Evaluation of Process Improvements in Pilot Scale – Activities Under the EU CESAR Project

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CESAR Project Consortium

**CESAR: CO₂ Enhanced Separation And Recovery**

- 3-year EU project (2008 – 2011) in the 7th Framework Programme
- Aim: To reduce the cost of CO₂ post-combustion capture

**R&D**
- IFP (FR)
- TNO (NL)
- SINTEF (NO)
- NTNU (NO)
- POLYMEN (FR)
- CNRS (FR)
- U. KAIERSLAUTERN (DE)

**Oil & Gas**
- STATOILHYDRO (NO)
- GDF (FR)

**Power Companies**
- DONG Energy (DK)
- VATTENFALL (SE/DK)
- E.ON (DE/UK)
- ELECTRABEL (BE)
- RWE (DE/UK)
- PPC (GR)
- POWERGEN (UK)

**Manufacturers**
- ALSTOM POWER (SE)
- DOOSAN BABCOCK (UK)
- SIEMENS (DE)
- BASF (DE)

Coordinator: TNO
Outline CESAR Project

WP1
Advanced separation processes
- Solvent selection
- Novel solvents
- High flux membrane contactors

WP2
Process modeling & Integration
- Development of process models
- Integration studies
- European benchmark task force

WP3
Solvent process validation
- Qualification of solvents
- Solvent process validation in Esbjerg pilot plant
- Environmental impact
CESAR Objectives of Pilot Plant Testing in Esbjerg

- Evaluate the potential of advanced absorption/desorption process configurations in pilot-scale
- Determine the performance of novel solvents in realistic operation conditions for future full-scale application in coal-fired power plants
- Measure energy requirement and temperature levels for regeneration of the novel solvents
- Monitor actual solvent degradation, losses and by-products, corrosion, fouling and emissions for novel solvents
Esbjerg Power Station (ESV)

**Esbjerg Power Station**
- 400 MWₑ pulverized bituminous coal
- High dust SCR deNOₓ plant
- 3 zones cold-sided ESP
- Wet limestone FGD (saleable gypsum)
The CO₂ Capture Pilot Plant at Esbjerg Power Plant

**Pilot Plant Specifications**

- Operates on a slip stream of flue gas taken directly after the wet FGD
- Flue gas flow: 5000 Nm³/h (0.5% of 400 MWₑ)
- CO₂ capture capacity: 1000 kg/h
- Cleaning efficiency: 90%
Esbjerg Pilot Plant Flow Diagram

- Bubble cap polisher
- Fresh water
- Absorber inter-cooling
- Flue gas from power plant
- Treated flue gas
- CO₂ Out
- Cooling water circuit
- Reboiler
- MEA/MEA heat exchanger
- Absorber inter-cooling
- Expansion of cross flow heat exchanger
- Installation of vapour recompression
- Condensate
- Steam
- Wash section
- Rich MEA
- Lean MEA
- Mechanical filters
- Revamping of absorber with structured packing
CESAR Pilot Plant Modifications: Inter-cooler & Flash Vessel

Absorber inter-cooler skid

Flash vessel for vapour recompression
Pilot Plant Operation History and Outlook

Four test campaigns have been conducted during CASTOR and three more are scheduled for the CESAR project:

- 1000 hours using standard solvent "30%-wt. MEA" (Jan – Mar 2006)
- 1000 hours using standard solvent "30%-wt. MEA" (Dec 2006 – Feb 2007)
- 1000 hours using novel solvent "CASTOR 1" (April – June 2007)
- 1000 hours using novel solvent "CASTOR 2" (Sep – Dec 2007)
- >1000 hours using standard solvent "30%-wt. MEA" (Mar 2009 – July 2009) in modified pilot plant
- >1000 hours using novel solvent "CESAR 1" (Oct 2009 – Dec 2009) in modified pilot plant
- >1000 hours using novel solvent "CESAR 2" (Feb 2010 – Jun 2010) in modified pilot plant
Outline of CESAR MEA Test Campaign

