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Advanced Oxygen Carrier Materials for Clean H_2 Production and CO_2 Seperation in Chemical Looping Processes

ABSTRACT

The evolution of Chemical Looping (CL) technology has shifted from mere combustion to selective value-added production, specifically Chemical Looping Hydrogen Production (CLHP) and CO_2 capture, enabling the utilization and upcycling of various synthesis gases with reducing effects on metal oxides. This positions CL as a pivotal technology for decarbonization, Power-to-X strategies, and the integration of fluctuating renewable energies. In this framework, the solid Oxygen Carrier (OC) functions as both a transfer medium and thermochemical storage, facilitating the direct splitting of steam or carbon dioxide to generate pure hydrogen and carbon monoxide through cyclic redox reactions. While standard materials like Nickel or Copper fail due to unfavourable equilibria or thermal instability, iron oxides represent a robust industrial choice for CL applications given their cost efficiency and ability to undergo complete reoxidation by H_2O. However, natural ores succumb to extreme cyclic loads, necessitating synthetic iron oxide composites to withstand specific degradation mechanisms. These include mechanical attrition driven by significant volume changes during phase transitions, thermal sintering above 850 °C which irreversibly reduces porosity and gas diffusion, and iron migration causing particle agglomeration and defluidization. To counter these degradation pathways, active iron is embedded into chemically stable support matrices such as Al_2O_3 or ZrO_2 via methods like co-precipitation. This approach optimizes crystallite size and pore structure to absorb volumetric stress and prevent sintering. Nevertheless, challenges persist, notably the irreversible formation of inactive spinels. Consequently, advanced research focuses on catalytic doping with rare earth oxides or utilizing perovskites to enhance oxygen mobility. Ultimately, the technical realization of clean hydrogen production relies on developing synthetic iron-based composites that retain microstructural integrity and kinetic performance over thousands of severe thermochemical cycles.

BIOGRAPHY

Julien Göthel is a Metallurgy Engineer (Dipl.-Ing.) and doctoral candidate at the Institute of Iron and Steel Technology at TU Bergakademie Freiberg (Germany). His work focuses on pyro-, hydro-, and process metallurgy, specifically advancing closed-loop and low-impact circular economy solutions. As Head of Process Design in System Integration at Rouge H2 Engineering AG, he leads the engineering of integrated systems and directs supporting scientific research.

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