



Value creation
through **innovation**

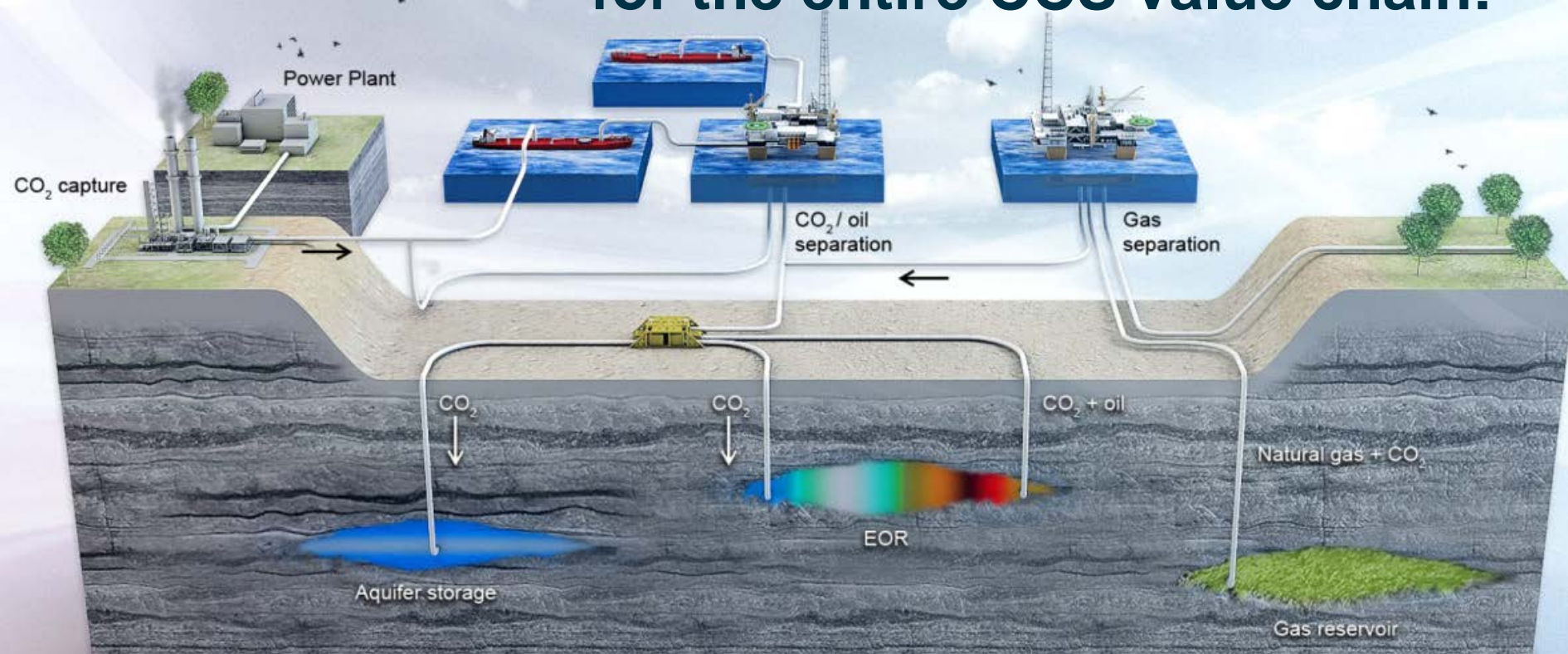


Results and Future Perspective of Aker Solutions' Amine project

Norcem CO₂ Capture Project, Langesund 20th of May 2015

Jacob N. Knudsen, Project Manager

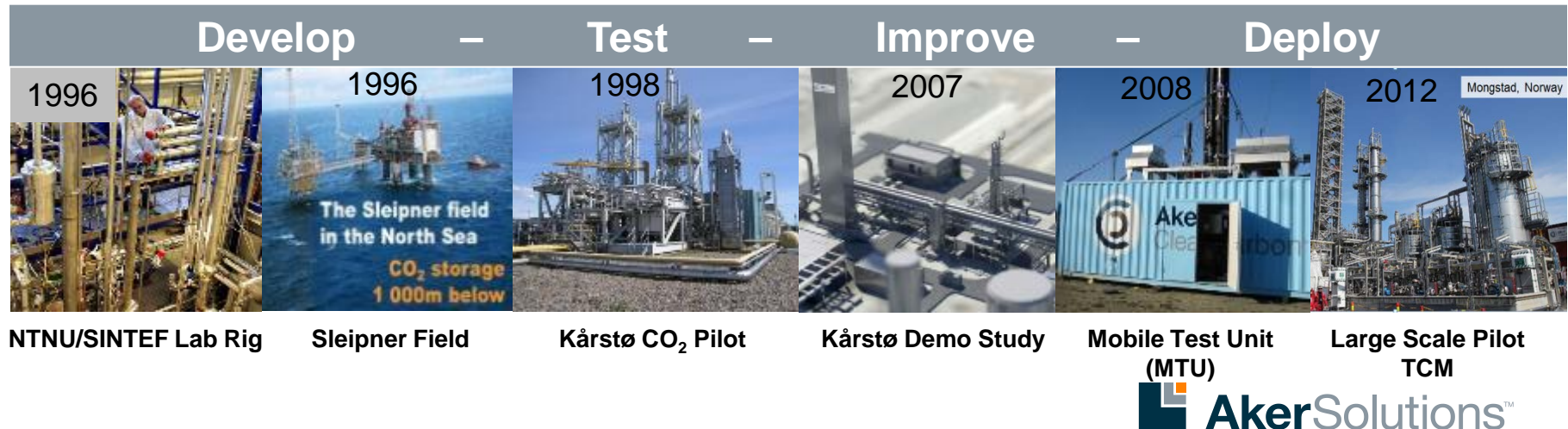
