Development of post-combustion capture of CO_2 within the CASTOR Integrated Project: First results from the pilot plant operation using MEA

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TNO | Knowledge for business

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CASTOR Project Goals

- Reduce the cost of CO_2 post-combustion capture
- Contribute to the feasibility & acceptance of the geological storage concept
- Validate the concept on real site(s)
  - Pilot testing for capture (25 t CO_2 / day)
  - Detailed studies of future storage projects

Duration: 4 years (2004-2008)

Consortium participants

30 partners from 11 European countries

R&D	Oil & Gas	Power Companies	Manufacturers
IFP (FR)	STATOIL (NO)	VATTENFALL (SE)	ALSTOM POWER (FR)
TNO (NL)	GDF (FR)	ELSAM (DK)	MITSUI BABCOCK (UK)
SINTEF (NO)	REPSOL (SP)	ENERGI E2 (DK)	SIEMENS (DE)
NTNU (NO)	ENITecnologie (IT)	RWE (DE)	BASF (DE)
BGS (UK)	ROHOEL (AT)	PPC (GR)	GVS (IT)
BGR (DE)		E.ON-UK (UK)	
BRGM (FR)			
GEUS (DK)			
IMPERIAL (UK)			
OGS (IT)			
TWENTE U. (NL)			
STUTTGARTT U. (DE)			

Co-ordinator: IFP

Chair of the Executive Board: Statoil

CASTOR main components

Strategy for CO_2 Reduction

WP1.1 Development of CO_2 reduction strategies

WP1.2 Geological storage options for CO_2 reduction strategy

Budget: 0,9 M€

Management Dissemination

WP0.1 Project Management

WP0.2 Dissemination & Training

Budget: 0,75 M€

CO_2 Post-Combustion Capture

WP2.1 Evaluation, optimisation & integration of post-combustion capture processes

WP2.2 Identification of most promising liquids

WP2.3 Designed of membrane based processes

WP2.4 Advanced processes

WP2.5 Process validation in pilot plant

Budget: 10,3 M€

CO_2 storage performance & risk assessment studies

WP3.1 Field case "Casablanca"

WP3.2 Field case "Lindach"

WP3.3 Field case "K13b"

WP3.4 Field case "Snohvit"

WP3.5 Preventive & corrective actions

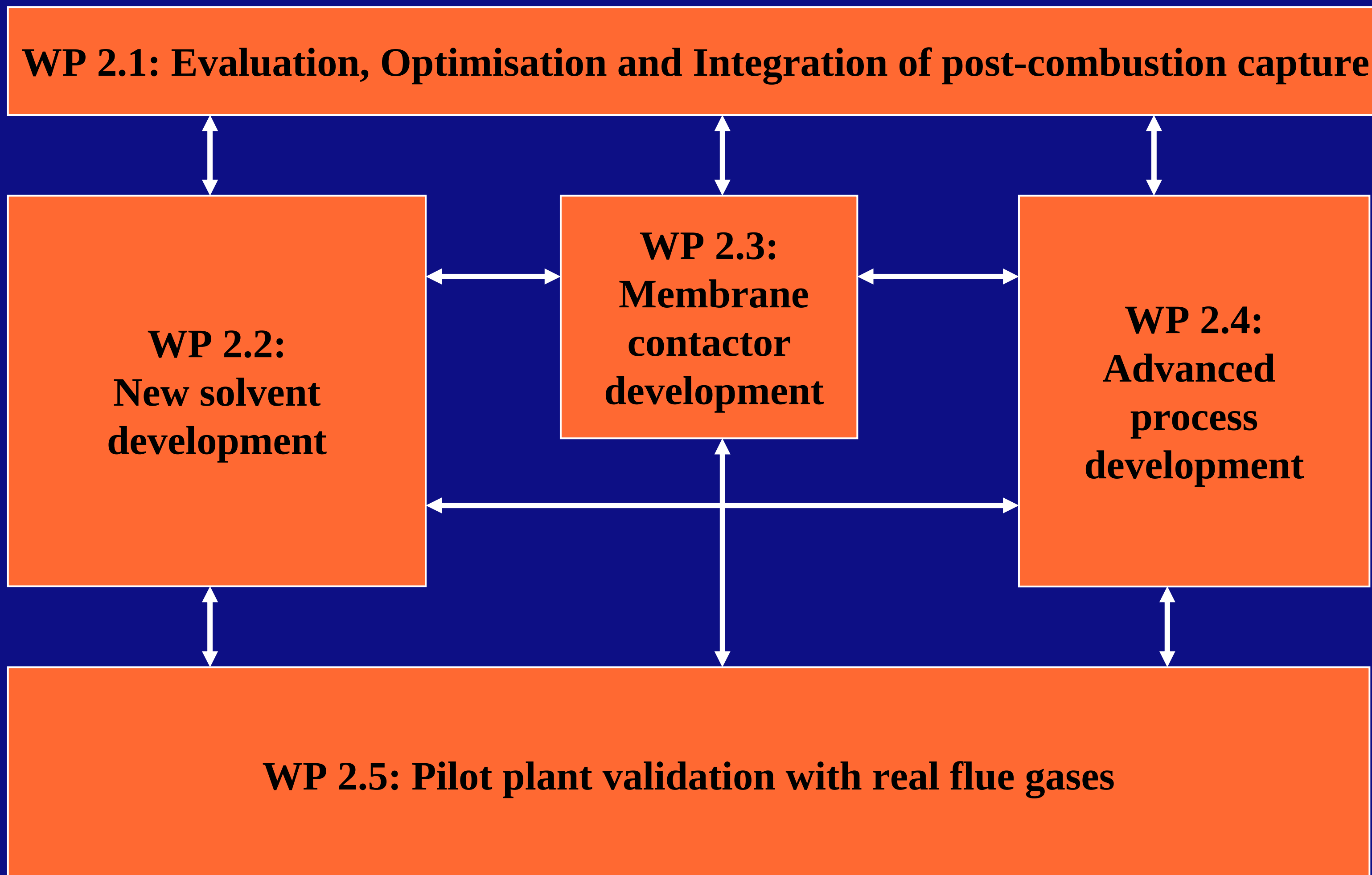
WP3.6 Criteria for site selection and site management

