Measurement of properties and pilot testing. CERE lab and model development

Fosbøl, Philip Loldrup

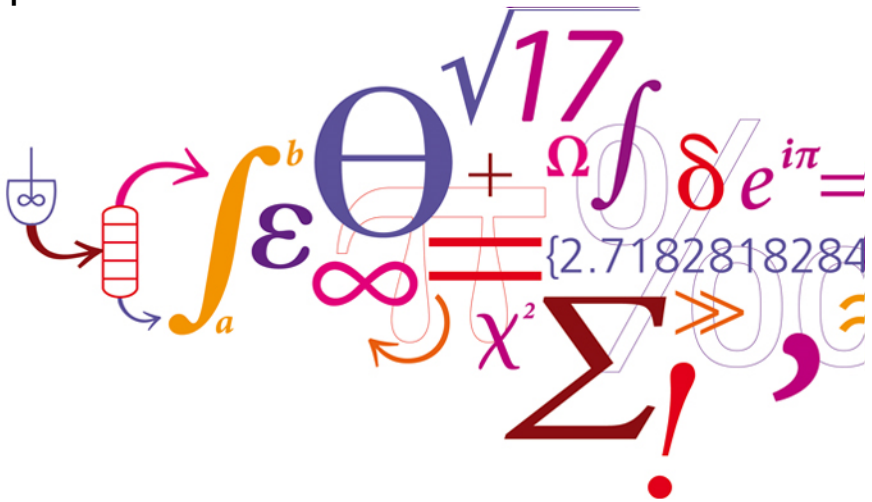
Publication date:
2016

Document Version
Peer reviewed version

Measurement of properties and pilot testing

CERE lab and model development

Application: Rate based modeling of CO_2 capture



Philip Loldrup Fosbøl
+ many students and faculty

EFCE WP, May 12th 2016

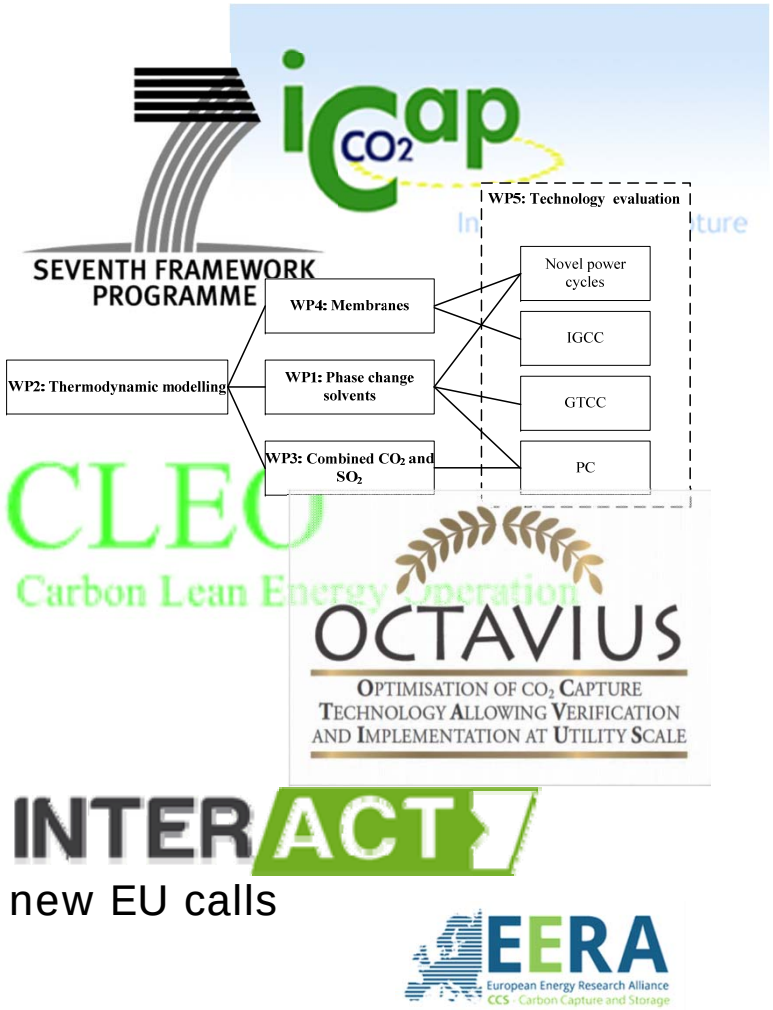
CERE
Center for Energy Resources Engineering

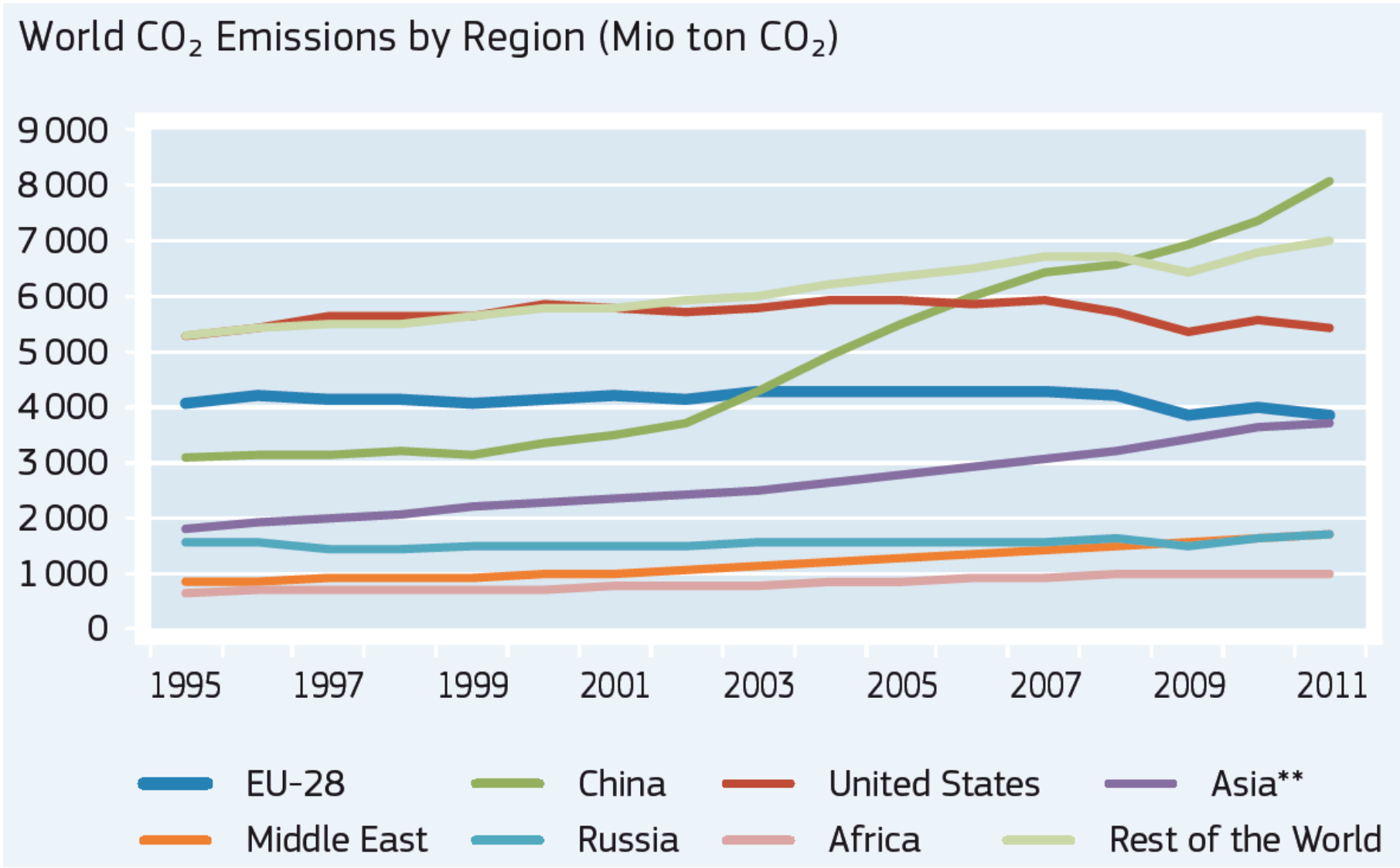
DTU Chemical Engineering
Department of Chemical and Biochemical Engineering

CERE Industrial Consortium 2016

EU Activities

- CASTOR
  - FP6 EU project
- iCap
  - Gas hydrate
  - Demixing process
- CESAR/CLEO
  - Thermodynamic model implementation
  - CASTOR comparison
- OCTAVIUS
  - Process Benchmarking
  - CAPE-Open develoment
- INTERACT
  - Lab scale & pilot trials using enzymes
- EERA
  - Preparation of consortia idea creation for new EU calls