We offer technology and solutions for the entire CCS value chain:



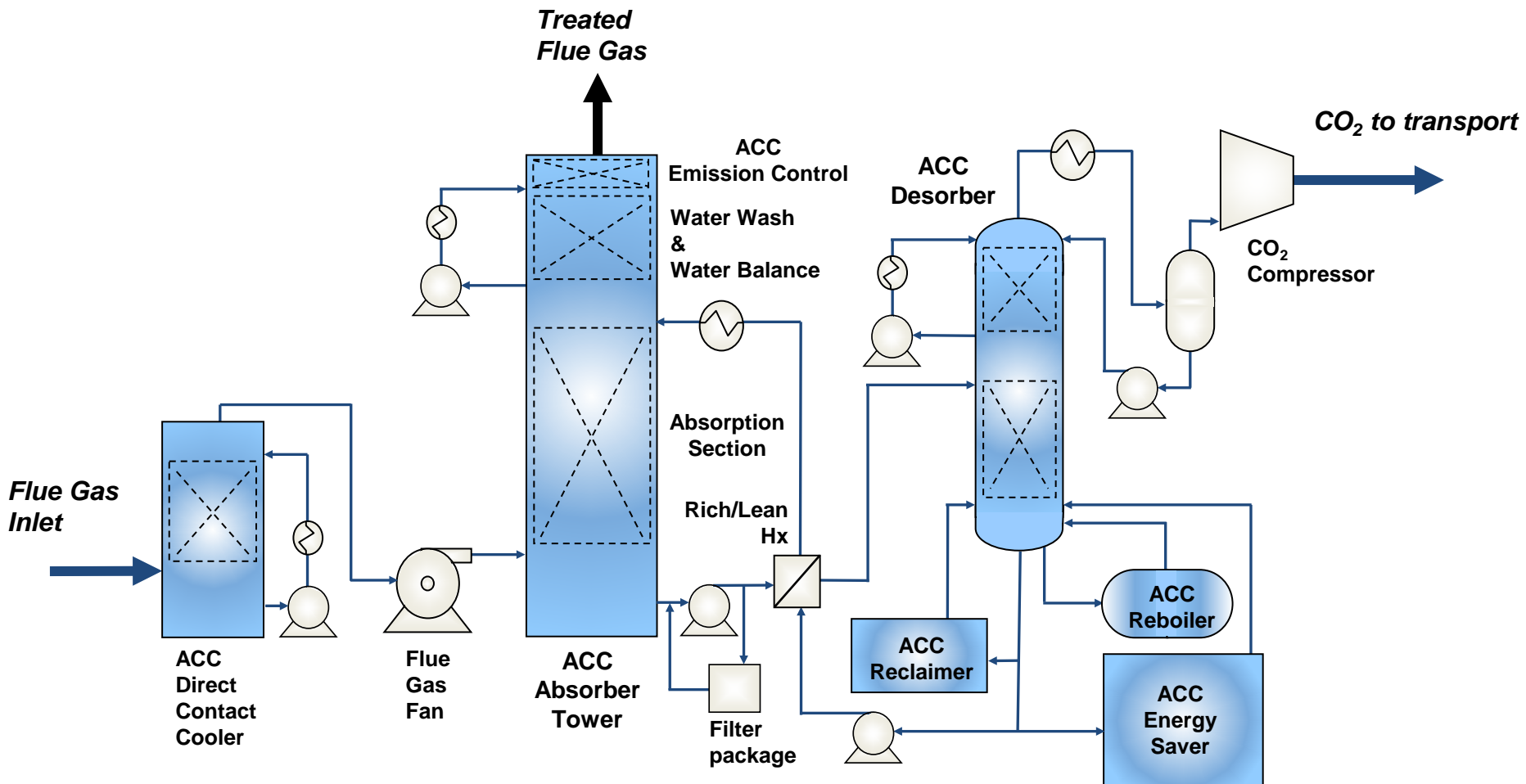
- Carbon capture technology
- CO₂ transport solutions
- CO₂ injection templates (subsea)
- CO₂ storage evaluations
- EOR evaluations
- CO₂ separation from natural gas
- Equipment delivery