Budget: 3,8 M€

SP2. CO_2 post-combustion capture

- Overall Objectives
  - Development of absorption liquids, with a thermal energy consumption of 2.0 GJ/tonne CO_2 at 90% recovery rates
  - Resulting costs per tonne CO_2 avoided not higher than 20 to 30 €/tonne CO_2, depending on the type of fuel
  - Pilot plant tests showing the reliability and efficiency of the post-combustion capture process

SP2 – Work package structure



Major technical results/deliverables

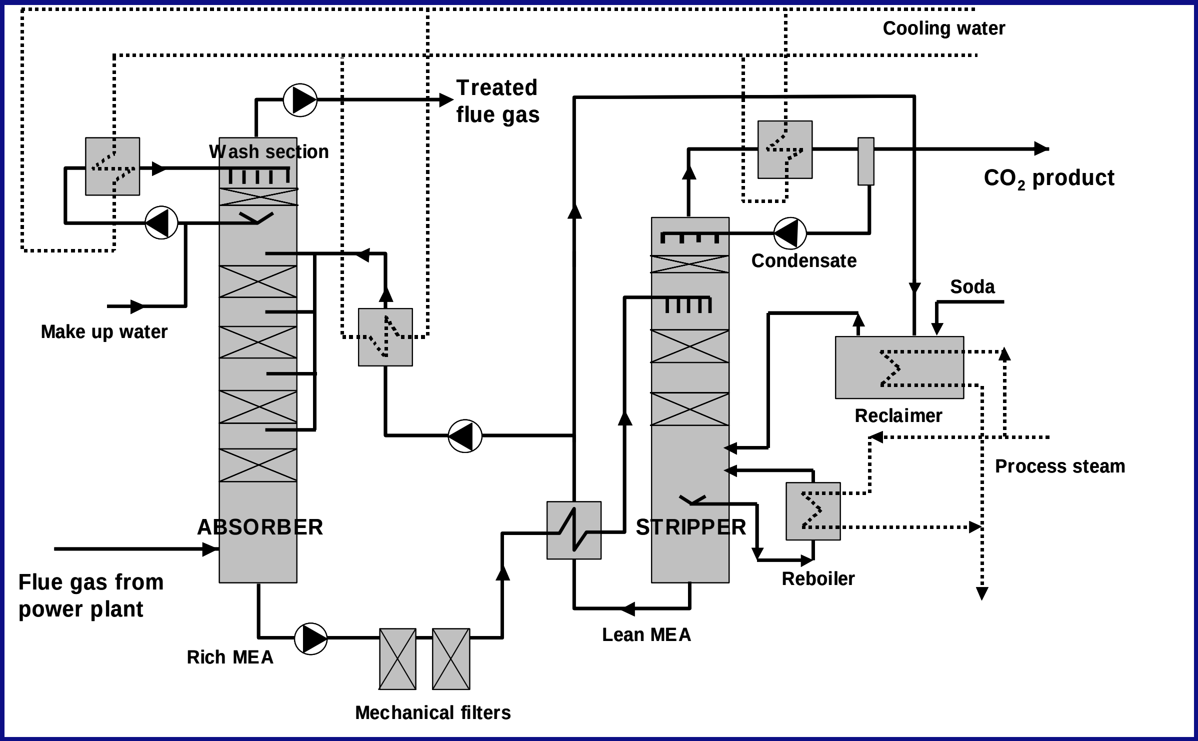
- New solvents resulting in less heat for regeneration
- Advanced processes resulting in lower power output losses
- Advanced equipment (membrane contactors) resulting in lower investment costs
- Pilot plant operating with real flue gas allowing hands-on-experience with absorption technology
- Methods for integration and optimisation resulting in lower power output losses

Objectives of the CASTOR pilot plant

As a central part of CASTOR a pilot plant has been built to fulfil two purposes:

- To demonstrate long-term continuous steady operation of solvent processes on a bituminous coal-based flue gas at a European power plant at a pilot plant industrial scale
- To make available a test facility for standard and novel solvents.

CASTOR pilot plant flow sheet



In operation early 2006 with production capacity of 1t/hr at 400 MW Esbjerg power plant

Overview first series of experiments with CASTOR pilot plant

Parameter	*Design value*
Flue gas capacity	5000 $Nm^3/h \approx$ 0.5% of ESV flue gas flow
CO_2 production (at 12 vol-% CO_2)	1000 kg/h
Absorption degree	90%
Max solvent flow	40 m^3/h
Max reboiler steam flow	2500 kg/h (3.5 bar)
Max stripper pressure	2 barg
Flue gas conditions	47°C (sat.), <10 ppm SO_2, <65 ppm NO_x, <10 mg/Nm^3 dust

- **Continuous operation at the nominal conditions (500 hours)**

The objective of the first 500 hours experiments is to control the operation of the CO_2-capture plant at its design point.

- **Continuous operation at off-nominal conditions (500 hours)**

The aim of the second 500 hours experiment is to gather data and information to validate the process and equipment models and to minimise the energy requirement for solvent regeneration.