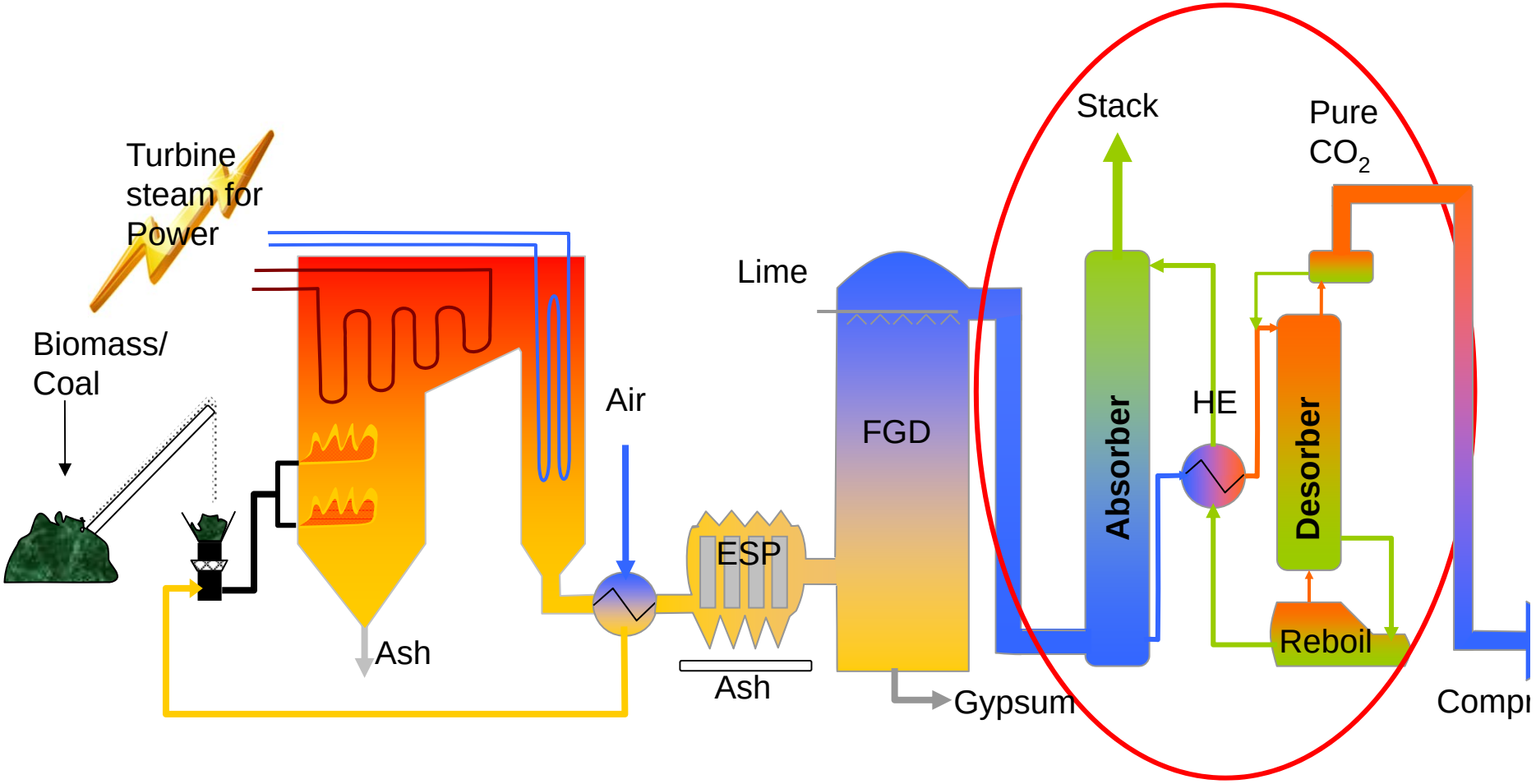




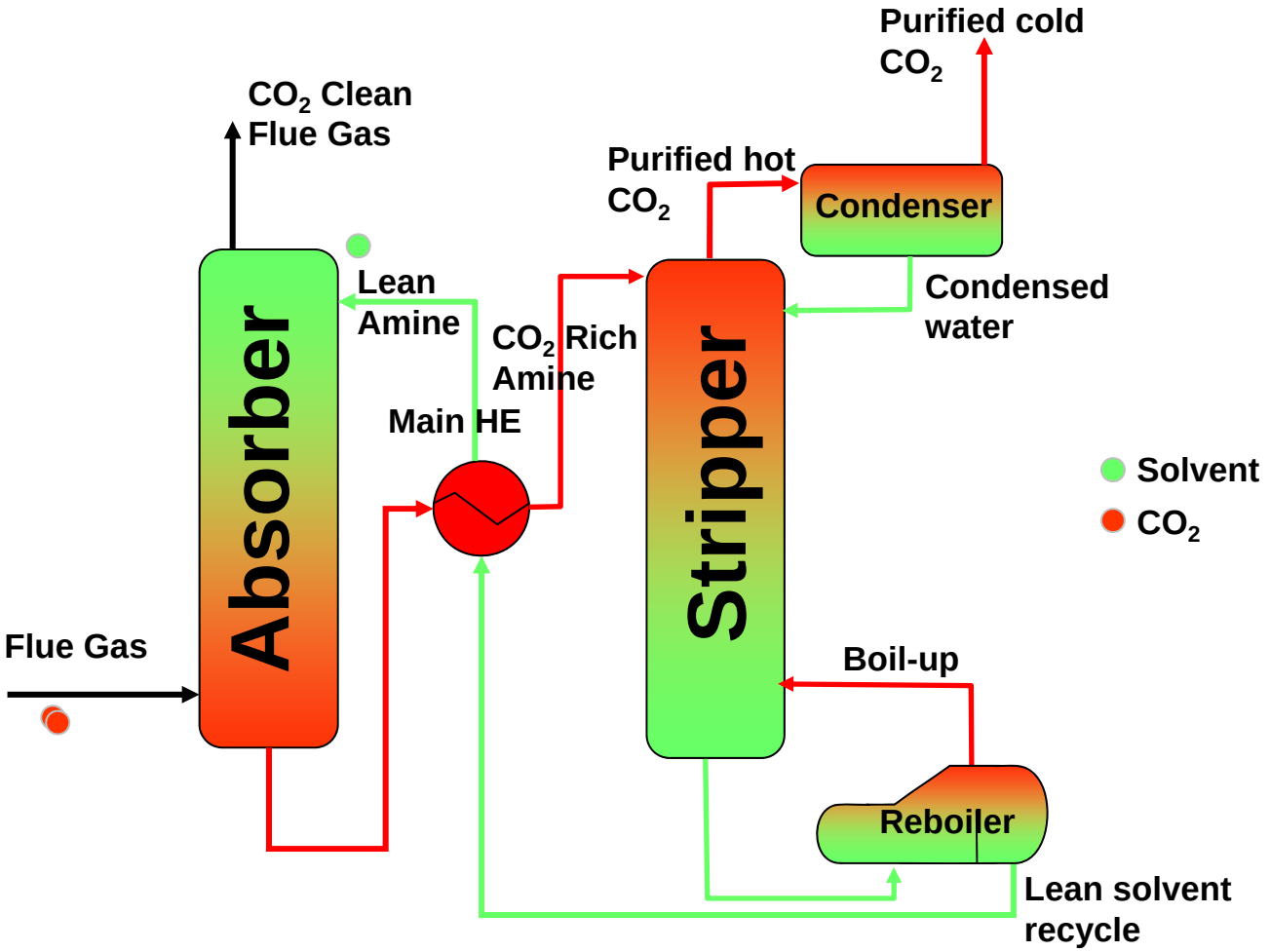
EU energy in figures 2014

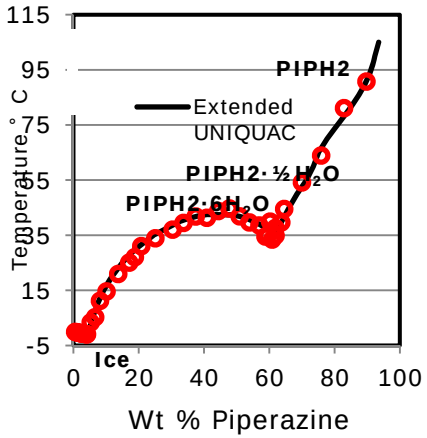
Australian “Coal Mountain”

Carbon capture and storage (CCS)



CO_2 capture


Purified cold
CO_2
CO_2 Clean
Flue Gas
Purified hot
CO_2
Condenser
Lean
Amine
CO_2 Rich
Amine
Condensed
water
Main HE
Absorber
Stripper
Solvent
CO_2
Flue Gas
Boil-up
Reboiler
Lean solvent
recycle



Modelling

- Energy consumption
- Heat of reaction
- Thermodynamics
- Kinetics

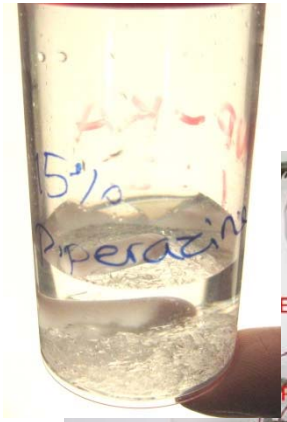
Pilot tests

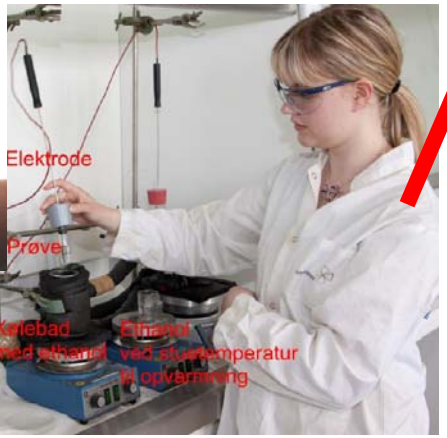
- Real life tests
- Solvent study
- Packing testing
- Energy requirements
- Mass transfer

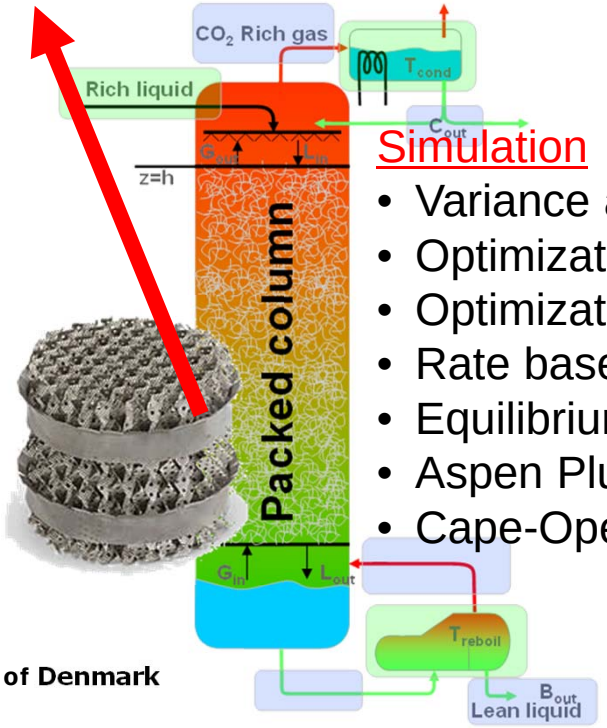
Emission CO_2 reduction

Experimental

- Physical Properties
- Equilibrium
- Kinetics







Simulation

- Variance analysis
- Optimization of energy use
- Optimization of packing
- Rate based approach
- Equilibrium approach
- Aspen Plus
- Cape-Open

Rate based model (CapCO_2)

W: H_2O
C: CO_2
G: Gas
L: Liquid
z: Distance
q: Heat conduct
N: Mass Flux

- Gas balance

Total: $\frac{dG}{dz} = -(N_C + N_W)aS$

CO_2: $G\frac{dy_C}{dz} = -y_C\frac{dG}{dz} - N_C aS$

H_2O: $G\frac{dy_W}{dz} = -y_W\frac{dG}{dz} - N_W aS$

Energy: $GC^G_{p,tot}\frac{dT_G}{dz} = -\left(\frac{dG}{dz}C^G_{p,tot} + aS\left(C^G_{p,W}N_W + C^G_{p,C}N_C\right)\right)T_G - qaS$