- **Test 1 – Parameter variation**
  a) Optimisation of solvent flow rate (at 90% capture)
  b) Effect of absorber inter-cooling
  c) Effect of vapour re-compression
  d) Variation of CO₂ capture percentage
  e) Variation of stripper pressure

- **Test 2 – 500 hours of continuous operation**
  - Operation at ”optimised” conditions and achieving 90% CO₂ capture (on average)
  - Quantification of solvent consumption and degradation
  - Characterisation of corrosion behaviour

- **Test 3 – Miscellaneous tests**
  - Transient test & load following capability
  - Emission measurements
  - Etc.
Optimisation of Absorber L/G with Improved Cross Flow HX

Specific steam consumption at stripper pressure 0.85 bar$_g$, flue gas flow $\approx$5000 Nm$^3$/h and $\approx$90 % CO$_2$ recovery

CASTOR: $\Delta T = 7.1$-$8.0^\circ$C

$\Delta T = 4.0$-$4.3^\circ$C
Effect of Process Modifications: Absorber Inter-cooling (1/2)

Flue gas flow ≈5000 Nm³/h, L/G ≈3 kg/kg, Stripper pressure =0.85 barg, CO₂ capture ≈90%

Steam consump. CO₂ recovery (%)

Abs. temperature (°C) vs Packing height (m)

Flue gas 48°C, Solvent 40°C
Effect of Process Modifications: Absorber Inter-cooling (2/2)

Flue gas flow ≈ 5000 Nm$^3$/h, L/G ≈ 3 kg/kg, Stripper pressure = 0.85 barg, CO$_2$ capture ≈ 90%

![Graph showing the effect of inter-cooler temperature on rich loading and temperature rich MEA.](image-url)

- Rich loading
- Temperature rich MEA (°C)

![Graph showing the effect of inter-cooler temperature on absorber pressure drop.](image-url)

- Absorber pressure drop (mm H$_2$O)

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**Inter-cooler temperature (°C)**

20 30 40 50 60

**Rich loading (mol CO$_2$/mol MEA)**

0.40 0.45 0.50 0.55 0.60

**Temperature rich MEA (°C)**

20 30 40 50 60

**Absorber pressure drop (mm H$_2$O)**

200 220 240 260 280 300
Effect of Process Modifications: Lean Vapour Re-compression

Flue gas flow ≈ 5000 Nm³/h, L/G ≈ 3 kg/kg, Stripper pressure = 0.85 barg, CO₂ capture ≈ 90%, no inter-cooling

![Graph showing the relationship between Flash pressure (barg) and steam and power consumption.](image)
CESAR MEA Test: 500 Hours of Continuous Operation

L/G ≈ 3 kg/kg, stripper pressure 0.85 bar, with inter-cooling and vapour re-compression

Average steam consumption: ≈ 3.07 GJ/ton CO₂ (± 24 kWh/ton CO₂)  Average CO₂ capture: 90%  (Result from CASTOR: ≈ 3.7 GJ/ton CO₂)
Influence of Reboiler Steam Input

Flue gas flow $\approx 5000$ Nm$^3$/h, L/G $\approx 3$ kg/kg, stripper pressure 0.85 bar$_g$

with inter-cooling and vapour re-compression

$$\text{Steam consump.}$$

$$\text{CO}_2\text{ recovery}$$

$$\text{Reboiler steam input (kg/h)}$$
Conclusions

Several process upgrades have been introduced at the Esbjerg CO₂ capture pilot plant. A benchmark campaign using 30% MEA has among others indicated that:

- Reducing the ΔT of the solvent cross flow heat exchanger from ≈7.5 to 4.5°C leads only to minor saving in reboiler steam consumption (≈ 0.1 GJ/ton CO₂), however, it allows for lower reboiler temperatures (i.e. higher L/G) at reduced penalty
- Inter-cooling seems to have only marginal effect on reboiler steam consumption with MEA, however, as a co-benefit the absorber ΔP is reduced
- Vapour re-compression may lower reboiler steam consumption substantially (3.6 to 2.8 GJ/ton) on account on increased power consumption. A full cost benefit analysis is required to determine the true benefits

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