1. **Determining the load following capability of the pilot plant**
2. **Minimizing the solvent flow**
3. **Changing the regeneration temperature**
4. **Optimisation of regeneration conditions**

- **Special interest experiments**

These experiments are aimed at gathering information on the effect of SO_2 on the overall process performance, and determining the pressure drop over the packing materials.

Results: **Continuous operation at the nominal conditions**

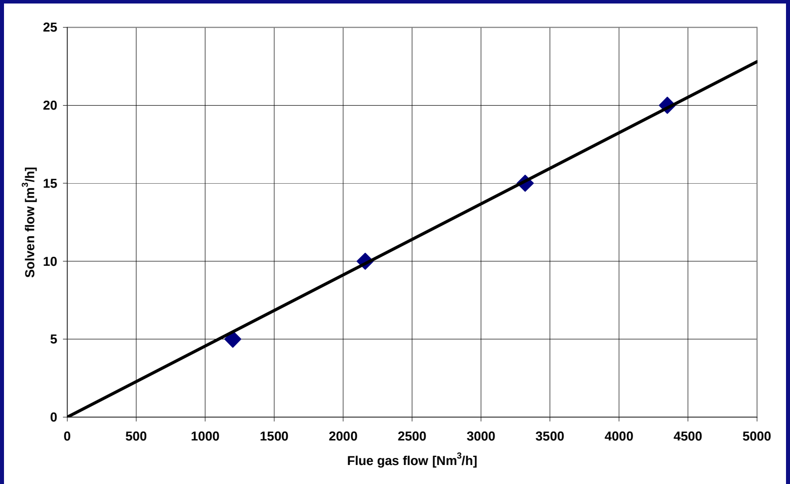
- A 500 hours test was carried out under conditions suggested by the supplier.

- Solvent flow rate (30 m^3/h), a reboiler temperature (109 ^oC), the flue gas flow rate was limited to (4400 Nm^3/h), the average CO_2 removal equalled (92.5%) at 846 kg/h and the thermal energy requirement was 4.4 GJ/tonne CO_2.

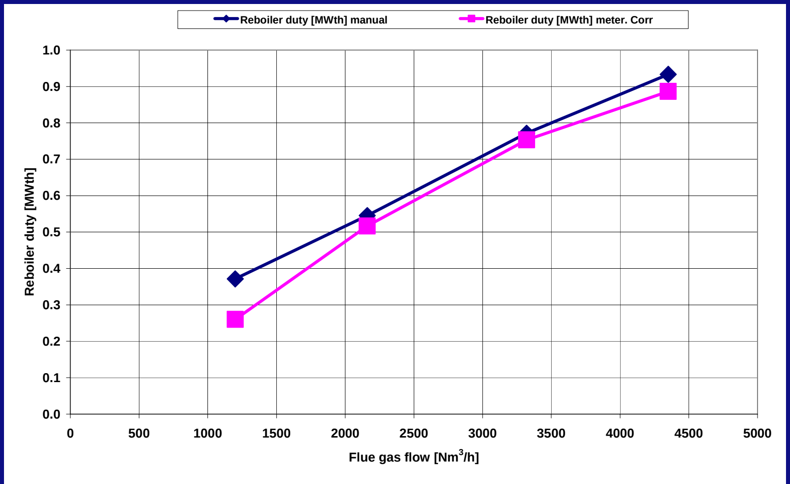
- The energy requirement was higher than e.g. determined from process modelling in ASPEN Plus based on a 30% MEA solution. However, the MEA concentration in the solvent was around 25% instead of the intended 30% and also the regeneration temperature was relatively low. Both conditions will tend to result in a higher thermal energy requirement.

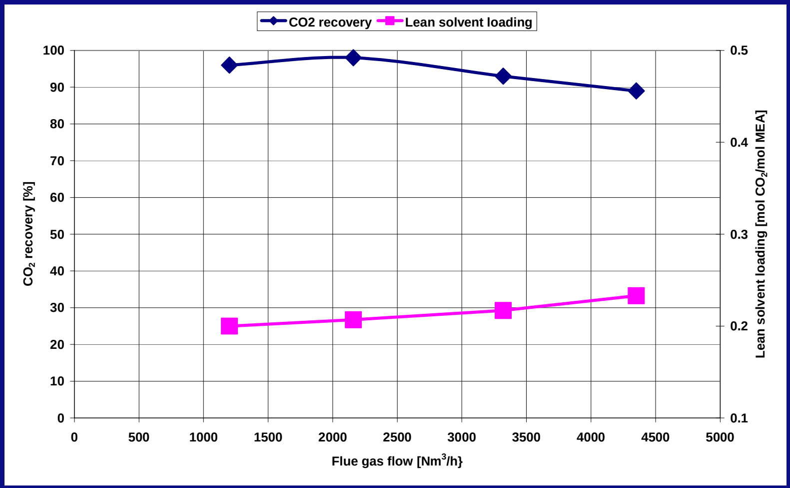
- During this initial period of testing the MEA-consumption amounted to 2.4 kg/tonne CO_2, which is around 50% higher than for a commercial solvent based on 30% MEA.