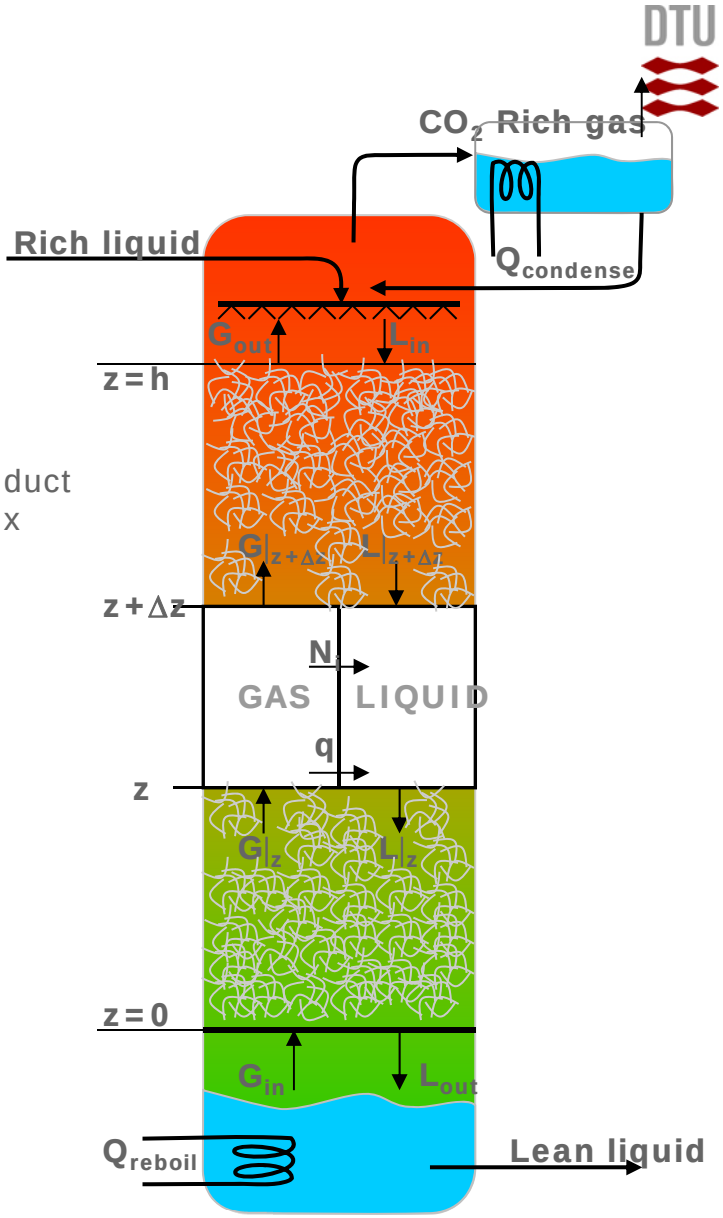
- Liquid balance

Total: $\frac{dL}{dz} = -N_W aS$

CO_2: $L\frac{dx_C}{dz} = -x_C\frac{dL}{dz} - N_C aS$

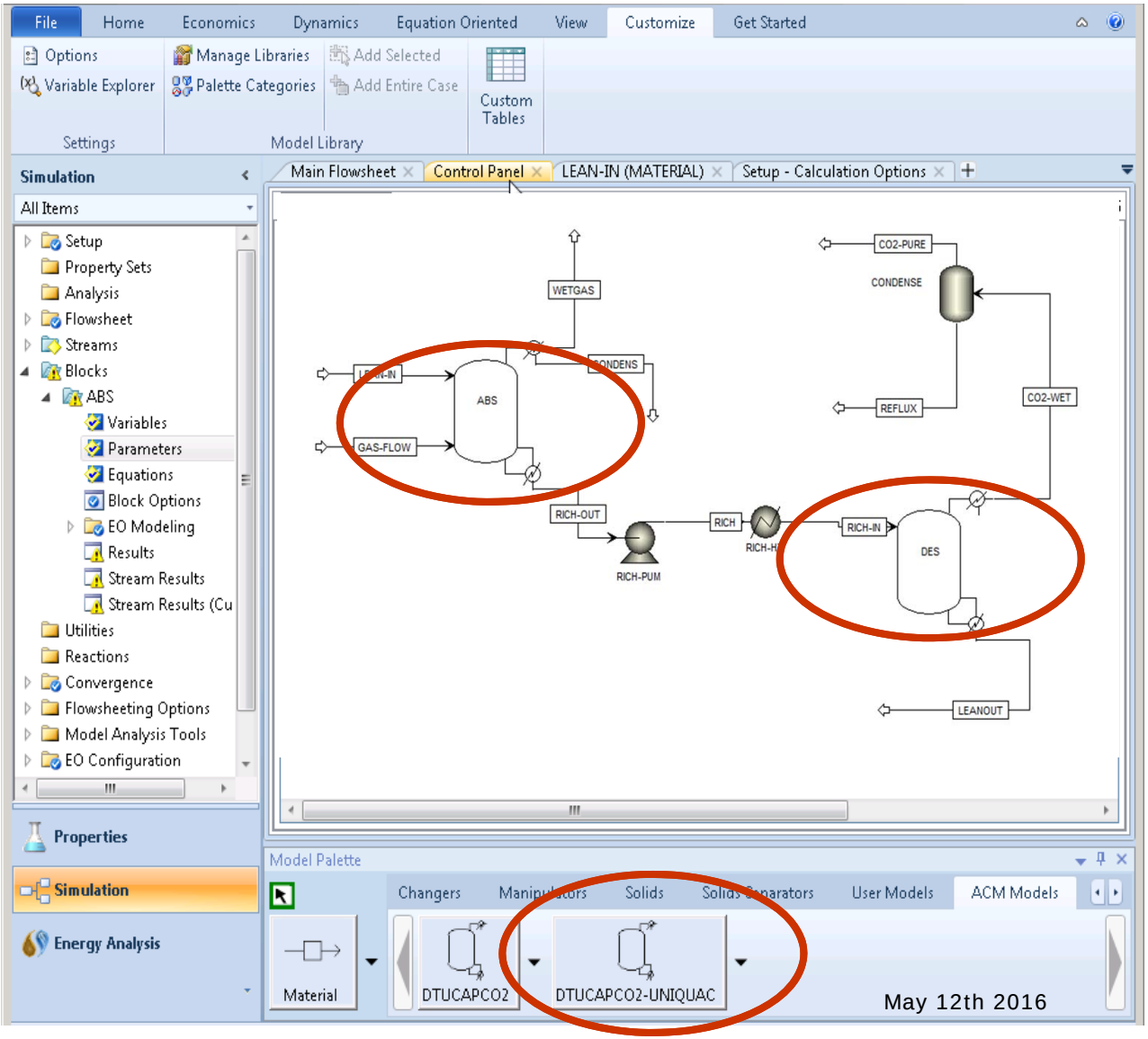
H_2O: $L\frac{dx_W}{dz} = -x_W\frac{dL}{dz} - N_W aS + N_C aS$

Energy: $C^L_{p,tot}L\frac{dT_L}{dz} = -C^L_{p,tot}T_L\frac{dL}{dz} - aS\left(\left(C^L_{p,W}T_G + \Delta_{vap}H_W(T_L)\right)N_W + \left(C^L_{p,C}T_G + \Delta_{CO_2,diss}H(T_L)\right)N_C\right) - qaS$



CAPCO2 unit operation

Aspen Plus



Physical properties in Rate based modelling

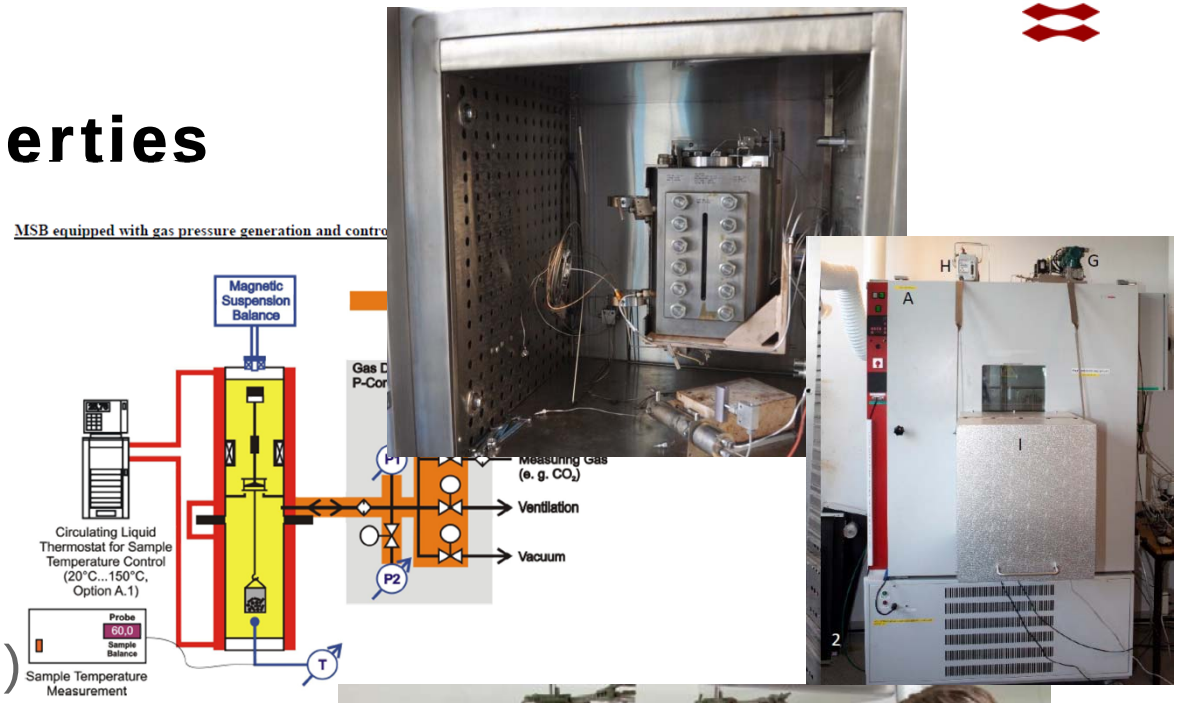
- Liquid properties
  - Diff. coef. A in W
  - Diff. coef. CO_2 in A-W sol.
  - Surface tension of W and A-W sol.
  - Viscosity of A-W sol.
  - Second order rate constant of CO_2 abs. in A-W
  - Thermodynamic properties
    - Heat cap. of solution
    - Henry's constant of CO_2 in A-W sol.
    - Equilibrium CO_2 pressure over A-W sol.
    - Heat of abs. of CO_2 in A-W sol.
    - Saturation pressure of W
    - Heat of vaporization of W
    - Density of pure W, A, and sol.

