Challenges of CO$_2$ capture as an application of fluid separation techniques

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Outline

1. Context
2. CO₂ Capture configurations and technologies
3. Future trends and challenges
4. Conclusion
Context: let’s start ab initio…
Mission statement of the EFCE

EFCE will help European society

- to meet its needs
- through highlighting the role of Chemical Engineering
- in delivering sustainable processes and products
What needs?

European Environment Agency, SOER 2015
Ecological footprint

Rockström et al., 2009, Nature 461, 472-475
The energy transition has already started…

But it has to address 2 objectives in contradiction: Limit GHG emissions, and meet the increasing demand!
The COP [...] notes that much greater emission reduction efforts will be required ...

The Paris Agreement

1. Falling emissions “as soon as possible” (Art. 4.1) Comparison point for least-cost 2°C target paths: 40Gt (Art. 17)

2. Net zero emissions 2050-2100 (=balance between anthropogenic emissions and sinks in second half of the century) (Art. 4.1)
Meeting the increasing demand is already a challenge in itself!

Global primary energy demand by type in the INDC Scenario

Note: “Other renewables” includes wind, solar (photovoltaic and concentrating solar power), geothermal, and marine.

IEA 2015, WEO special report, Energy & Climate Change
Possible answers: Trias Energetica

Lysen E., The Trias Energica, Eurosun Conference, Freiburg, 1996
CO₂ capture is basically a matter of fluid separation

Purity of sources varies between 0.04% and almost 100%
2. CO₂ Capture technologies & configurations
CO\textsubscript{2} separation technologies

- Avoid fluid mixtures
- Absorption
  - Physical
  - Chemical
- Adsorption
- Membranes
- Cryogenic separation
- Others…
CO\textsubscript{2} capture configurations
Industrial processes

1. CO₂ not resulting from combustion
   - Cement plants
     - Leilac: 21 M€, -60% CO₂
Industrial processes

1. CO₂ not resulting from combustion
   - Steel mills
     - Steelanol: 87 M€, -70% CO₂

www.steelanol.eu
Oxyfuel combustion

2. Burn the fuel with pure oxygen
   - Air separation needed
   - Waiting for large-scale projects
Post-combustion capture

3. Capture CO$_2$ from combustion gases
   - Usually chemical solvents
Post-combustion capture

3. Capture CO$_2$ from combustion gases
   - Characteristics of a chemical solvent

- Reaction with CO$_2$: mechanism, kinetic, ...
- Regeneration of the solvent: regeneration energy, regeneration efficiency
- Physico-chemical properties of the CO$_2$-solvent system: density, viscosity, diffusivity, solubility, ...
- Solvent degradability: reactions with other components (SOx, NOx, ...) of the flue gas, irreversible reactions with CO$_2$, effects on equipment, ...
- Industrial availability of the solvent
- Cost of the solvent

Dubois, UMons, 2011
3. Capture CO₂ from combustion gases

- Amines (1, 2, 3ary) in water

Léonard et al., 2014 & 2015. DOI: 10.1021/ie5036572, DOI: 10.1016/j.compchemeng.2015.05.003
Post-combustion capture

3. Capture CO₂ from combustion gases
   - Alternatives to amines
     - Chilled Ammonia, amino-acids, ionic liquids…
     - Demixing solvents => LLV and thermo models

Heldebrant et al., 2009; Raynal et al., IFP, 2011
Post-combustion capture

3. Capture CO$_2$ from combustion gases
   - Boundary Dam, Saskatchewan
     - Coal power plant 160 MWe
     - 2700 tCO$_2$/day captured (~90% capture rate)
       => Flue gas: 180 Nm$^3$/s; Solvent: 550 L/s
   - Petra Nova, Texas: 4400 tCO$_2$/day
Pre-combustion capture

4. Remove C from the solid fuel by gasification
Pre-combustion capture

4. Remove C from the solid fuel by gasification
   - Great Plains Synfuel Plant, North Dakota (US)
   - 8 200 tCO$_2$/day captured (~50% capture rate)

http://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/great-plains
4. Remove C from the solid fuel by gasification

- GPSP Rectisol process: physical absorption in cold methanol
- Largest utility consumption and largest plant bottleneck

Practical experience gained at GSPS, US DOE report, 2006
Pre-combustion capture

4. Remove C from the solid fuel by gasification
   - Kemper County (Mississippi): IGCC, 582 MWe
   - 9500 tCO$_2$/day captured (~65% capture rate)
   - Cost estimation: from 2.9 to 6.6 bn$ (still increasing)
Pre-combustion capture

4. Remove C from the solid fuel by gasification
   - Kemper County: CO₂ separation using the Selexol process
   - Physical absorption in dimethylethers of polyethylene glycol
Pre-combustion capture

4. Remove C from the fuel => Natural gas sweetening
   - Usually physical and/or chemical solvents
   - Also membranes for off-shore platforms
     - Pre-treatment: TSAdsorption for Hg, H₂O and heavy HC
3. Future trends and challenges
Negative CO$_2$ emissions

- Biomass-enhanced CCS
- Direct air capture

Direct air capture

- ~ 400 ppm in the air
  - Adsorption
  - Temperature-swing, or humidity-swing

Wang et al, 2011
CO₂ re-use

- CCS has become CCUS
CO$_2$ re-use

- CCS has become CCUS

Diagram:

- CO$_2$, H$_2$O energy
- Electrolysis
- Fuel synthesis
- Industrial CO$_2$ capture
- Air capture
- Renewable energies
- Power-to-gas: H$_2$, CH$_4$, DME...
- Power-to-fuel: Methanol, Diesel...
5. Conclusions
Perspectives

- World-scale challenge
- Large variety of technologies and of TRL


World CO₂ emissions abatement in the 450 Scenario (Bridge Scenario 2015-2040), IEA 2015, WEO special report, Energy & Climate Change
EFCE to create the EFCE energy section

- Support the key contributions of chemical engineering in the energy sector and the key aspects of energy for the chemical industry.
  - Sub-section 2: Energy conversion, renewable energy and CO$_2$ mitigation
  - Sub-section 7: CO$_2$ capture & reuse

http://efce.info/Energy.html
Thank you for your attention!

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