Development of Aker Solutions' ACC™ process

- Aker Solutions' Advanced Carbon Capture™ (ACC™) process has been developed based on 20 years design and operating experience with amine technology
- Several novel amine solvents have been developed through Aker Solutions' SOLVit R&D program
- Substantial field testing with the Mobile Test Unit (MTU) since 2008 at various coal and natural gas fired power plants
- Scale-up and validation of technology demonstrated through design, delivery and operation of the amine plant at Technology Centre Mongstad (TCM)



Generic flow sheet of Aker Solutions ACC™ process

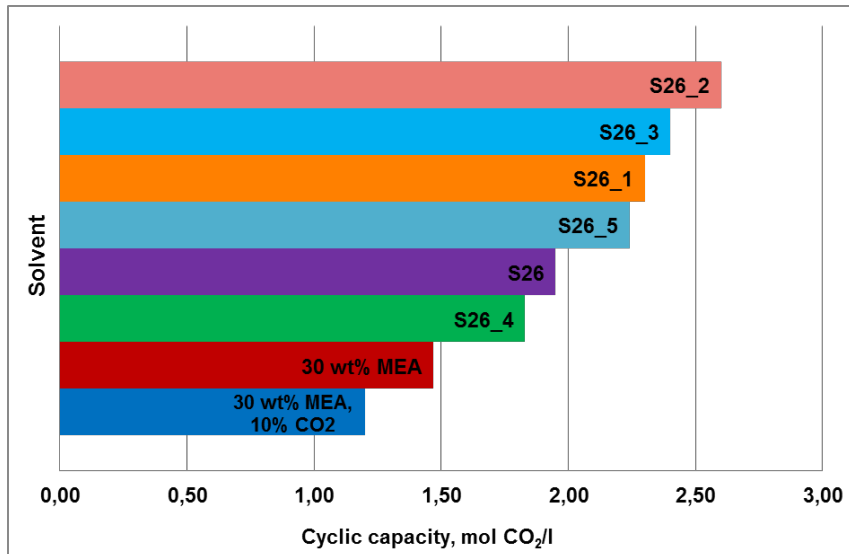


Objectives and scope of Aker Solutions' test program at Norcem Brevik

- Project scope:
 - Install Aker Solutions' Mobile Test Unit (MTU) at the Brevik plant and operate it for six months on flue gas from the cement kiln
 - Conduct a feasibility study for a "full-scale" CO₂ capture plant at Norcem Brevik using performance and design parameters established in the MTU Test Campaign