Results: Continuous operation at off-nominal conditions

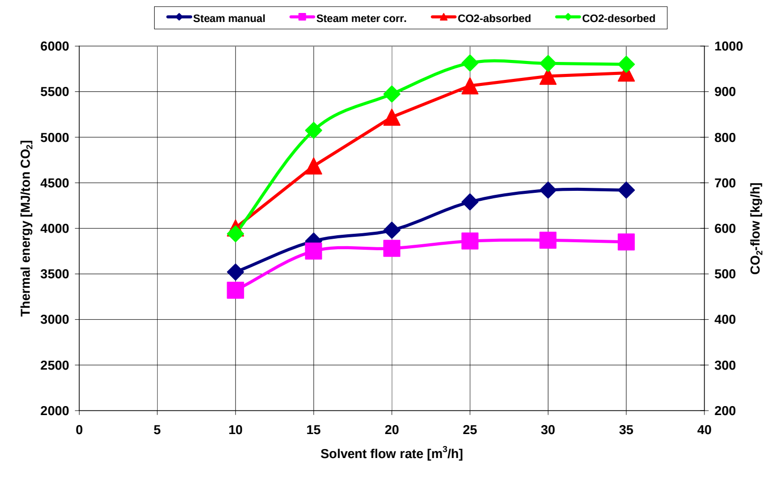


2a: Determining the load following capability of the pilot plant

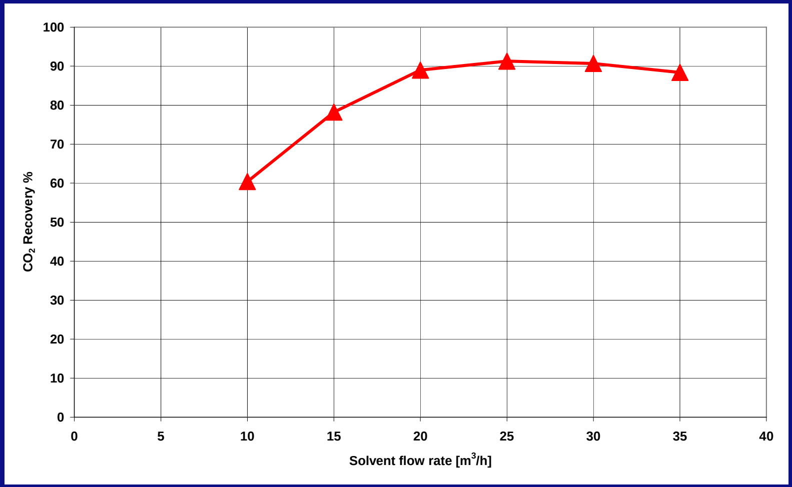




Results: **Continuous operation at off-nominal conditions**



2b: Minimizing the solvent flow



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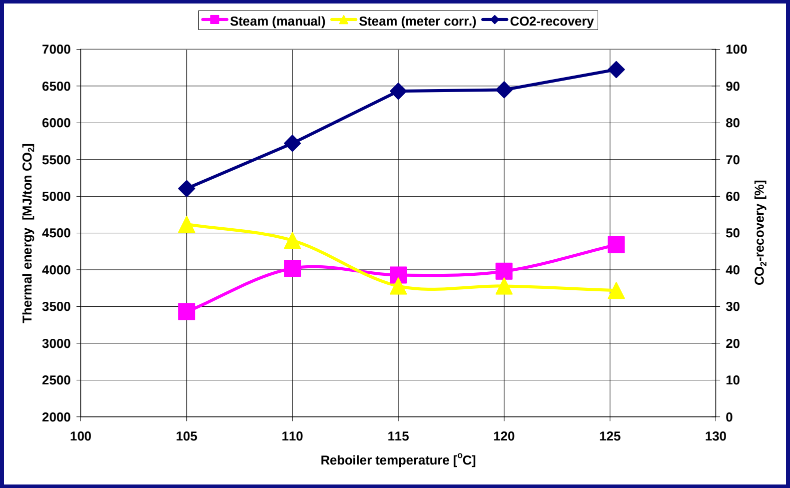
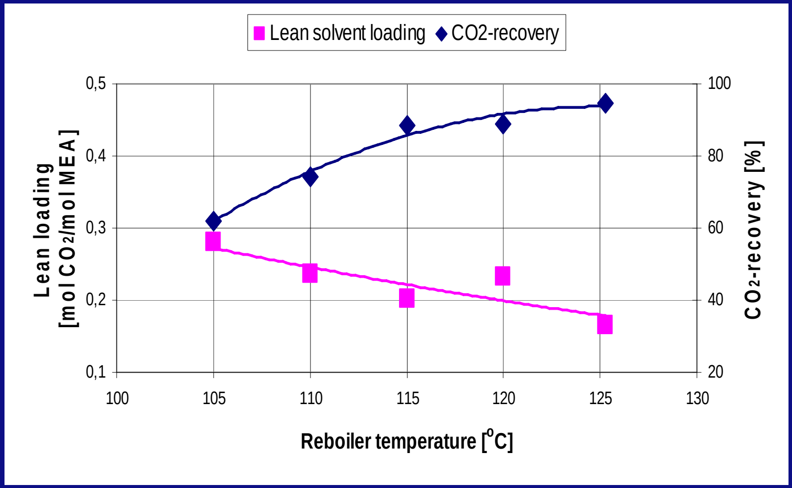
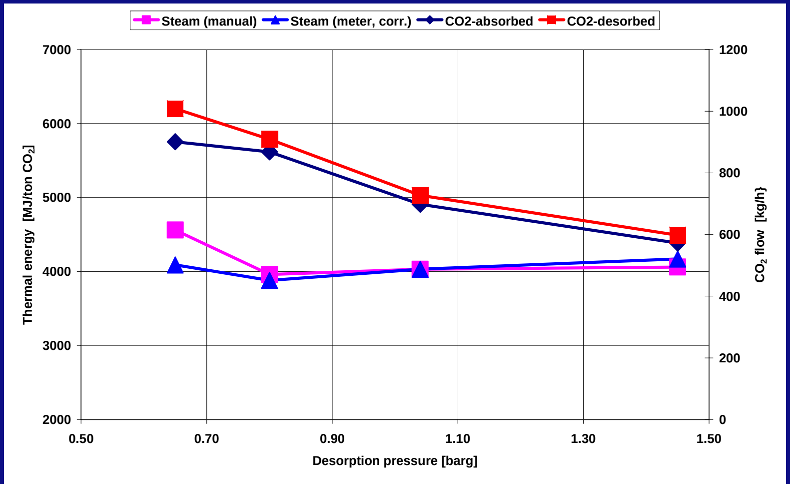
Results: Continuous operation at off-nominal conditions