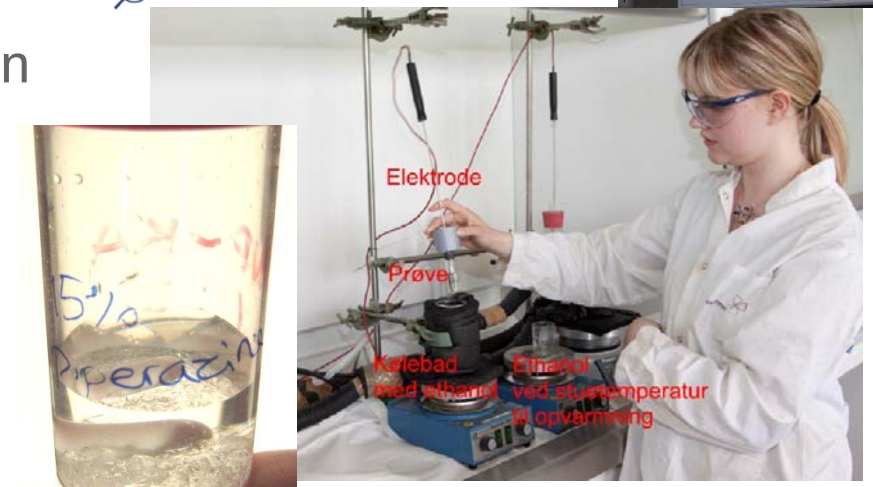
- Gas properties
  - Diffusivity of CO_2 in gas
  - Diffusivity of W in gas
  - Viscosity of gas (CO_2-Air-W)
  - Thermodynamic properties
    - Density of gas
    - Heat cap. of gas (CO_2, Air, W)

W: Water
A: Amine
Sol.: Mixture

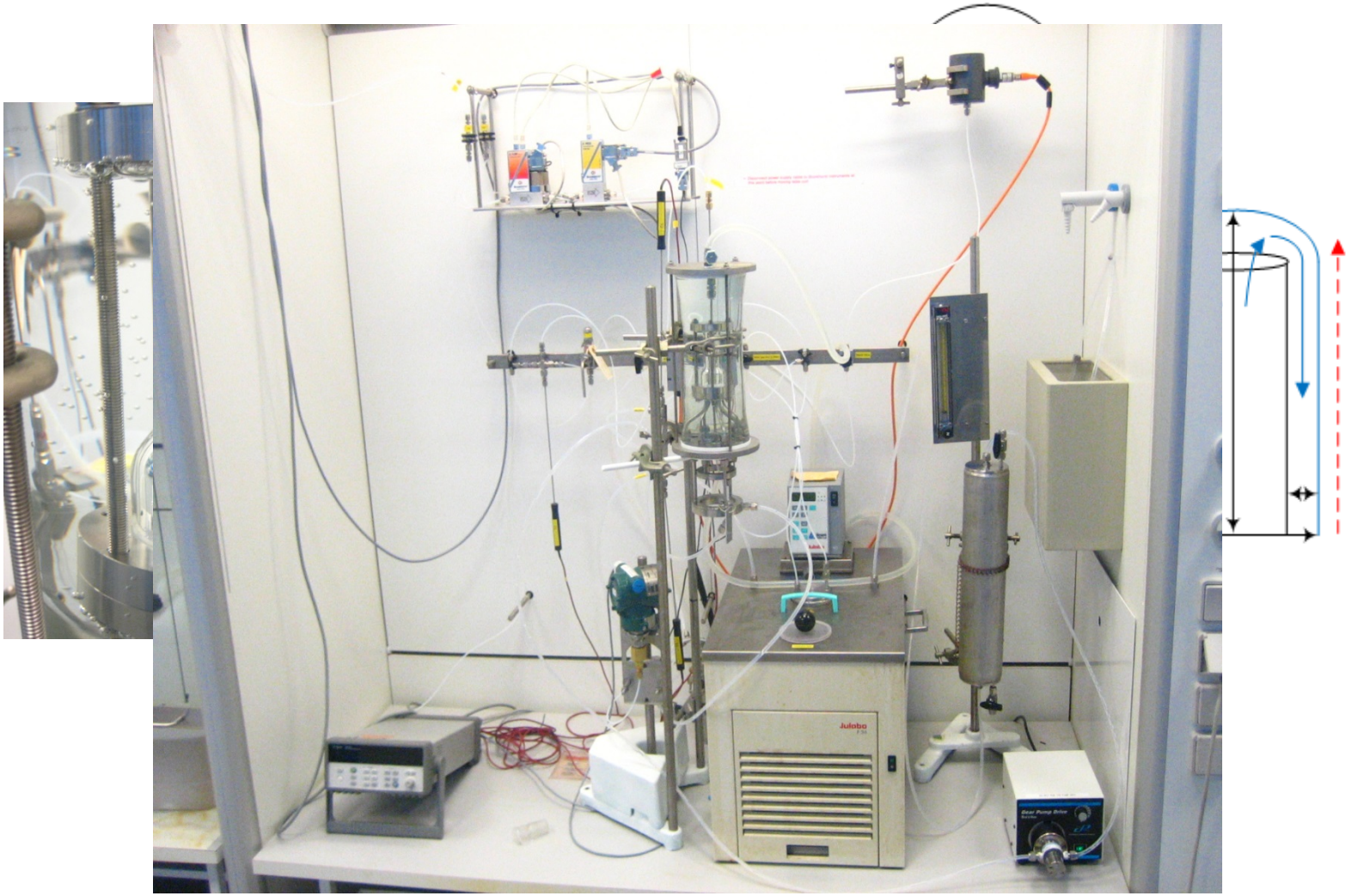
Phase eq. & properties

- CO_2 solubility
  - VLE
  - High P and T
- Slurry formation(SLE)
  - Freezing point depression
  - Solubility measurement
- Density
- Viscosity
- Surface tension

