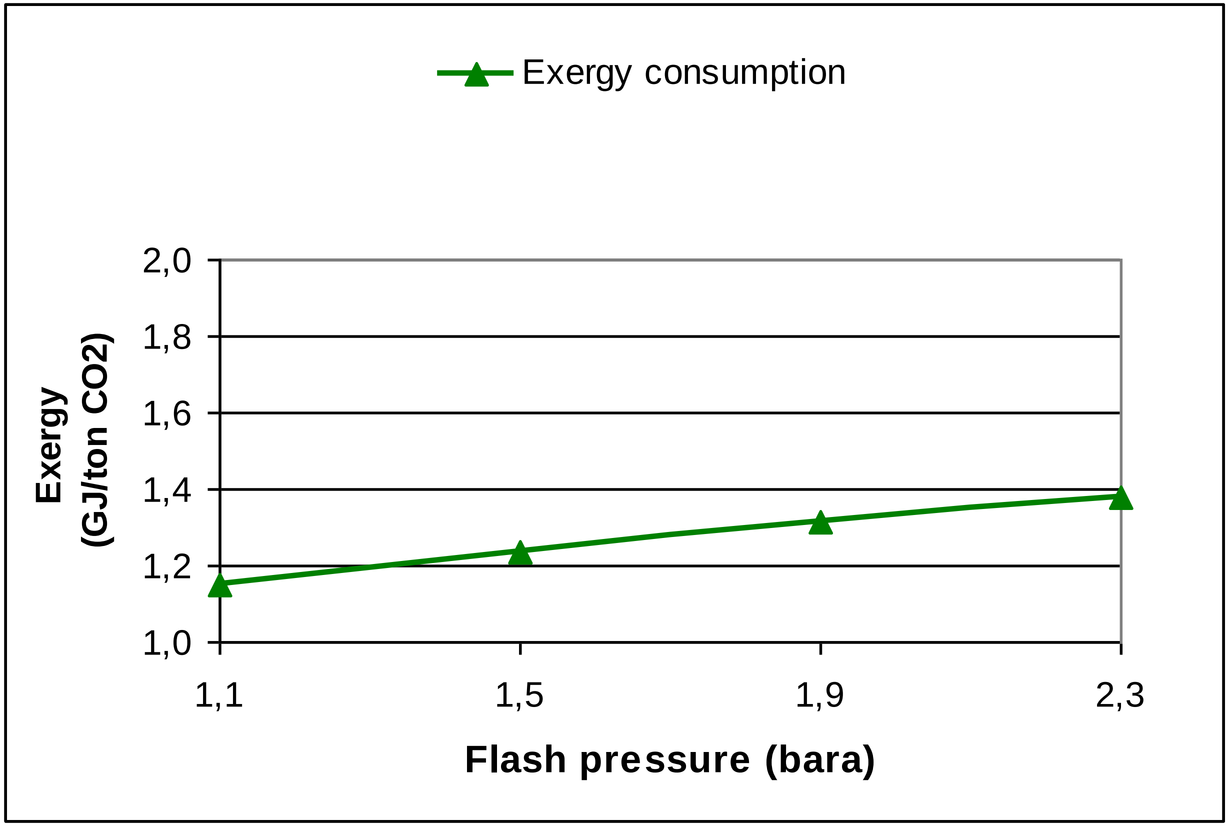
- Exergy calculation

Exergy = Thermal energy * Carnot efficiency

Carnot efficiency : $\eta = 1 - \frac{T_C}{T_H}$

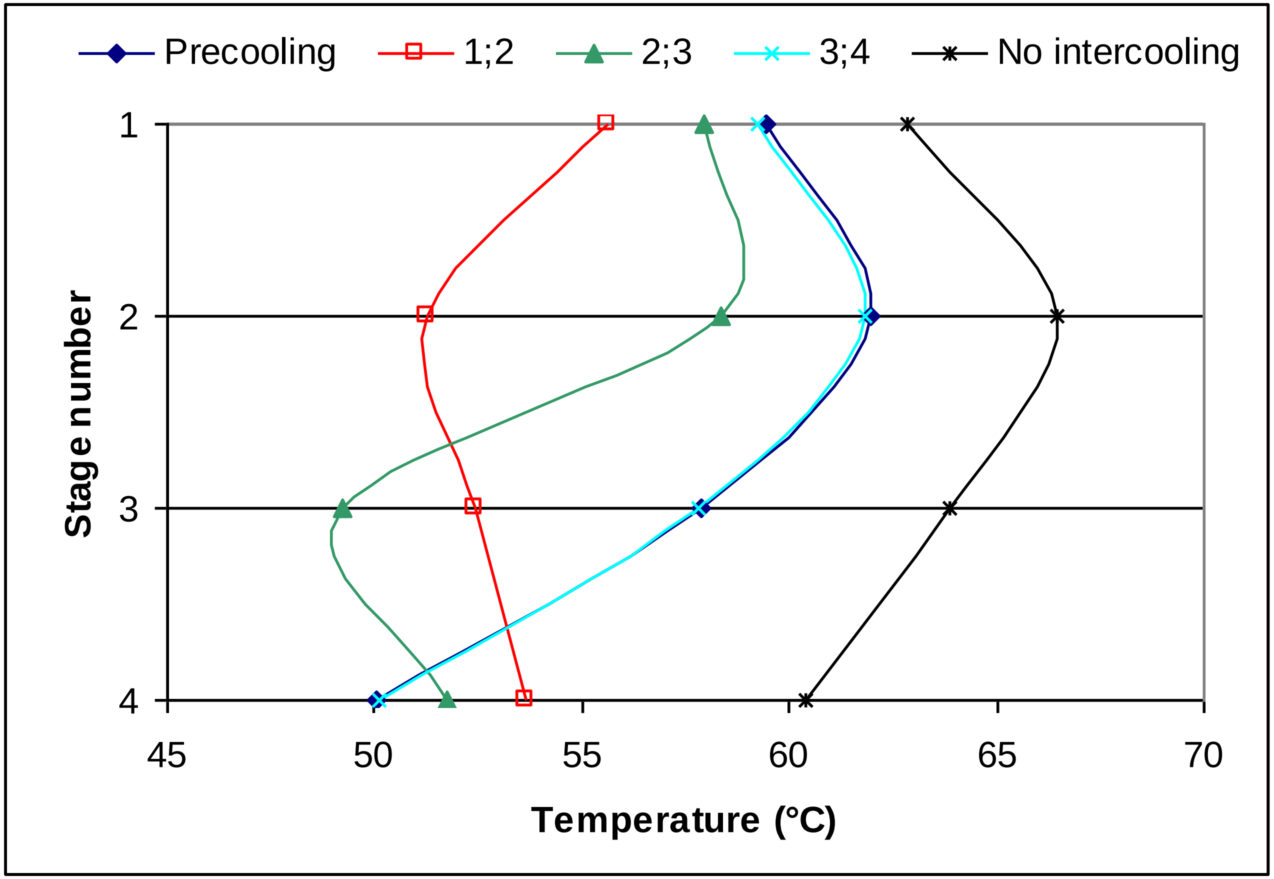
Flash-pressure	Thermal energy consumption	Normalized Compressor duty	Normalized Blower Duty	Normalized Pump duty
bar	GJ/ton CO_2	GJ/ton CO_2	GJ/ton CO_2	GJ/ton CO_2
2,3	1,316	-	0,057	0,006
1,90	1,225	0,025	0,057	0,006
1,50	1,118	0,056	0,057	0,006
1,10	1,002	0,093	0,057	0,006

Back-up slide



Back-up slide

- Absorber profile when Intercooling



Back-up slide

Precursor model analysis

- Thermal energy consumption : 600 MWth by a flue gas flow of 700 m³/s (500 ton CO_2 h^{-1} ⇔ 0,15 ton CO_2 s^{-1})

  => 0,6 MWth / 0,15 ton CO_2 s^{-1} => ~ 4GJ/ton CO_2

- Heat exchanger :

  $Q = 2{,}8\ m^3s^{-1} \cdot 4180\ Jkg^{-1}K^{-1} \cdot 10°K \cdot 1100\ kg\ m^{-3}$

  => 128 MW