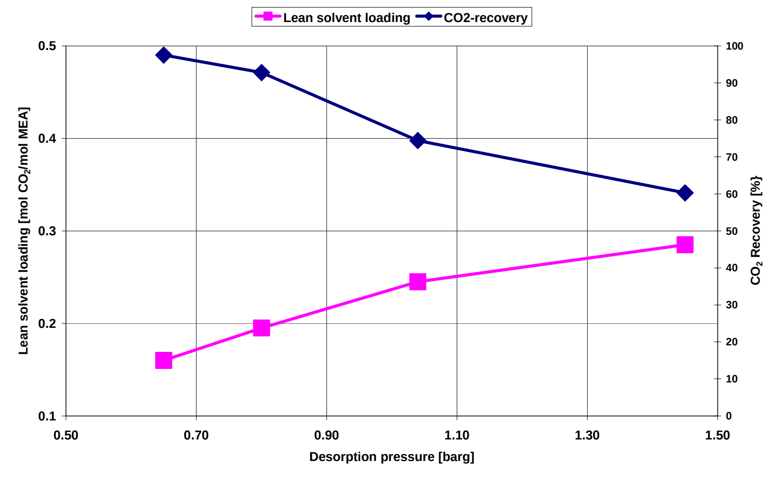
2c: Changing the regeneration temperature



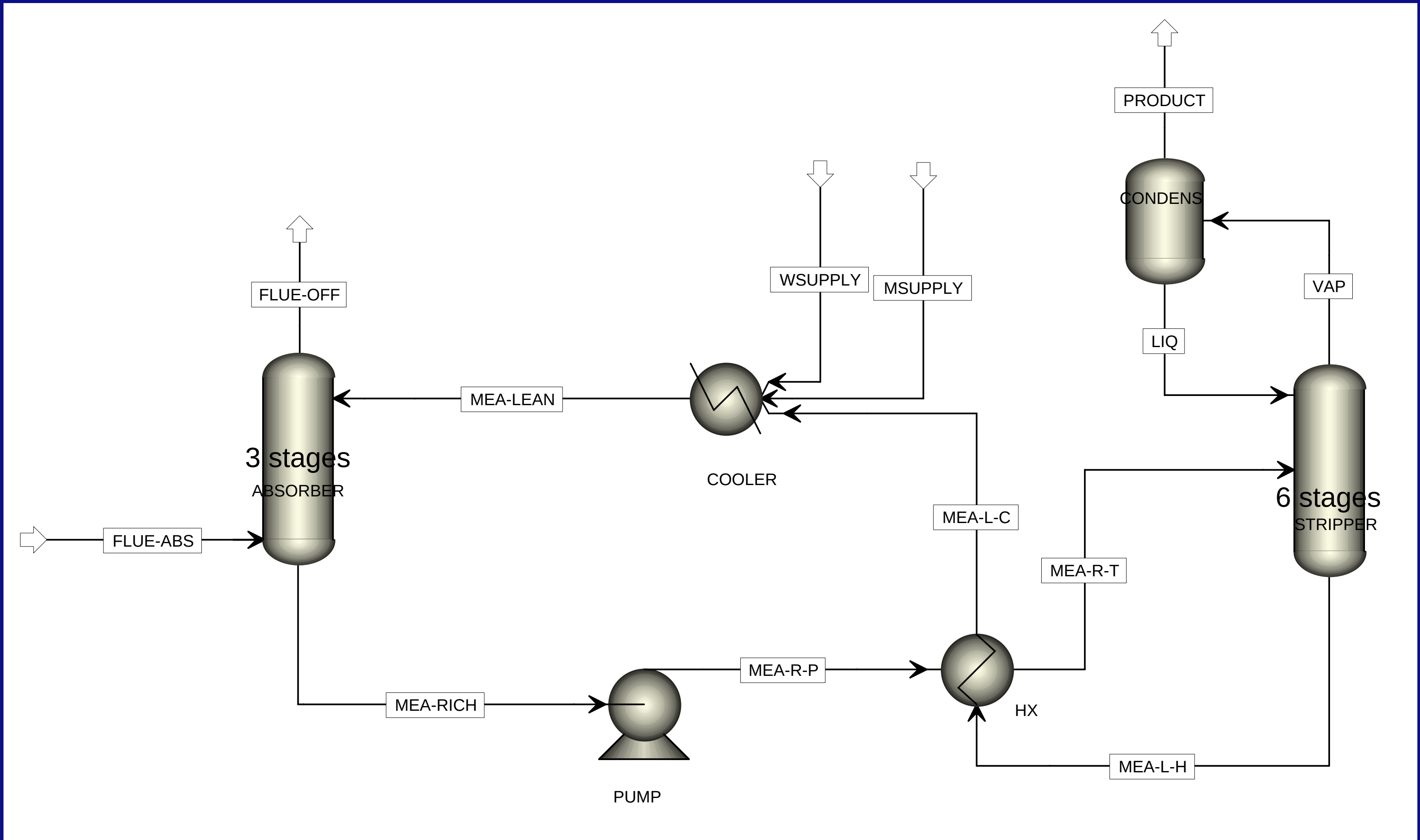
Results: Continuous operation at off-nominal conditions