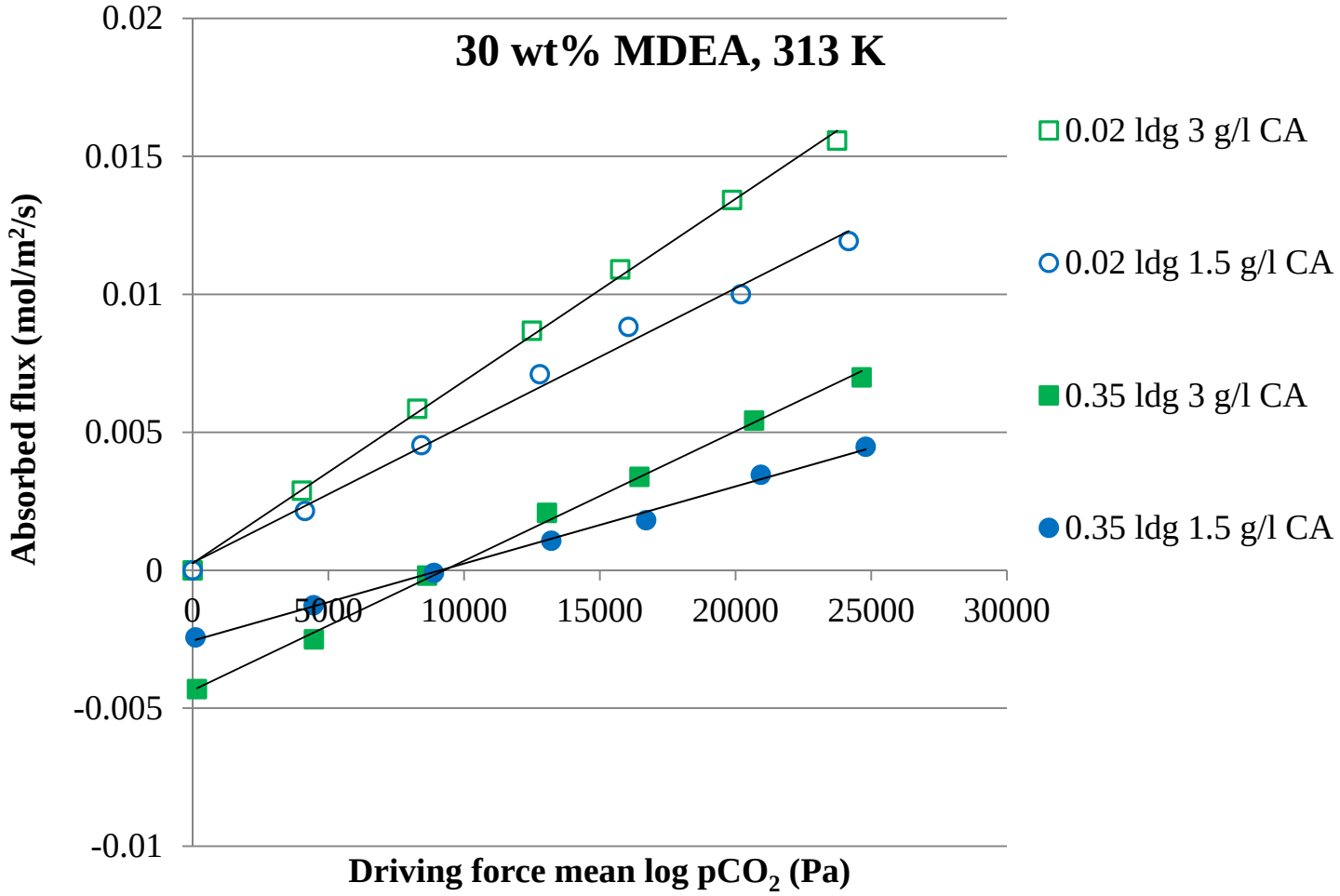




Reaction kinetics between CO_2 and solvent

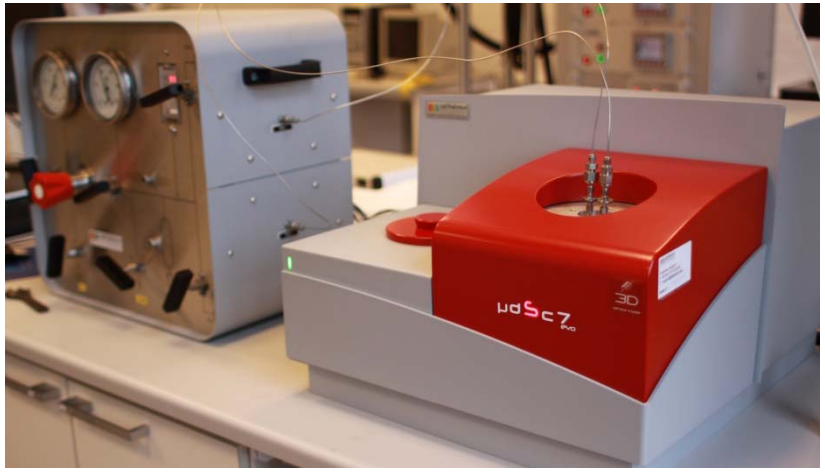


Kinetic result

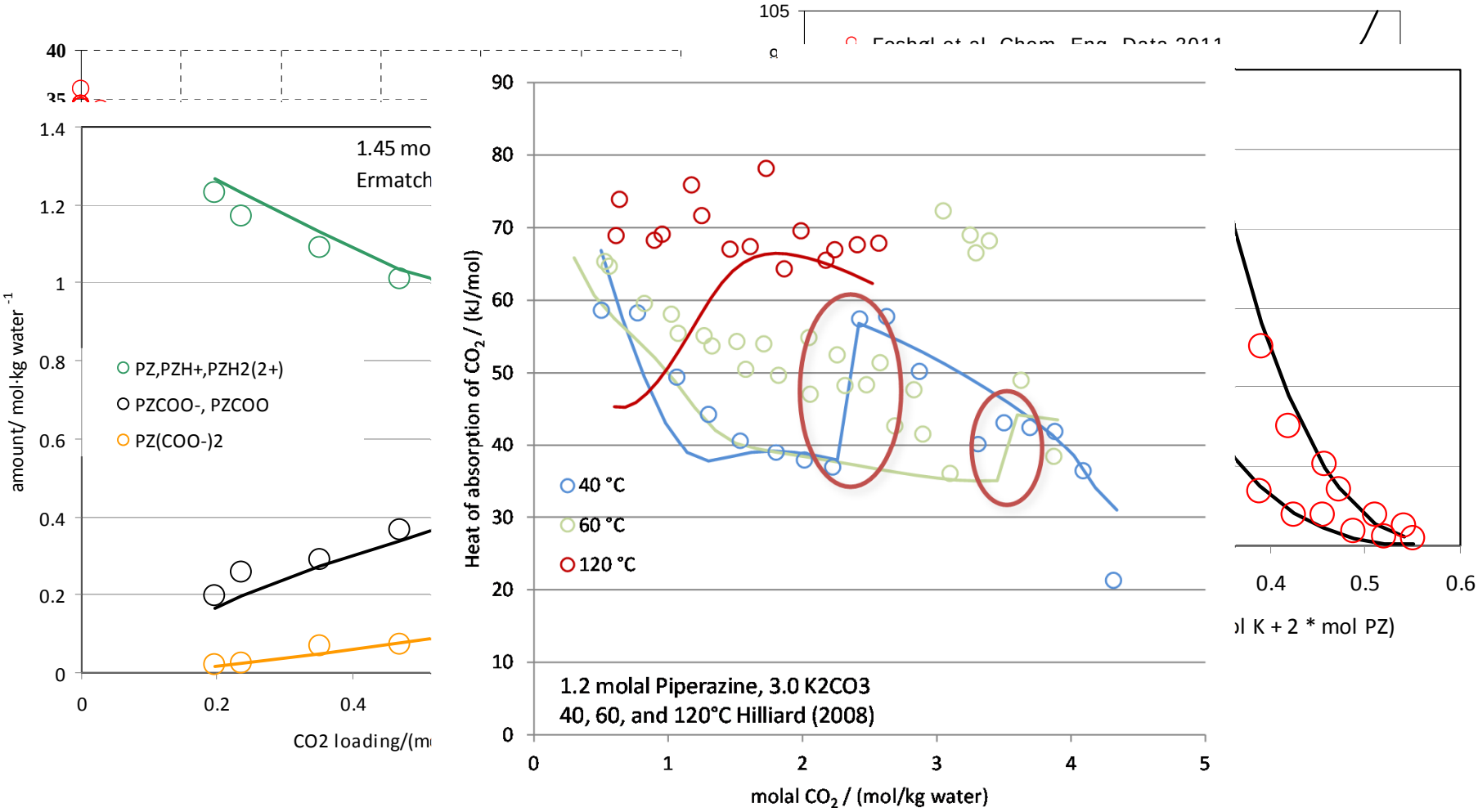


Experimental work - calorimetric

- High pressure DSC
- Phase change, heat of absorption by DSC



Thermodynamic modelling
ex: CO_2-PZ-K_2CO_3-$KHCO_3$-H_2O



Pilot tests and demonstration

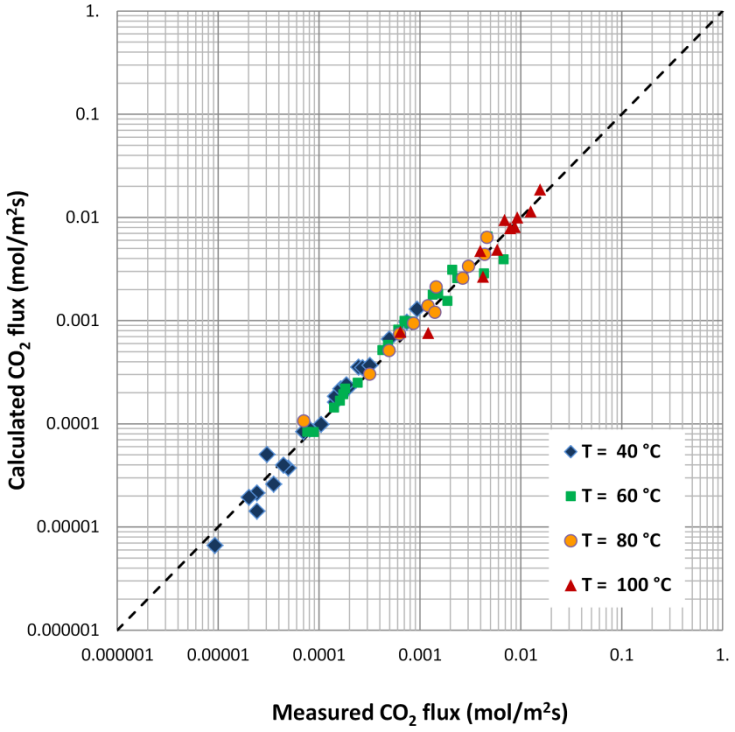
- CO_2 Absorber
  - 10m height (Variable height)
  - 10cm diameter
  - Capacity: Approximately 40Nm^3/h
  - Structured packing (Mellapack)
  - Temperature and sampling readings
    - Every meter
    - Temperature and loading profiles
  - Well developed DAQ for flow etc.