- Objectives test campaign:
 - To demonstrate the feasibility of the Aker Solutions' ACC™ process on cement kiln flue gas with a solvent customised for cement plants
 - To establish process performance at realistic operating conditions to enable scale up to full-scale application
 - Confirm key operating data: Energy requirement, Amine degradation and Emissions
- Project duration: June 2013 (Kick-off) to Jan 2015 (final report)

Solvent selection and optimisation for cement flue gas

- Aker Solutions S26 solvent was selected for the MTU test campaign because of its good efficiency, high stability and good HSE properties
- In collaboration with SINTEF, tests were conducted to optimise S26 for the high CO₂ content (20%) of cement flue gas
- Performance of selected solvent tested in Tiller R&D pilot plant



Results from screening of different S26 blends for CO₂ carrying capacity



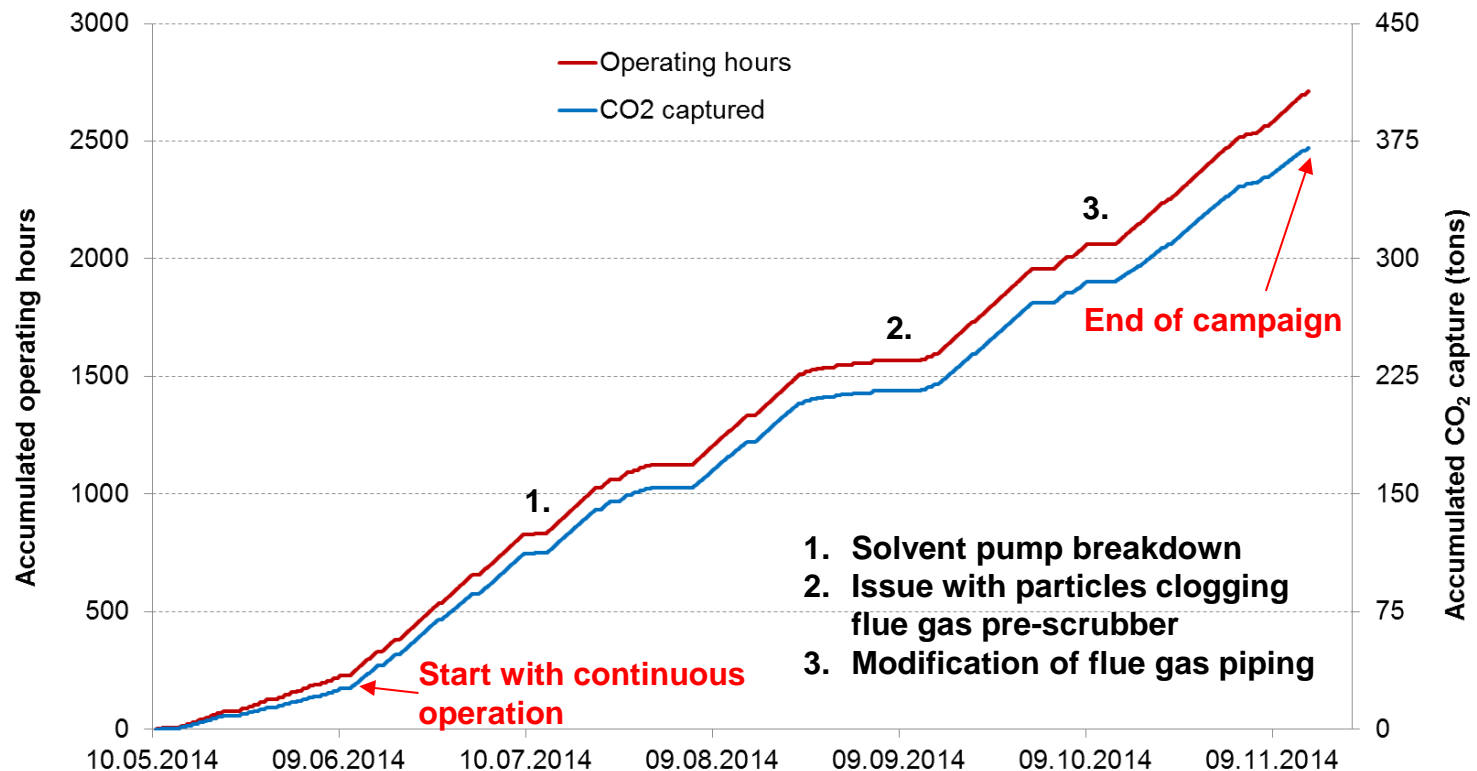
Installation of Mobile Test Unit at Norcem Brevik

