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Demonstration of highest capture rates for deep removal - Pilot plant test with CO_2 capture rates from 98% to >99.9% with an AMP/PZ-based solvent

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Abstract

In the Clean Energy Transition Partnership project DRIVE (Deep Removal of CO_2 and InnoVative Electrification concepts), for the first time a holistic evaluation of deep removal technologies is carried out, comprising technical, economic, and environmental analysis and validation in long-time tests at real industrial conditions. At the CO_2 capture pilot plant at Niederaussem, Germany the key performance data of amine-based CO_2 capture with highest capture rates from 98 to >99% are assessed in extended testing campaigns (24/7) with the CESAR1 solvent, an aqueous solution of 3.0 M 2-amino-2-methylpropan-1-ol (AMP) and 1.5 M piperazine (PZ), after 6,500 h operation without exchange of the solvent inventory and without reclaiming. Systematic parameter studies and tests of different process configurations are carried out to validate process models for highest capture rates on the effect of solvent flow, desorption temperature, intercooler positioning, and the level of the solvent feed-in into the absorber column (3 or 4 active beds of structured packing). The performance analysis also comprises a careful monitoring of the emissions of AMP, PZ, NH_3, and acetaldehyde by FTIR spectroscopy depending on the activated emission mitigation technologies (water wash, double water wash, dry bed (OASE aerozone™), acid wash, two flue gas pre-treatment technologies, and wet electric precipitator (WESP)). Additionally, organic degradation products, metals and accumulated inorganic trace compounds are analyzed.

Keywords: AMP, PZ, piperazine, CESAR1, capture rate, deep removal, emission mitigation, solvent degradation, pilot plant

Capturing CO_2 from industrial point sources is key for achieving the global climate ambitions (net zero by 2050) and the amine-based absorption technology is the most mature technological option for this, with several commercial plants in operation and under construction. Since the minimal specific energy consumption of the amine-based processes - and therefore also the minimal CO_2 avoidance costs - are achieved at CO_2 capture rates between 85-95% [1-3] it is sometimes overlooked that no general technical limits exist to significantly elevate the capture rate which means a huge potential to minimise the need for the offset of residual emissions by carbon dioxide removal (CDR) technologies, such as direct air capture, that have a high cost (DAC costs are currently around 600 €/tCO_2 [4]) and a high specific energy consumption due to the low CO_2 partial pressure in air. However, applying of deep CO_2 removal from industrial flue gases towards CO_2-neutral and even CO_2-negative operations has not yet been thoroughly realised in open pilot studies and representative long-time tests.

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A recent theoretical study carried out by the Electric Power Research Institute (EPRI, USA) indicates that achieving capture rates as high as 99,95% would be feasible using 30 wt% monoethanolamine (MEA) [5]. For a coal-fired power plant, it was estimated that the capture cost increases from $46.1 to $51.3 per ton CO_2 when increasing the capture rate from 90% to 99.95% (carbon-negative). This cost increase relates both to increased CAPEX (on average a 30% increase on equipment costs, and an 80% increase in absorber cost) and OPEX (11% higher, with attention to the increased thermal reboiler duty from 3.79 to 4.07 GJ/tCO_2).

Another theoretical study investigated high CO_2 capture rates using a 95-99% CO_2 capture model for a plant with 35wt% MEA at a CCGT plant and reported that a high capture rate of 99% can be achieved at 7.7% increased energy penalties (from 3.50 to 3.77 GJ/tCO_2) as compared to 95% capture if the packing height of the absorber is sufficient (24m) and at elevated desorber temperature (130°C) [6]. It was concluded that the operating costs of capture rates higher than 95% might be attractive if DAC is the alternative. The same study also pointed out that, with a plant designed for 95% capture rate, it is still possible to operate at 99% capture rate, but in that case the energy penalty increased by 12% [10].

At the National Carbon Capture Center (NCCC), demonstration of capture rates up to 99.1% was achieved with 5 m PZ (piperazine) and 12 m of packing in the absorber [7]. Only very short tests have been carried out using MHI's proprietary KM CDR ProcessTM based on the KS-21TM solvent at Kansai Electric Power Co., Inc.'s Nanko Power Station pilot system and at the Technology Centre Mongstad (TCM) in Norway in a range of the capture rate from 90% to 99.5%. However, presented data and conclusions are mainly predictions by an in-house simulator [8]. No information was published about amine emissions, solvent consumption due to changes in degradation rates and other possible operational issues (like foaming or disturbance of the water balance).

The only concrete data from tests at pilot plants (Niederaussem, TCM) with real flue gas and with CESAR1 have been published by the ALIGN-CCUS project, but are also limited to capture rates of <98% [9-11]. Also, very important in this context is the fact that the models used for evaluating the techno-economic feasibility of the deep removal operation regime have not yet been validated with real plant data. An accurate and comprehensive benchmarking exercise is key to establish the importance of point-source deep removal in achieving net zero emissions. This exercise is conducted in the DRIVE project based on testing campaigns (in total 14 months) with the CESAR1 solvent at Niederaussem and at capture rates between 98 and >99%. Flue gas source is a lignite-fired power plant and the capture plant capacity is 300 kg CO_2/h at 90% capture rate. To investigate the process and operational performance at the negative CO_2 emission regime (CO_2 concentration in the treated flue gas < 400 ppmv CO_2) an IR CO_2 analyser with the necessary accuracy was installed (0-3000 ppmv; detection limit 1%, linearity deviation +/-15 ppmv). Results from the systematic operational parameter tests are presented, which comprised variation of the liquid-to-gas ratio, the intercooling position, the lean loading (temperature in the desorber), and the active packing height and are compared with the results from optimised models. Also, the effect of highest capture rates on the emissions of the capture plant and the solvent degradation will be discussed.

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