- Absorber test runs
  - Standard Amines
  - Enzymes

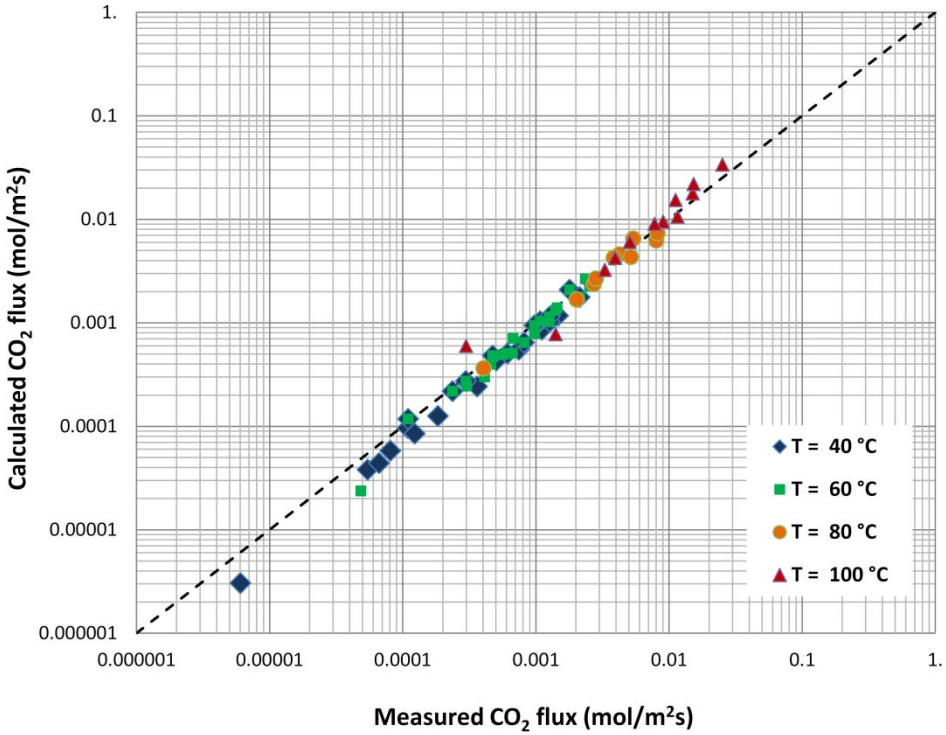
- Desorber
  - Design in progress

Mass Transfer Modeling

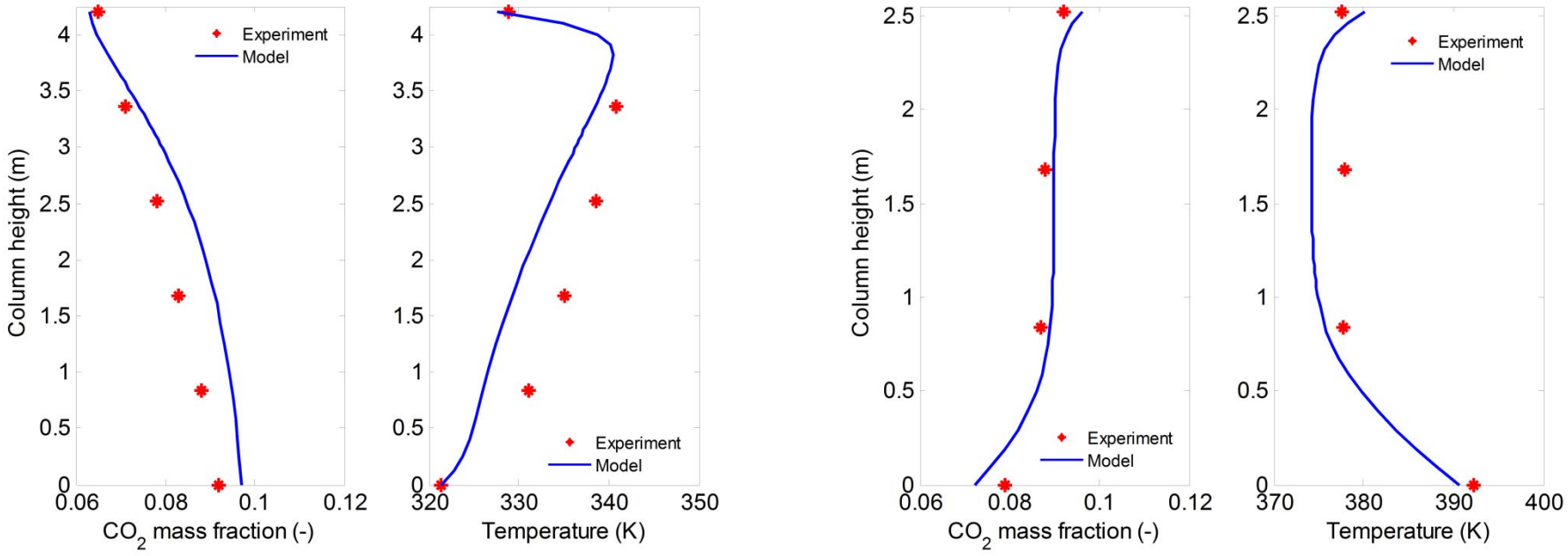
30 wt.% MEA



5 molal PZ

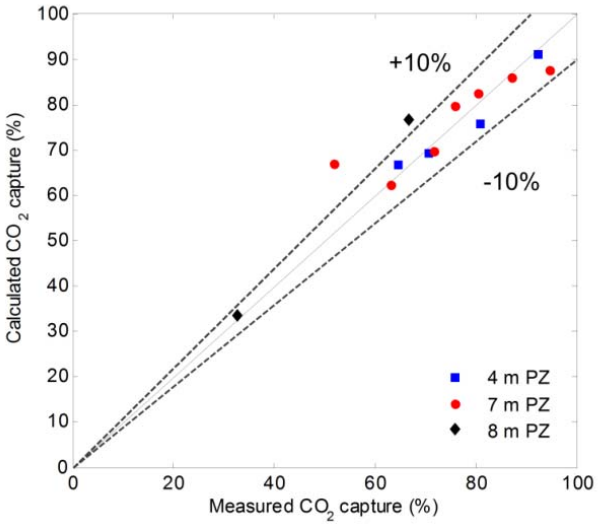


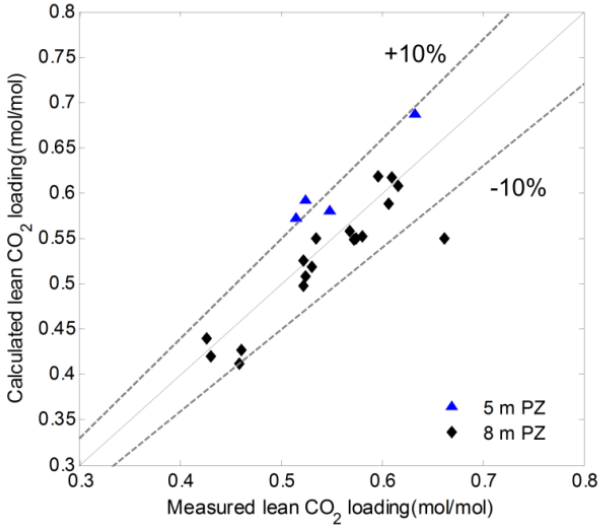
Comparison to pilot data

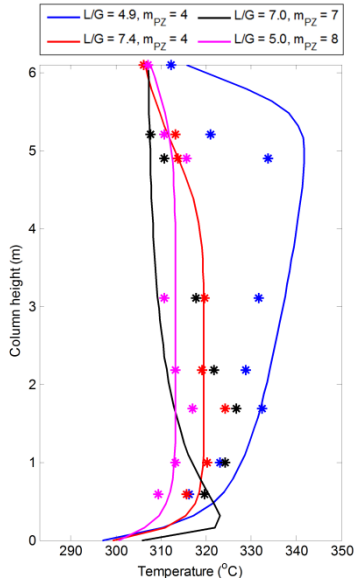


Modeling Innovative Solvents

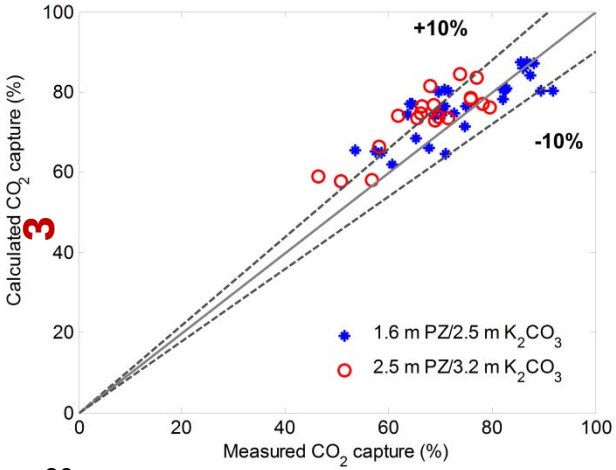
PZ

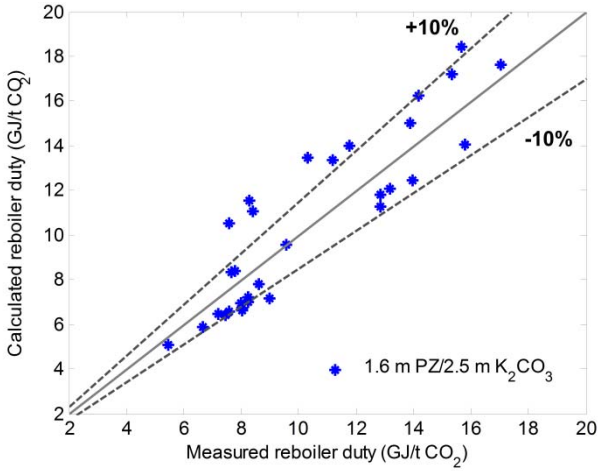


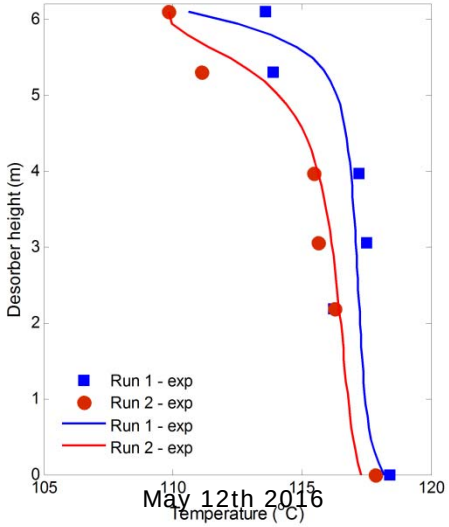




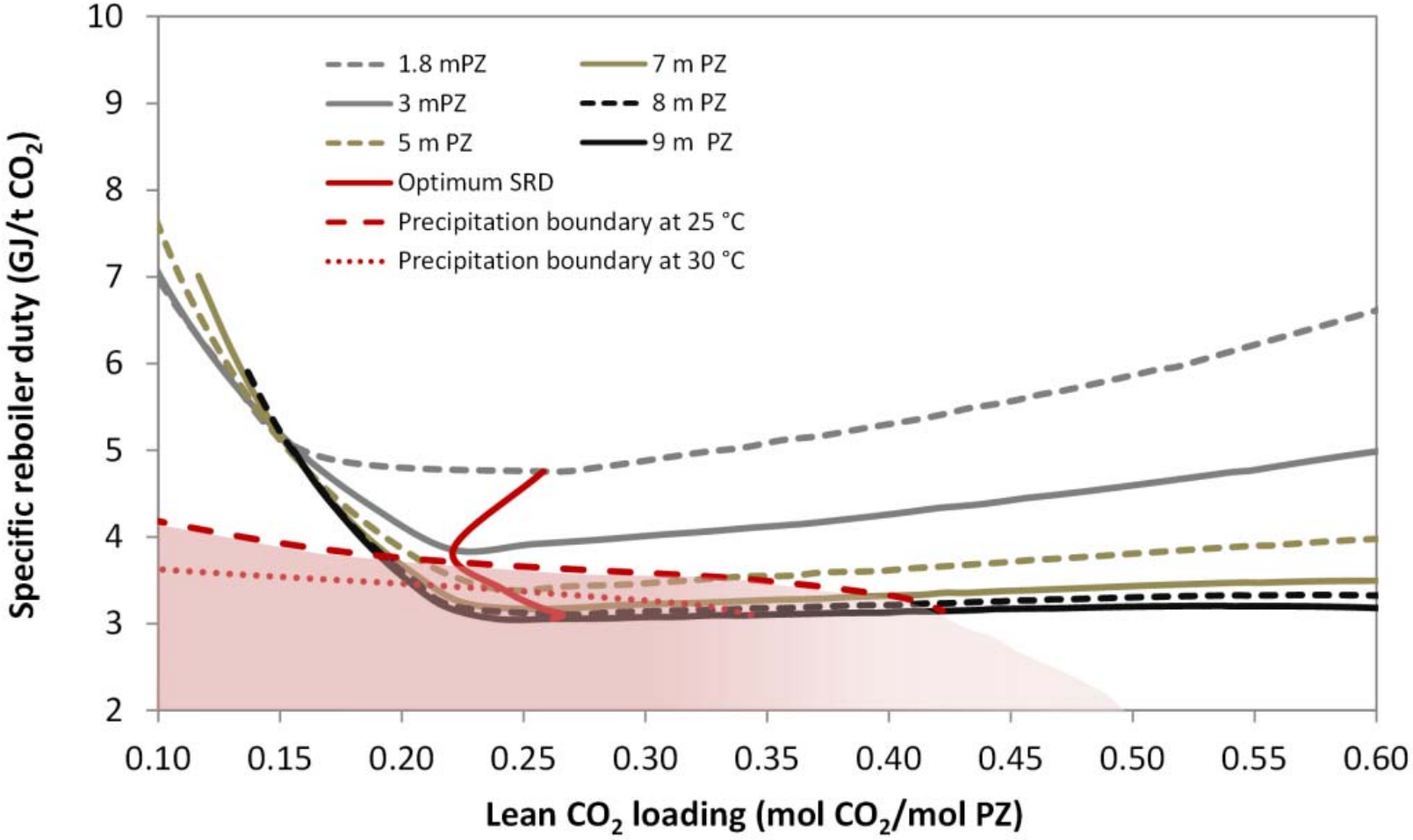
$PZ+K_2CO_3$





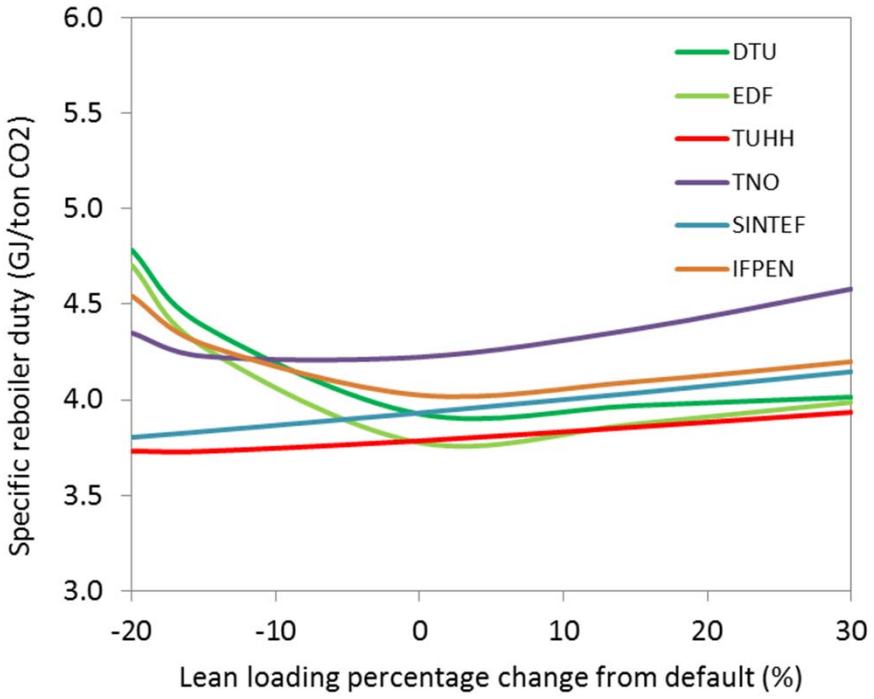


Rate based simulation with solids (PZ)

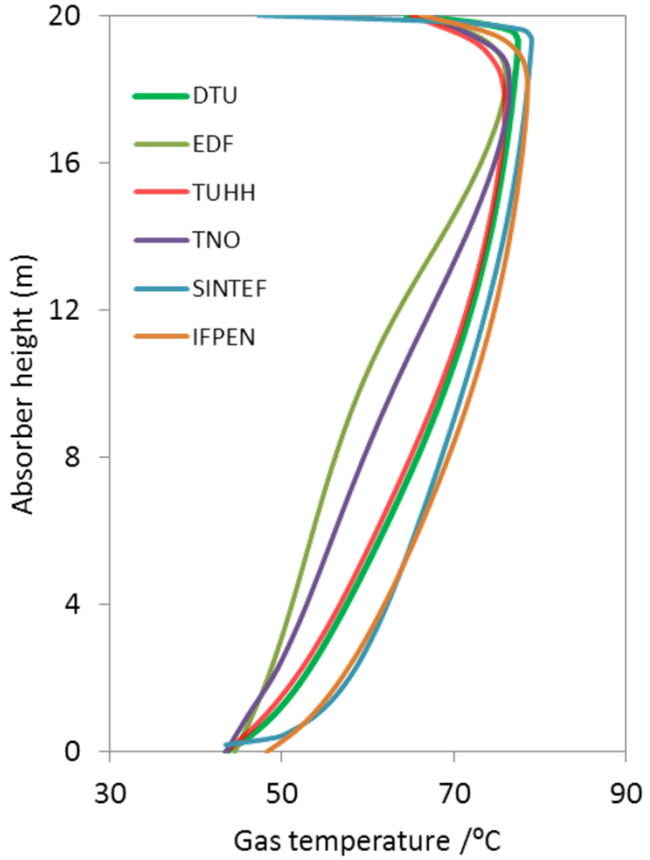


EU benchmarking

- Desorber reboiler duty
  - Good reproducibility (±5%)
  - High scatter at high flooding