2d: Optimisation of regeneration conditions



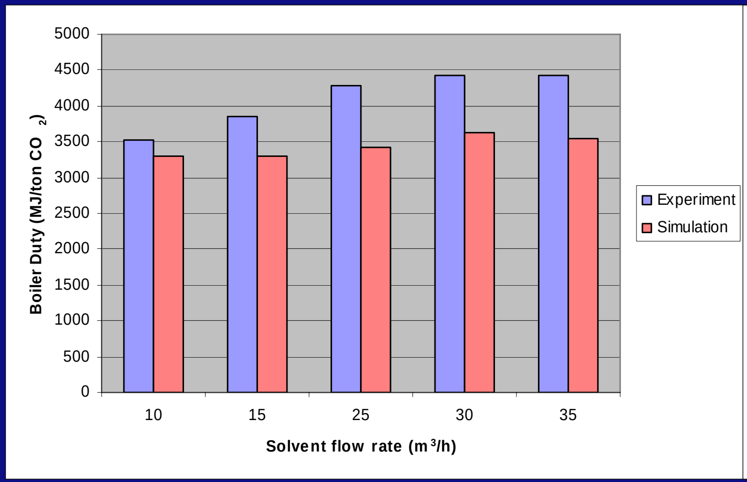
Aspen Plus simulation flow sheet

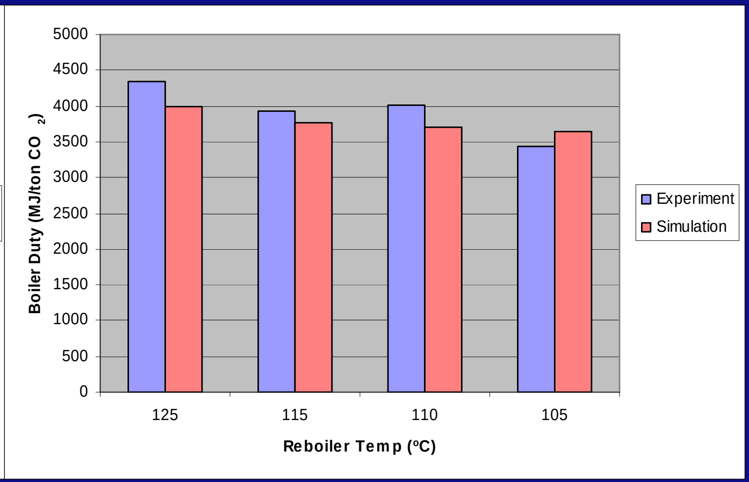


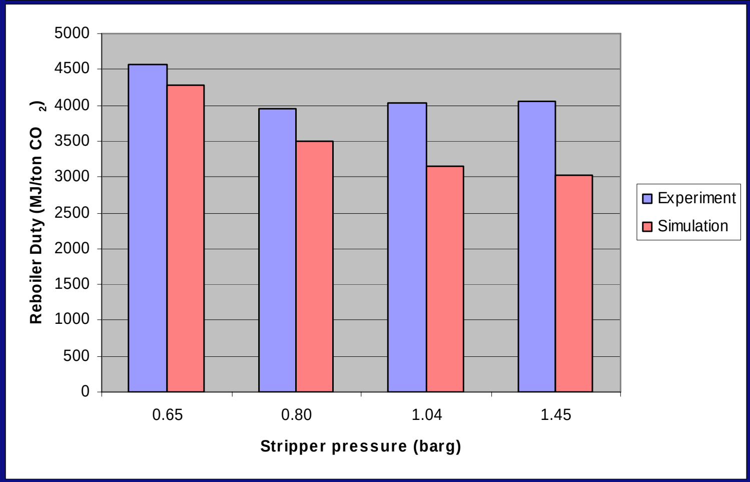
The main simulation input parameters

- Lean solvent flow rate
- Lean loading
- Rich loading
- Reboiler temperature
- CO_2 recovery %
- Reboiler duty

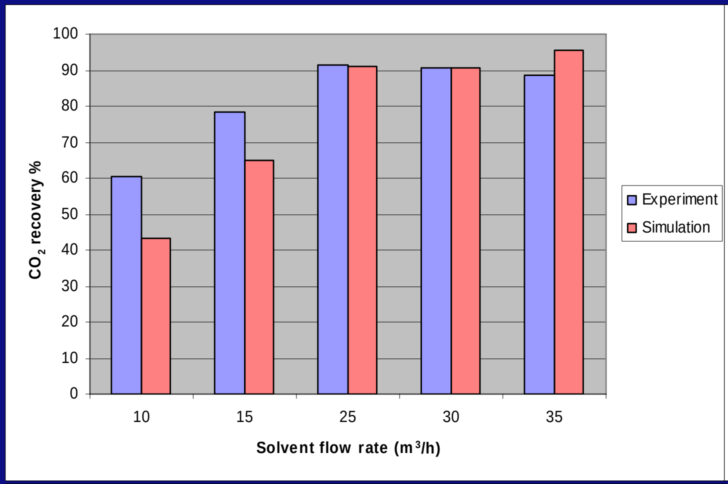
Reboiler duty (MJ/tonne CO_2)