- The MTU is build to be representative of the full-scale Aker Solutions' ACC™ process, which allows for long term solvent testing on real flue gases in an industrial environment.
- MTU installed and hooked-up to infrastructure prepared by Norcem during April 2014
- Few modifications installed to improve process and allow for operation on flue gas with high CO₂ content
- Started operation on flue gas from kiln no. 6 in Brevik on 10th of May 2014



Overview MTU test campaign

- Six months test campaign: 12.05.2014 to 14.11.2014
- Approx. 2700 operating hours (with CO₂ capture) & 370 tons of CO₂ capture achieved
- Some downtime due to MTU mechanical failures (solvent pump, gas analyzer), Norcem production outages and flue gas supply to MTU



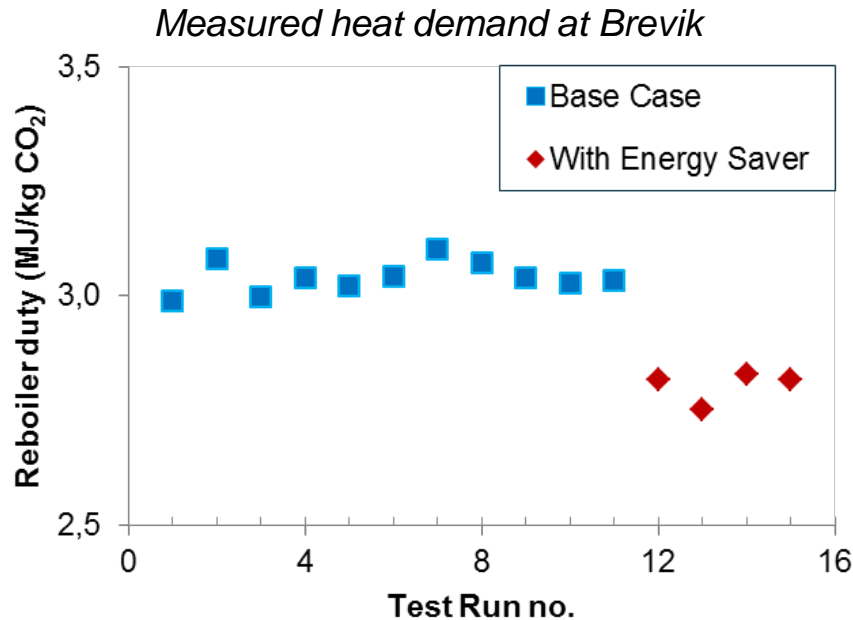
General performance results

- Stable operation on flue gas from cement kiln demonstrated. No operating problems related to the nature of the flue gas
- Test runs conducted to optimise operating conditions and provide information for design and scale-up
- Easy to obtain 90% CO₂ capture due to high CO₂ content in flue gas (17-20%) => compact absorber
- Capture plant handles well changes to the type of clinker that is being produced at the Brevik plant i.e. changes in flue gas composition
- No negative influence of capture plant performance observed due to presence of trace level pollutants from the cement kiln
- High quality CO₂ is produced with <50 ppm inerts => CO₂ fulfill specifications for transport, EOR and storage



