Bipolar Membrane Electrodialysis for Direct Air Capture applications

Scaling up an electrodialysis system for carbon removal from TRL 3-4 to TRL 5-6 focuses on bubble formation, membrane-solvent compatibility, and simulating future cell designs.

THE CONTEXT

Ucaneo Biotech GmbH develops pioneering biomimetic direct air capture technology, featuring an electrochemical direct air capture (e-dac) system powered by renewable energy. Their cutting-edge approach combines bio/catalytic solvents with electrochemistry and proprietary components like solvent and cell stacks. The fully electrical, modular technology operates without (waste) heat and can be paired with renewable energy.

While electrodialysis for carbon removal is novel with limited industrial-scale knowledge, Ucaneo's benchtop tests show promising energy efficiency. An external study predicts energy use could drop to 1000 kWh/t at scale. This project aims to reduce scale-up risks and optimize processes through empirical data and simulations.

This project provides qualitative data to minimise scale up risks and provides insights into process optimization possibilities at large scale regarding membrane compatibility and process performance both empirically validated and through simulation.

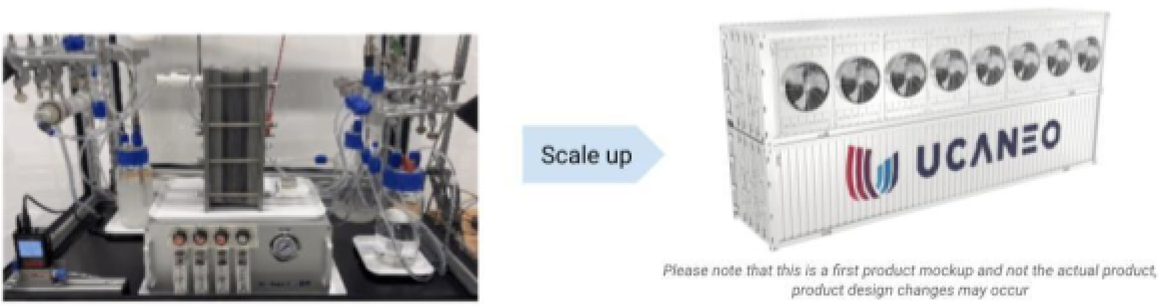

Fig 1: Demonstrating the scale up dimension from bench top to industrial size to deploy the new process in the application of carbon removal.

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THE CHALLENGE

The main objective of the project is to create a standardised membrane stress testing protocol for bipolar membranes and an empirically validated simulation to predict scaled process performance of the ED stack.

The challenge is unknown membrane material composition from different bipolar membrane suppliers together with novel solvent additives which makes chemical interactions almost not predictable. On top, is carbon removal not a standard application for bipolar membranes in industry yet, which poses additional / other operating conditions and challenges for the membranes.

As the process is focused on concentrating and releasing CO2, a higher gas evolution within the solvent and with that higher degree of bubble formation is expected, local phenomena and resistance profiles gained through simulation can help to understand and optimise the process performance of the ED stack better.

THE RESULTS

Six commercial bipolar membranes from different suppliers were tested, both with and without additives. A two-chamber cell with separate electrolyte cycles was used. Stress tests involved base on the anode side and acid on the cathode side. A standardized protocol was developed, heating the electrolyte to 60°C. Testing starts with a "begin of life" (BoL) procedure, where a polarization curve between 0-50 mA/cm² is recorded. A 5-hour stress test at 300 mA/cm² follows, with voltage and pH monitored. Afterward, fresh electrolytes are used, repeating the process for the "end of life" (EoL).

Simulation to assess process efficiency and resistances within the ED stack

Empiric validation of the simulation regarding process efficiencies, current density limitations and bubble formation at small and larger stack sizes.

CONCLUSION

A suitable membrane for scale up has been identified. The standardised testing protocol was developed and showed significant performance difference between different bipolar membrane suppliers.

The simulation showed no limitation in conductivity depletion within the process when compared to empiric process performance at small scale.

CO2 bubble formation within the solvent does not pose a risk for scaling up, however current density limitation showed larger impact than expected. Further investigation is required to follow up on the unexpected current density limitation which is likely due to the process itself, but was out of scope of this project.

TECHNIQUES USED

Titration

DLS

SEM

COMSOL & MATLAB simulation

Use of transparent ED stack

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