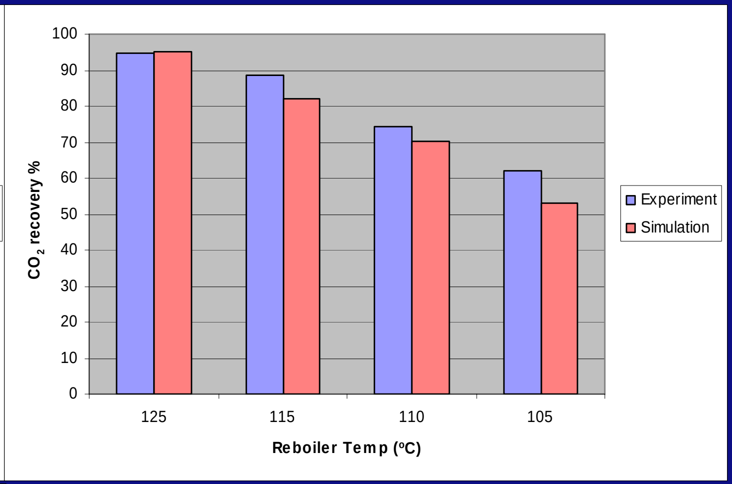


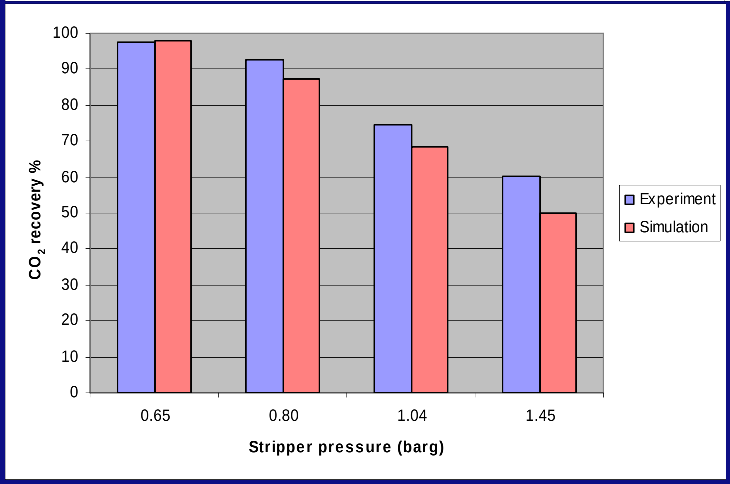




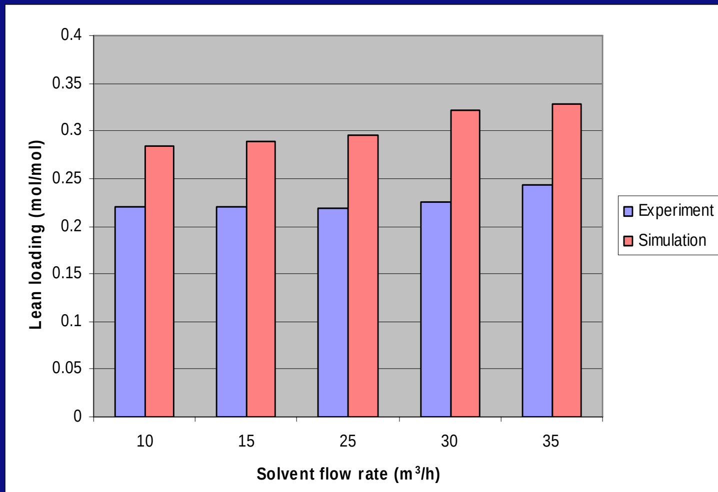
CO_2 Recovery %

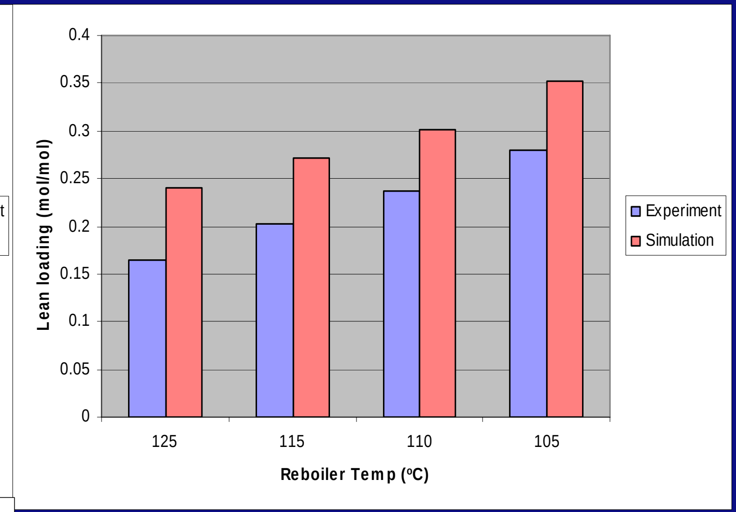


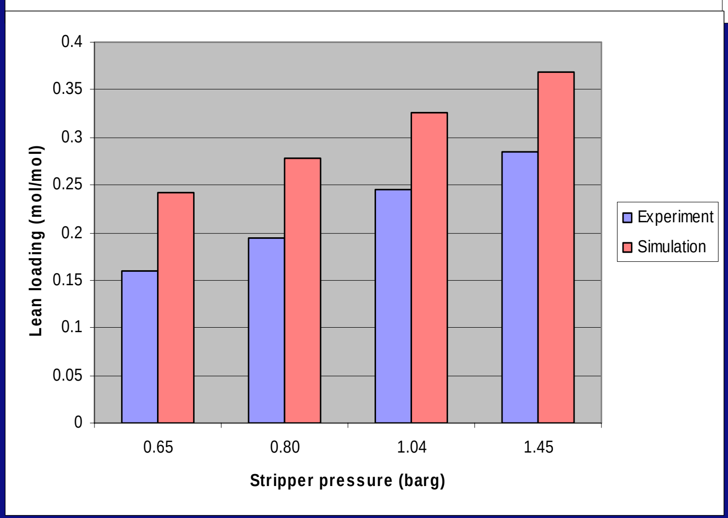




Lean solvent loading (mol CO_2/mol MEA)







