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MCFC AS ELECTROCHEMICAL DEVICES FOR CO₂ CAPTURE AND PRODUCTION OF SYNTHETIC FUELS

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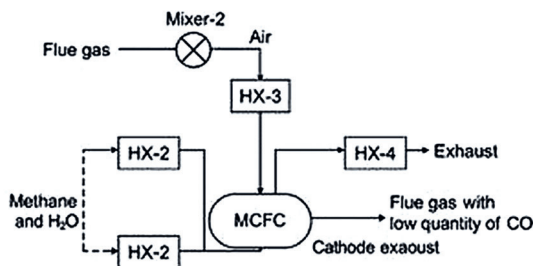
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Abstract – Molten Carbonate Fuel Cells (MCFCs) enable simultaneous electrochemical CO₂ capture and power generation by selectively extracting CO₂ from flue gases at high temperature. This study analyses the integration of an MCFC downstream of a coal-fired power plant, treating the system as both a decarbonization unit and a CO₂ concentration platform for synthetic fuel production. System-level modelling shows that MCFC integration can reduce net CO₂ emissions by up to 56 % (288 kg CO₂/MWh) while increasing total electrical power output, demonstrating the potential of MCFCs as a bridging technology between carbon capture and Power-to-Fuels systems.

Separating CO₂ from flue gases using a molten carbonate fuel cell

The Molten Carbonate Fuel Cell (MCFC) can simultaneously capture CO₂ from flue gas and increase total power generation due to its high electrical efficiency. In the analysed system, MCFC operation is optimized with respect to power generation efficiency while enabling electrochemical CO₂ separation. Fuel cell efficiency is defined on a higher heating value basis. Because coal-fired flue gas contains insufficient oxygen, additional air is supplied to achieve a CO₂/O₂ molar ratio of approximately 2.0. The system configuration, shown in figure, integrates the MCFC stack with four heat exchangers to recover heat from fuel, steam, and flue gas streams. Optimization variables include fuel flow rate, current density, heat exchanger effectiveness, and air addition, subject to constraints on maximum stack temperature (650 °C), positive cell voltage, and a minimum steam-to-carbon ratio of 1.4. CO₂ removal is quantified based on the reduction of CO₂ mass flow at the cathode. The results show that the MCFC produces 2.7–3.2 kW per Nm³·s⁻¹ of flue gas, increases total plant power output by about 50%, and achieves fuel cell efficiencies of 37–41 %. Depending on the optimization target, CO₂ emission reduction reaches up to 70 %, confirming the suitability of MCFC technology for efficient CO₂ capture in existing fossil-fuel-based power plants.

Keywords – *Carbon capture and utilization (CCU); coal-fired power plant decarbonization; electrochemical CO₂ capture; flue gas decarbonization; high-temperature electrochemical systems; integrated energy systems; Molten Carbonate Fuel Cells (MCFC); Power-to-Fuels; CO₂ separation; synthetic fuel production*



Schematic diagram of the MCFC-based system integrating four heat exchangers (HX-1 to HX-4), a flue gas-air mixer (Mixer-2), and the MCFC stack. Flows of fuel, steam and flue gas are highlighted to illustrate process integration and heat recovery