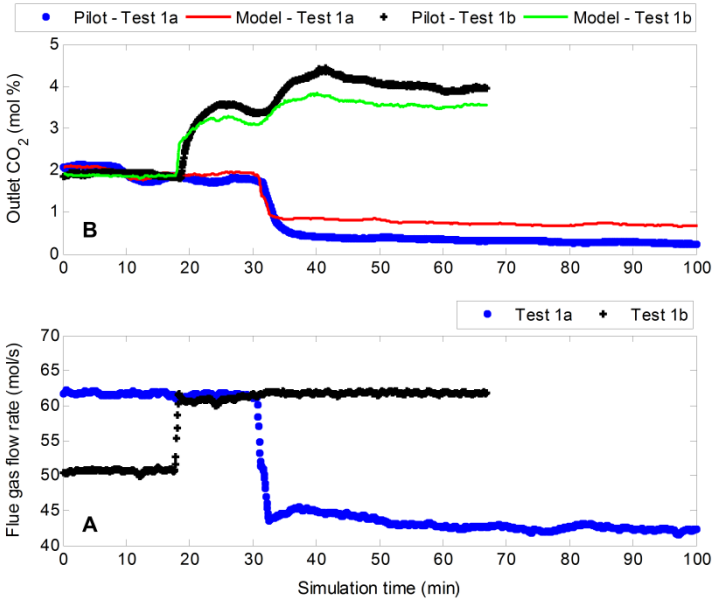


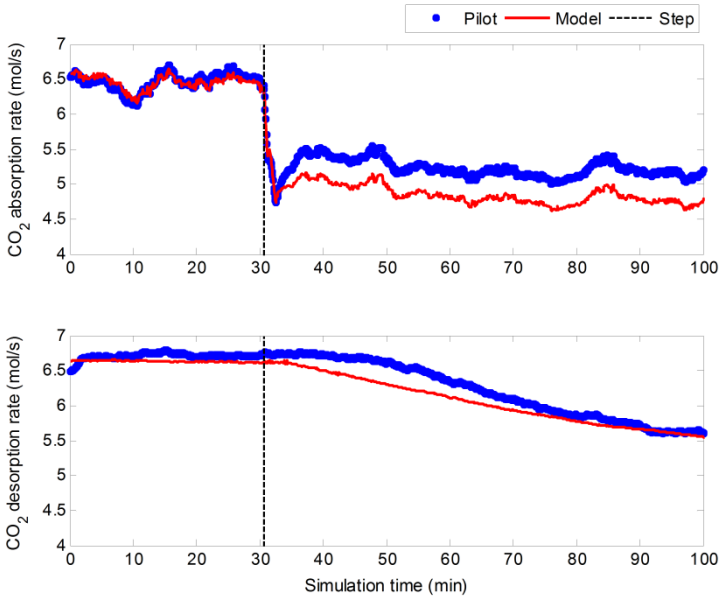
- Absorber temperature profiles
  - Midsection scattered (10°C)
  - Top+bottom high reproducibility (1-5°C)