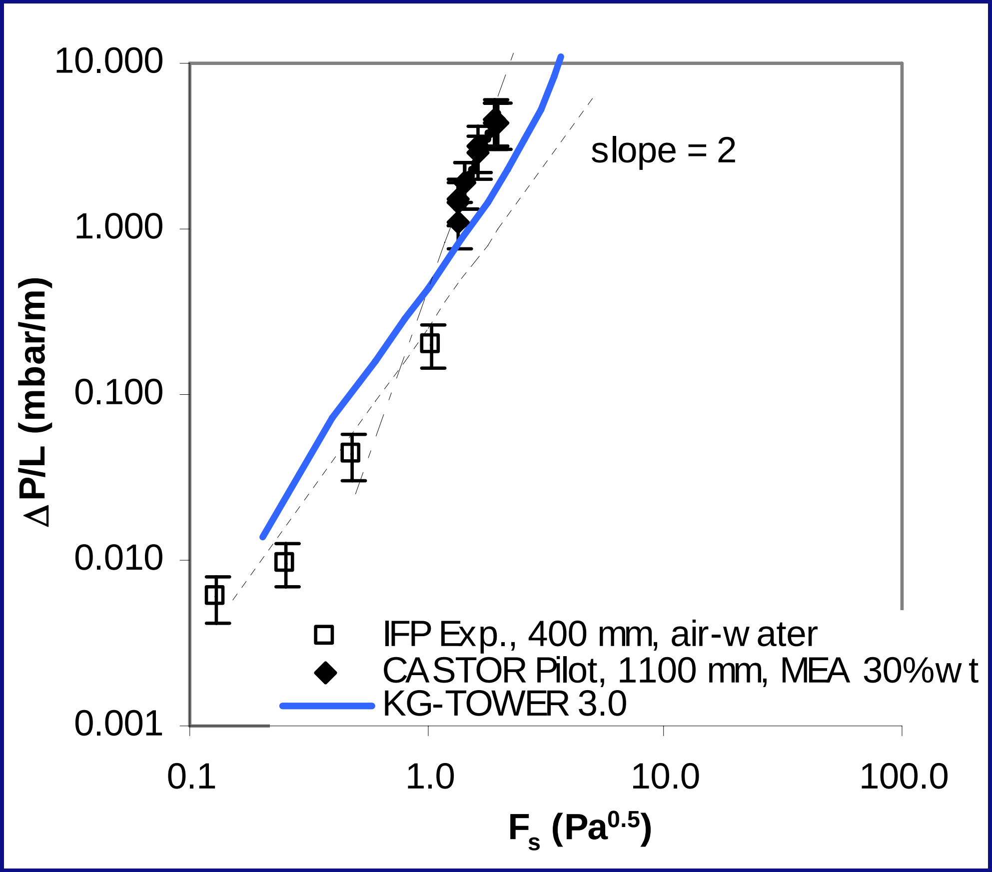
Results of Special interest experiments

SO_2-injection experiments and CO_2 quality

Point	Before SO_2 injection	1st SO_2 injection 0.68 kg/h	2nd SO_2 injection 1.19 kg/h	3d SO_2 injection 2.10 kg/h
Flue gas inlet [ppm]	**9.2**	**9.2**	**11.1**	**9.7**
Absorber inlet [ppm]	**9.2**	**56**	**101**	**185**
Absorber top [ppm]	**9.4**	**3.3**	**4.0**	**n.a.**
After absorber wash [ppm]	**n.a.**	**0.6**	**1.8**	**2.1**
Stripper product [ppm]	**1.6**	**4.0**	**2.4**	**2.1**

Results of Special interest experiments

Pressure drop measurements



Conclusions

- The operation of a MEA based CO_2 capture pilot plant was successfully demonstrated during a 1000 hr testing period.
- The average steam consumption for the operational conditions was equal to 4.4 GJ/ton CO_2 at 92.5% CO_2-recovery.
- Decreasing the solvent flow rate will lead to a lower reboiler duty (3.9 GJ/ton CO_2), but also a reduced CO_2-recovery.
- The effect of changing the reboiler temperature on the steam consumption at a constant solvent rate could not be distinguish from the present set of experiments. Similarly changing the desorption pressure did not have a clearly discernable effect on the steam consumption. In both experimental series the steam consumption was around 4.0 GJ/ton CO_2.
- SO_2, when present in the flue gas at levels between 55 and 185 ppm will be removed from the flue gas by approximately 99% by the CO_2-aborber and the water wash. It will predominantly accumulate in the solvent as sulphate and other sulphur compounds.
- The pressure drop measurements showed good agreement with results from mock-ups at zero wetting, but a higher than expected pressure drop with wetted packing. The experimental results furthermore revealed that the plant was designed for a low capacity factor.

Conclusions

- The corrosion monitoring experiments showed that AISI 316 stainless steel had low corrosion rates compared to AISI 1018 carbon steel. The corrosion rates of AISI 1018 carbon steel were unacceptably high at the lean solvent stripper outlet and, surprisingly, the lean solvent absorber inlet. Corrosion rates in the CO_2-product stream were higher than those in the flue gas as a consequence of the more acid nature and wet conditions.

- A major concern is the increase in the heat stable salt concentration and particularly the iron content of the solvent during the operation. The increase is accelerated by raising the reboiler temperature to 120 ^{o}C.

- Matching simulation data with experimental data is difficult, because plant was not always in equilibrium conditions.

- In general a lower reboiler duty, lower CO_2 recovery % and higher lean loading was found from the simulation results comparing to the experimental data.

Acknowledgments

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Thank You