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Comparison of carbon capture technologies for steel and cement off-gases

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The defossilisation of hard-to-abate industries such as steel and cement is a major challenge for achieving climate-neutrality in 2050. In these sectors, some CO2 emissions are unavoidable due to chemical reactions during raw material processing (e.g., limestone calcination) and the use of carbon in steel production. Therefore, efficient and scalable carbon capture technologies are essential to capture and reduce emissions, enable carbon utilisation, and support the transition toward sustainable industrial practices. Within this context, the Austrian flagship project ZEUS –Zero Emissions throUgh Sector Coupling aims to demonstrate integrated, climate-neutral process chains by combining renewable hydrogen production with CO2 capture and utilisation under real industrial conditions. The project addresses the steel and cement industries, which are among the most difficult to bring to climate neutrality, and evaluates practical solutions for cross-sector integration and energy optimisation.

This work presents a comparative assessment of two pilot-scale carbon capture units and technologies treating industrial off-gases with varying CO2 concentrations ranging from 15 to 25 vol.%:

1) an amine scrubber operated with steel mill off-gases, and

2) two membrane separation units, one treating steel mill off-gases and one treating cement plant off-gases.

The amine scrubber demonstrates a CO2 capture rate of approximately 800 kg/day with product purity exceeding 99%, while optimisation efforts focus on minimising energy consumption and maintaining long-term solvent stability under fluctuating flue gas compositions. The membrane units, designed for up to 500 kg/day CO2 separation, employ modular membrane elements to enable flexible operation and high capture efficiency (>90%) at food-grade CO2 quality. Continuous pilot operation under real flue gas conditions provides detailed insights into membrane durability, process dynamics, and energy efficiency.

In parallel, process simulation models of both pilot plants are developed using gPROMS (General PROcess Modeling System). These models are calibrated with experimental data and allow a systematic evaluation of performance metrics, including specific energy demand, separation efficiency, and product quality. Simulation results are further used to explore optimal operating strategies and to assess opportunities for integrating the two technologies into broader industrial process chains.

The combined experimental and modelling results illustrate the strengths and limitations of amine scrubbing and membrane separation for steel and cement applications. By providing quantitative insights into process behaviour, energy requirements, and operational flexibility, this work informs technology selection and contributes to the ZEUS objective of demonstrating integrated CO2 capture and utilisation technologies across industrial sectors.

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