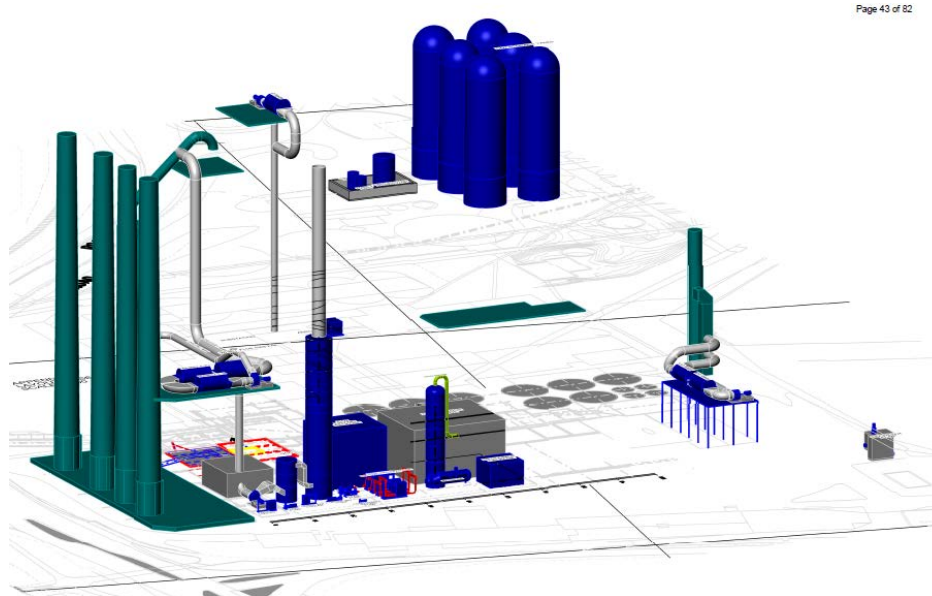
Validation of heat demand of CO₂ capture process

- The heat demand of Aker Solutions' advanced amine process has been validated in the MTU campaign. The heat demand is very dependent on process design and heat integration:
 - Energy demand determined to ~3.0 MJ/kg CO₂ @ 90% CO₂ capture for basic process without heat integration
 - With ACC™ Energy Saver: ~2.7 MJ/kg CO₂
 - With waste heat utilization from CO₂ compression: ~2.0 MJ/kg CO₂
 - With waste heat utilization from cement plant: 0 MJ/kg CO₂



Energy consumption – Implications for a cement plant

- The feasibility study indicates that approx. 400.000 tons/year of CO₂ can be captured from the Brevik plant (nearly 50% of annual emissions) with use of waste heat only
- Concept also developed for capture of up to 85% of annual emissions (715.000 tons) with waste heat only, but this requires more extensive (and costly) heat integration
- => Only electricity is required to drive the CO₂ capture and conditioning process. 80% of total consumption is used for CO₂ compression and drying

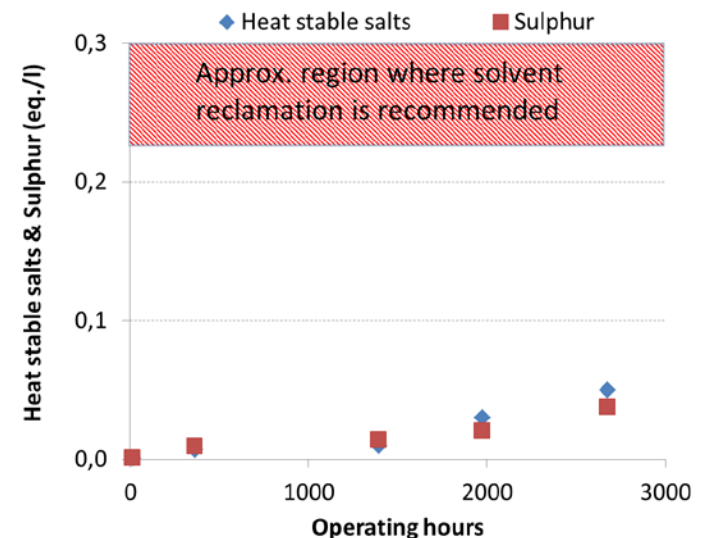
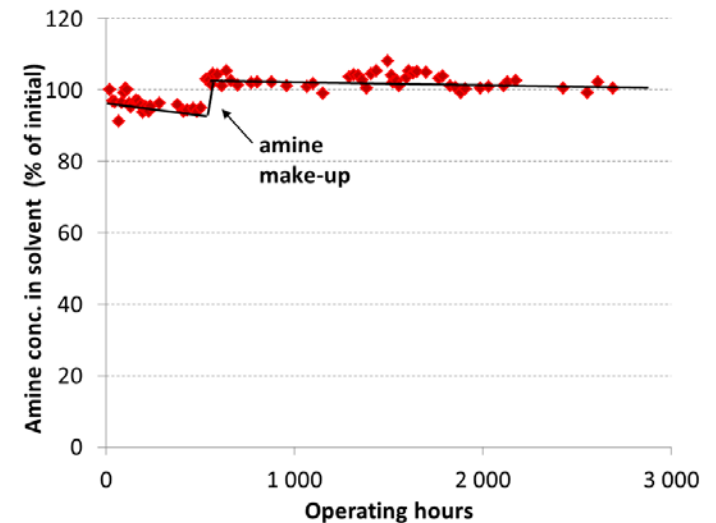