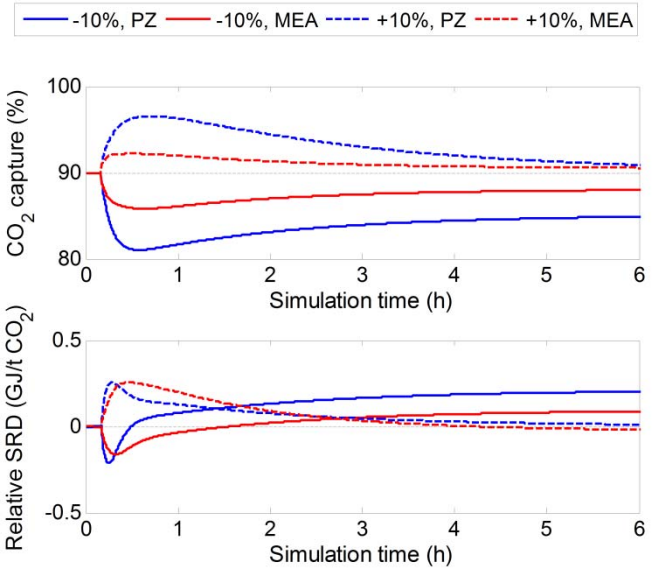
Dynamic Absorber and Desorber Model

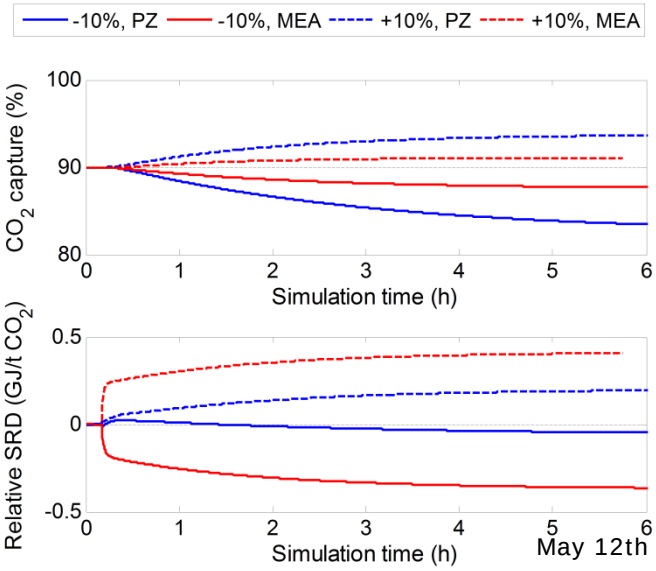
MEA





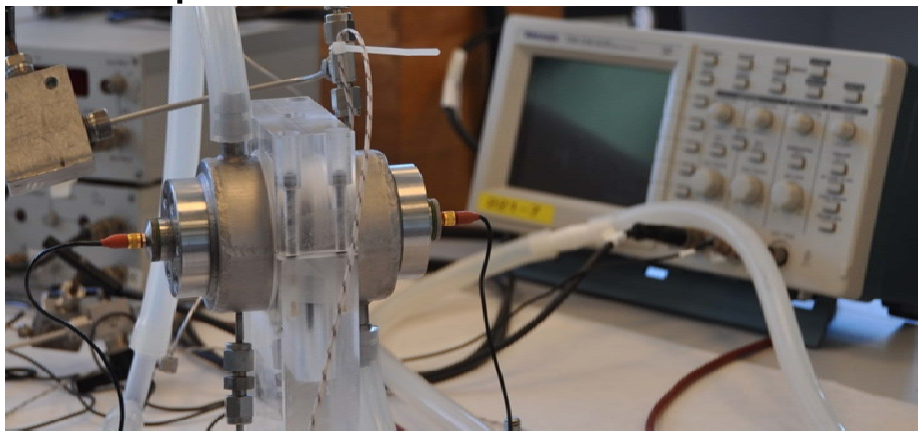
PZ





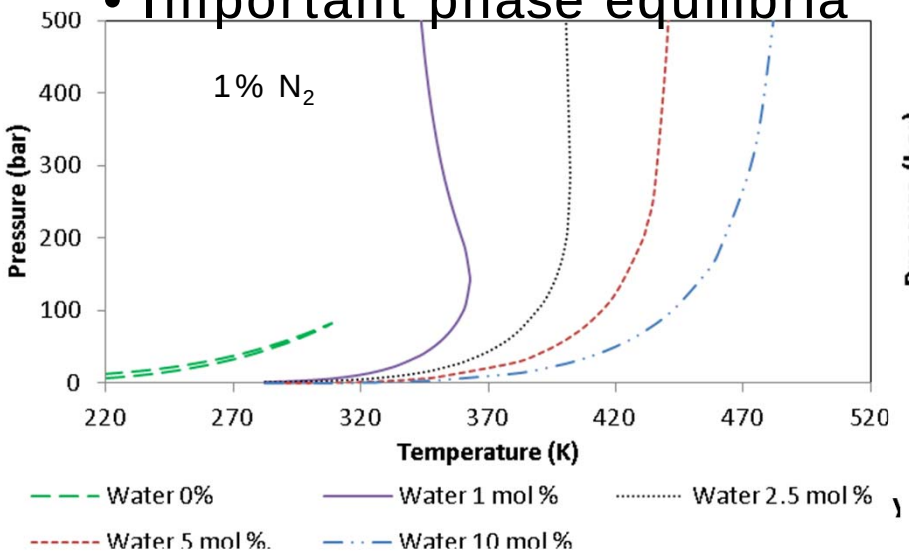
Compression & transport

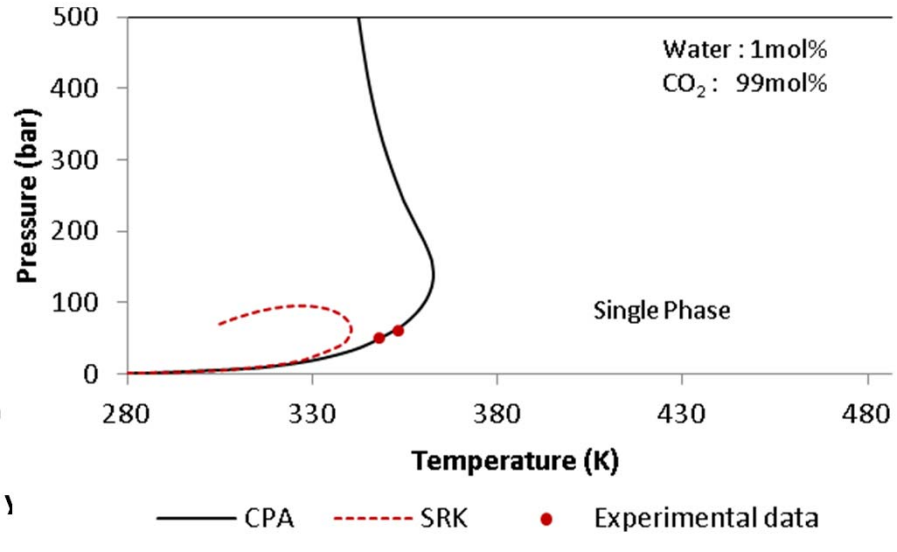
- Speed of sound



- HP Gas diffusion

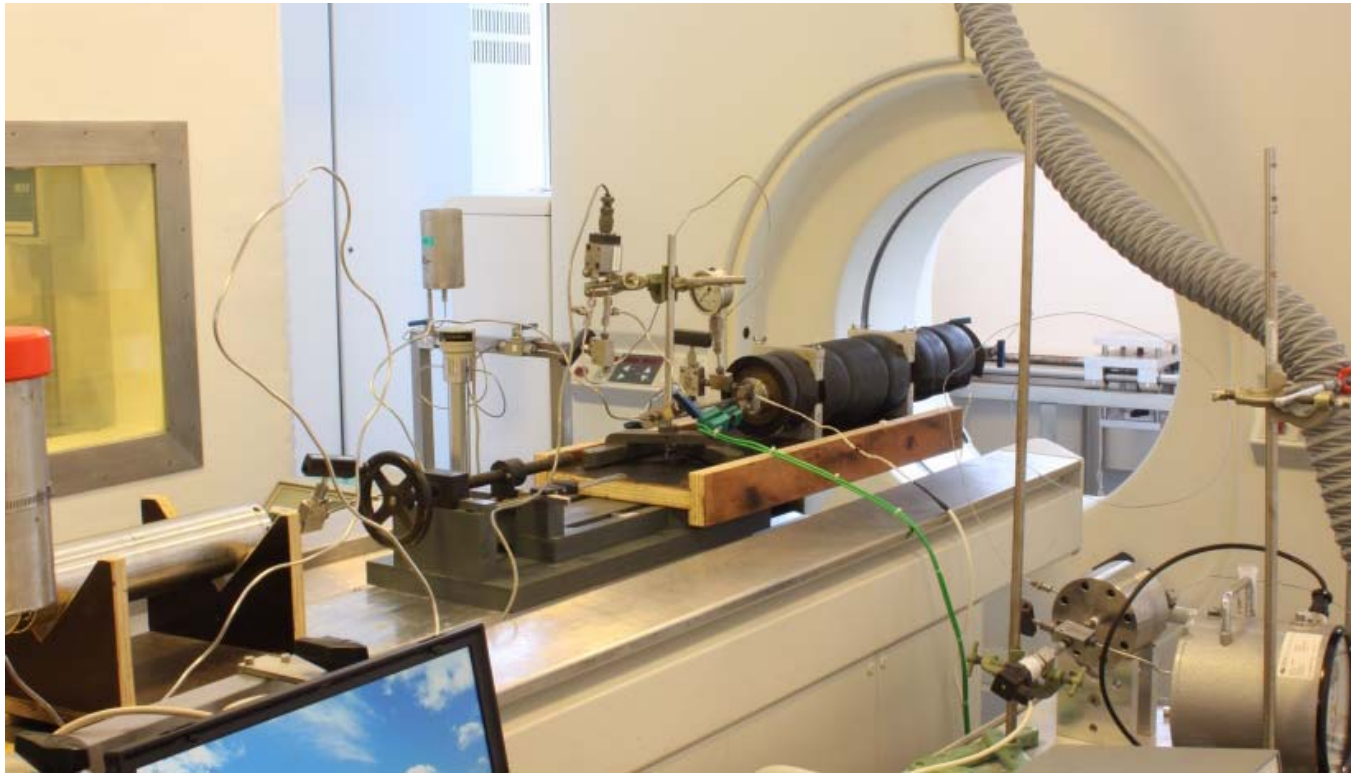
- Important phase equilibria



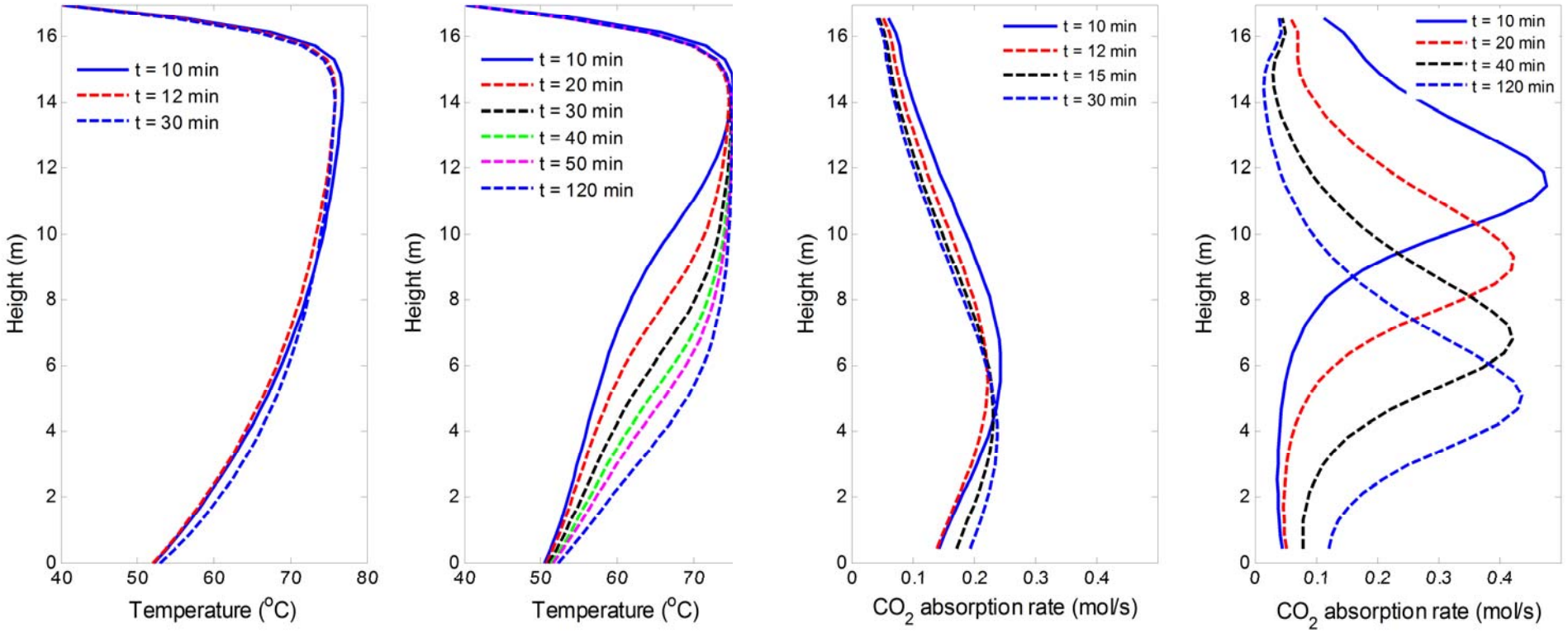


CO_2 storage

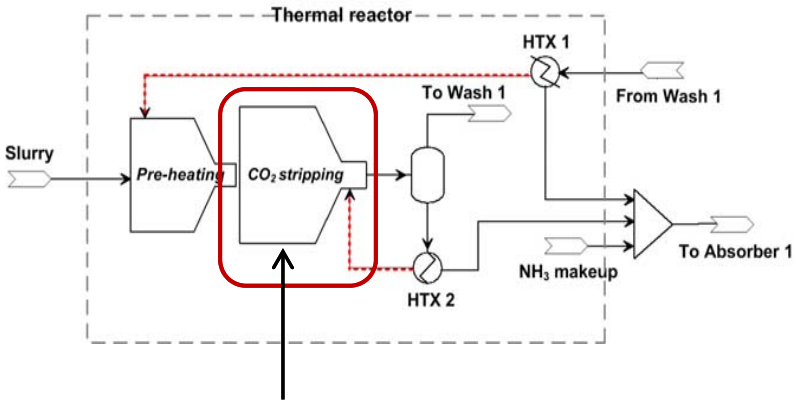
- Reservoir CO_2 injection using CT-scanning



Dynamics (dCapCO2), MEA vs. PZ



Optimization of energy consumption



T = 88 ° C
P = 1 bar

Low- and mid- temperature waste / process heat integration!

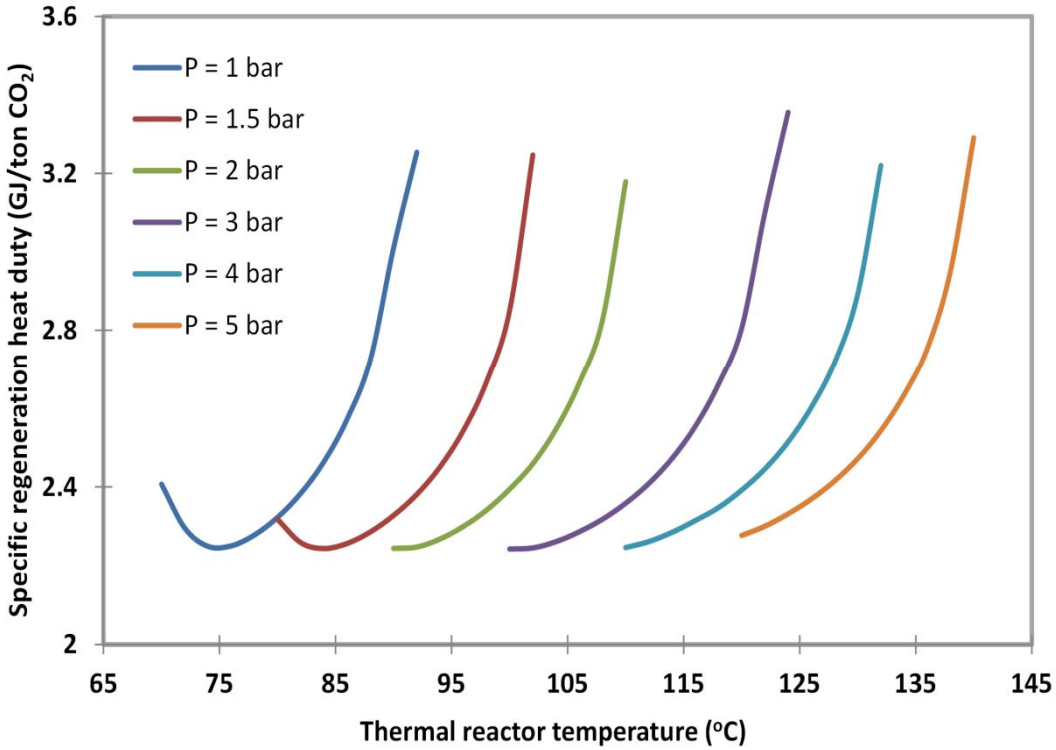


Fig. 5. Influence of temperature and pressure on the specific regeneration energy

Statements on CO_2 emitting energy sources

- Cheap energy sources will be used by 3rd world countries as long as they are available
- Coal and oil are cheap and "easy" energy resources
- Renewable technologies will be beneficial for developed countries but will take longer to implement in the 3rd world
- Several industrial processes produce noticeable amounts of CO_2 which may not be reduced by renewable energy
  - Cement industry
  - Fermentation industry (Medicine, food, and bioethanol production)
  - Agriculture
  - Transportation

CAPCO2 unit operation

Aspen Plus