Experience with the CASTOR/CESAR Pilot Plant

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Presented by:
Jørgen Nørklit Jensen
DONG Energy – Business Model

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Outline of Presentation

- Introduction to post combustion carbon capture (PC CC)
- Introduction to the CASTOR / Esbjerg CO₂ capture pilot plant
- Overview of operation history and outlook
- Interaction of capture plant and power plant
- (Water balance issues & control)
- (CESAR project - Upgrades and process modifications introduced)
Industrial Post Combustion CO₂ Capture Amine Process'

- ABB Lummus / Kerr-McGee: 15 - 20% MEA
  Only technology used on flue gas from coal firing (up to 400 ton CO₂/day)

- DOW MEA / Fluor Econamine FG: 30% MEA
  Large number of plants, up to 330 ton CO₂/day

- Mitsubishi Heavy Industries (MHI): KS-1 solvent
  Large number of plants, up to 450 ton CO₂/day

- Several other vendors of solvents and small scale plants (few tons a day)

A 750 MWₑ coal fired power plant will produce > 500 ton CO₂/hour
The production of CO$_2$ by this technology has been applied for decades, however:

- Goal has been commercial production of CO$_2$, not the reduction of CO$_2$-emissions
- The consumption of energy has not been important in this commercial production
- Limited experience on CO$_2$ absorption from flue gases from coal fired power plants
- The largest plants built are 20 - 40 times smaller than necessary for coal fired power plants

Therefore the erection of the CASTOR pilot plant at the Esbjerg power plant!
Placing of Post Combustion Carbon Capture Plant

Known power plant technology

- Air
- Fuel
- Combustion → Flue Gas Cleaning
- Heat & Power

CO₂ Capture → CO₂ Compression → CO₂ Transport

New power plant technology

- EOR
- Storage
- Industrial use

DONG Energy has a unique position because of our 3 business units:

- Power
- Gas Distribution & Storage
- Exploration & Production
Esbjerg Power Station (ESV)

- 400 MW<sub>e</sub> pulverized bituminous coal
- High dust SCR deNO<sub>x</sub> plant
- 3 zones cold-sided ESP
- Wet limestone FGD (saleable gypsum)
CASTOR Pilot Plant Specifications

- Pilot plant erected and commissioned during 2005
- Design of pilot plant based on a commercial CO₂ production plant (MEA)
- Pilot plant operates on a slip stream taken directly after the wet FGD
- Design flue gas conditions: ~47°C saturated, <10 ppm SO₂, <65 ppm NOₓ, <10 mg/Nm³ dust

Key design parameters

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<th>Parameter</th>
<th>Design value</th>
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<tr>
<td>Flue gas capacity</td>
<td>5000 Nm³/h</td>
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<tr>
<td>CO₂ production (at 12% CO₂)</td>
<td>1000 kg/h</td>
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<td>Absorption degree</td>
<td>90%</td>
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<tr>
<td>Max solvent flow</td>
<td>40 m³/h</td>
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<td>Max stripper pressure</td>
<td>2 bar</td>
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CASTOR Pilot Plant Flow Diagram

- Flue gas from power plant
- Treated flue gas
- Make up water
- Cooling water circuit
- CO₂ Out
- Reclaimer
- Steam
- Mechanical filters
- Rich MEA
- Lean MEA
- MEA/MEA heat exchanger
- Condensate
- Reboiler

Diagram elements:
- CASTOR Pilot Plant Flow Diagram
- Coolant circuit
- Reclaimer
- Steam
- Mechanical filters
- MEA/MEA heat exchanger
- Condensate
- Treated flue gas
- Make up water
Operation History and Outlook at the Esbjerg Pilot Plant

Four test campaigns have been conducted in CASTOR:

- 1000 hours using standard solvent "30%-wt. MEA" (Jan. – Marts 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)

During 2008 a series of process upgrades have been installed at the Esbjerg pilot plant as part of the CESAR project.