3D model of CO₂ capture plant and liquefaction plant installed at Norcem Brevik

Solvent stability and degradation

The ACC™ S26 solvent shows excellent stability towards cement flue gas:

- Amine consumption as low as 0.15 kg/ton CO₂ for the entire campaign
- Low build-up of degradation products i.e. heat stable salts
- Heat stable salts formation mainly due to slip of SO₂ through pre-scrubber
- Reclaiming campaign omitted because of low degradation rate of solvent
- Low formation of nitrosamines in S26 solvent (<0.2 mmol) despite high NOx content of flue gas
- Low build-up of metal ions e.g. iron, in solvent => low corrosiveness of S26



Emissions and environmental aspects

- The MTU is fitted with ACC™ Anti-Mist technology that ensures low emission of solvent amines
- Emissions from MTU in Brevik have been documented to be low in two manual emission measurement campaigns. Main findings:
 - Amine emission: 0.3-0.5 mg/Nm³
 - Ammonia emission: 3-4 mg/Nm³
 - Nitrosamines: <0.3 µg/Nm³ (similar level as observed with S26 on NG flue gas)
 - Nitramines: <0.1 µg/Nm³
- Amines used in S26 solvent are non-toxic, easy biodegradable and do not form nitrosamines
- Because of the low degradation rate of S26 solvent also secondary formation of nitrosamines from degradation products is minuscule
- Except from reclaimer waste, no liquid waste or waste water is produced from the CO₂ capture and conditioning plant

Further testing and studies at Norcem

- Norcem and Aker Solutions decided in Autumn 2014 to continue the MTU test campaign in Brevik until September 2015 to gain more information on long-term operation:
 - Almost one year of operation at Brevik and approx. 5500 operating hours have been achieved till date
 - Operation continues to be stable and trouble-free on cement flue gas
 - No significant changes in process and solvent performance
 - Amine consumption and degradation continue to be low
 - No reclaiming of solvent has been required up till now
- In addition, Aker Solutions is currently working on a conceptual study for a large-scale CO₂ capture plant at Norcem Brevik



Summary

The test campaign and feasibility study at Norcem Brevik has demonstrated that Aker Solutions' ACC™ process is mature and very suitable for CO₂ capture from cement plants:

- Capture plant has minimal impact on existing clinker production line
- Robust to load and production changes at the cement plant
- Energy efficient and capable of utilizing low grade waste heat from cement plant:
 - At Norcem Brevik this implies capture of approx. 400.000 tons/year CO₂ without need of additional thermal energy
- Compact and efficient CO₂ absorption train (due to high driving forces) compared to that of gas and coal-fired power plants
- Good HSE performance of S26 solvent: low emissions, low consumption of amines, low waste production and low toxicity of amines and degradation products
- Scale-up of Aker Solutions' ACC™ process and qualification of the S26 solvent demonstrated at Technology Centre Mongstad

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