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Electrochemical CO_2 Capture: Demonstration of new technology at industrial sites across Europe

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Introduction

Post-combustion CO_2 capture (PCCC) is a vital technology for reducing carbon emissions. The most commonly adapted technology is amine-based solvent capture. However, this method presents challenges such as high energy consumption, solvent degradation, corrosion, and emissions. In contrast, inorganic solvents like potassium hydroxide (KOH) remain underexplored for PCCC. Since KOH does not react with oxygen, it eliminates the issue of oxidative degradation—a major concern in amine-based systems. Additionally, electrochemical regeneration of KOH has demonstrated energy consumption levels comparable to amine-based methods (Shi et al., 2024; Vallejo Castaño et al., 2024).

This study presents a pilot-scale demonstration of CO_2 capture using a KOH-based solvent, coupled with electrochemical regeneration. The pilot demonstrations were conducted at two industrial sites: OMV Petrom in Romania and Grecian Magnesite in Greece.

Demonstration Unit

The demonstration unit comprises three main modules: capture, regeneration, and utilization. It has a CO_2 capture capacity of 100 kg/h.

- **Capture Module:** This module includes a pre-scrubber, an absorber, and a wash column. The pre-scrubber conditions the flue gas by removing SO_x and NO_x before it enters the absorber. Inside the absorber, the gas interacts with a 1 molal KOH solution, forming potassium carbonate (K_2CO_3) and potassium bicarbonate ($KHCO_3$). The CO_2-rich solvent is then directed to the regeneration module (see Figure 2).

- **Regeneration Module:** This module consists of two electrochemical stacks, each containing 126 cell pairs. It is a scaled-up version of a lab setup, details of which are available in a previous publication (Shi et al., 2024; Vallejo Castaño et al., 2024).
- **Process Overview:** A simplified process flow diagram of the absorption column and the electrochemical stack is shown in Figure 1.

This pilot-scale demonstration highlights the potential of KOH as an alternative solvent for PCCC, offering a promising route for more efficient and sustainable carbon capture.

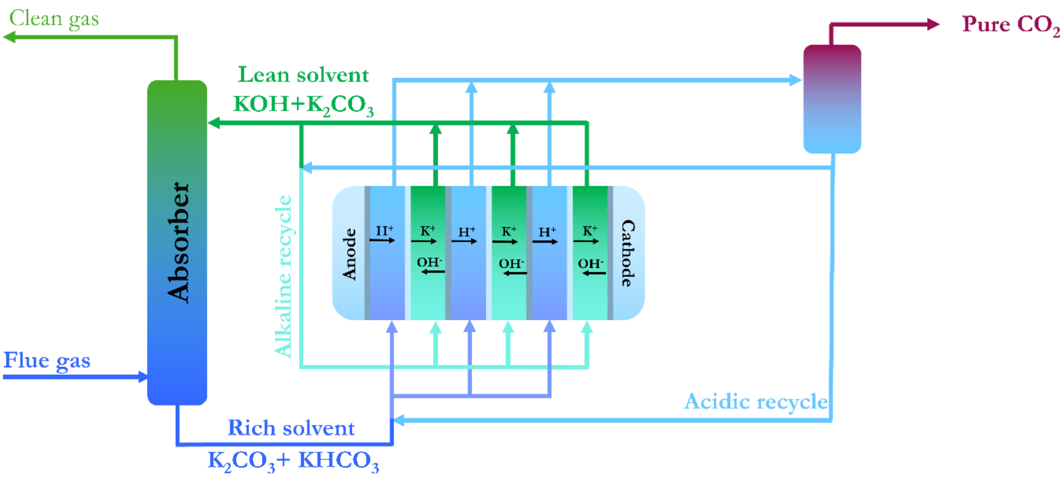

Figure 1: Simplified process flow diagram of the capture and electrochemical regeneration of CO_2

Demonstration sites

The demonstration of this novel technology took place at three industrial sites under varying flue gas conditions. It was tested at the Aalborg Portland cement facility in Denmark from December 2023 to May 2024, at the OMV Petrom refinery in Romania from June 2024 to November 2024, and at Grecian Magnesite from January 2025 to June 2025. Each site presented distinct CO_2 concentrations, saturation temperatures, and impurity levels, including SO_x and NO_x. These variations ensured the technology's robustness and provided valuable insights into stack design, enhancing overall system performance and adaptability.

Figure 2: Demonstration unit at Aalborg Portland (left) and Grecian Magnesite (right)

Table 1 provides the composition of the flue gas at the three different locations highlighting the variability of the concentration of CO_2 and impurities present.

Table 1: Composition of flue gas at the three test sites

Parameter	Aalborg Portland	OMVPET	Grecian Magnesite
Temperature (ºC)	122	170	150-200
CO_2 (vol%)	20.9	3.5	15
O_2 (vol%)	6.9	14.5	7-15
H_2O (vol%)	35	6.5	6-13
SO_2 (mg/Nm^3)	0.29	22	1500
NO_X (mg/Nm^3)	253	95	700-1500
Particles/dust (mg/Nm^3)	11.2	1.7	-

Experimental Campaigns and Results

Experimental campaigns were designed to assess the pilot's performance under varying operating conditions, including current density, load ratio, L/G values, and CO_2 concentration. These tests have provided critical insights into the system's efficiency and ensured its reliability across different ambient and flue gas conditions.

Since this technology has rarely been demonstrated at scale, its pilot implementation across multiple industrial sites has offered valuable knowledge about its performance and potential challenges for full-scale deployment.

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