Test programme in CESAR:

- 2000 hours using standard solvent "30%-wt. MEA (Mar. – July 2009)
- 2000 hours using novel solvent "CESAR 1" (fall 2009)
- 2000 hours using novel solvent "CESAR 2" (spring 2010)
Outline of Test Campaigns

- **Test 1 – Parameter variation**
  a) Optimisation of solvent flow rate (at 90% capture)
  b) Variation of reboiler steam input at optimum solvent flow
  c) Variation of stripper pressure (at 90% capture)

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

- **Test 3 – Miscellaneous tests**
  - Absorber pressure drop measurements
  - Emission measurements
  - Etc.
MEA Test: Solvent Flow Rate Optimization

Specific steam consumption and CO$_2$ recovery at stripper pressure 0.85 bar$_g$ and flue gas flow ≈5000 Nm$^3$/h

![Graph showing steam consumption and CO$_2$ recovery vs. Absorber L/G ratio](image-url)
MEA Test: 500 Hours of Continuous Operation

Average steam consumption: $\approx 3.7$ GJ/ton $\text{CO}_2$  
Average $\text{CO}_2$ capture: 88 %
Influence of Power Plant Load on CO₂ Content of Flue Gas

Example: 48-hours load profile at the Esbjerg coal-fired power plant
Influence of Power Plant Load on CO₂ Capture Degree

Example: 48-hours operating period with fixed settings at the CO₂ capture plant
Absorber Response to Step Change in CO$_2$ Inlet Concentration

"Optimised" conditions
MEA flow: 15.5 m$^3$/h

Solvent flow rate higher than "optimum"
MEA flow: 19 m$^3$/h
Influence of Absorber Liquid-to-Gas (L/G) Ratio on Absorber Response to Power Plant Load Changes

L/G ≈ 3 kg/kg

L/G ≈ 4 kg/kg

Examples: 4-hours operating period with fixed settings at the CO₂ capture plant
Absorber Response to Step Change in CO$_2$ Inlet Concentration

Example: CESAR tests with inter-cooling at stage 4
Conclusion on Operating Flexibility based on CASTOR Pilot Plant

- The CO$_2$ capture plant will be as flexible as the power plant!
- What about the rest of the down stream equipment?:
  - Compression
    - single stage compressors and no of trains?
    - multistage compressor and no of trains?
    - with or without heat recovery and/or inter-cooling?
  - Transportation
    - pipeline?
    - injection well?
  - Storage / use
    - enhanced oil/gas recovery?
    - depleted oil/gas field?
    - saline aquifer?
    - (Industrial use)?
Thank you for your attention!

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The Water Balance Issue

A CO₂ post combustion capture unit is an "open" system concerning water. A fundamental mass balance apply:

\[
\text{Ingoing water} + \text{Make-up water} = \text{Outgoing water} + \text{Accumulated}
\]

- The accumulated term must be zero, if neither dilution nor concentration of the amine solution should take place
- Ingoing: Water content of flue gas entering the plant
- Outgoing: Water content of flue gas, CO₂ product leaving the plant, and drain of condensate
- Make-up: Fresh water supply to wash sections (optional)
Controlling the Water Balance

- Treated flue gas
- Outlet temperature
- Cooling water Flow Controller
- Wash section
- Make up water
- Inlet temperature
- Flue gas from power plant
- Temperature set point
- Cooling water Flow Controller
- CO₂ Out
- CO₂ temperature
- Bleed of condensate (not desirable, contains amine)
- Sump level
CESAR Project Overview

- The CASTOR project ended in January 2008
- A 3-year follow up EU project "CESAR" was launched 1st of February this year
- 20 partners in the CESAR consortium

Pilot plant activities in CESAR:
- Implementation of process improvements at the Esbjerg Pilot Plant
- 3 × 2000 hours test campaigns (1 benchmark & 2 novel solvents)
- Focus on minimization of the energy consumption
- Focus on dynamic behavior
- Focus on the environmental impact of amine scrubbers
Treated flue gas

Flue gas from power plant

Wash section

Absorber inter-cooling

Revamping of absorber with structured packing

Expansion of cross flow heat exchanger

MEA/MEA heat exchanger

Installation of vapour recompression

CO₂ Out

Cooling water circuit

Make up water

Condensate

Steam

Reboiler

Lean MEA

Rich MEA

Mechanical filters

Bubble cap tray

CESAR Pilot Plant Flow Diagram
CESAR Pilot Plant Modifications: Inter-cooler & Flash

Absorber inter-cooler skid

Flash vessel for vapour recompression