Review of Fuel Cell Technologies with CO₂ Capture

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Abstract

In recent years the increase of power generation efficiency and the deployment of Carbon Capture and Storage (CCS) have been considered of high importance in order to meet the targets agreed at COP 21. Currently, the most advanced CO₂ capture technologies for application to large scale power plants are post-, pre- and oxyfuel combustion. However, the main drawback of the three technologies is the energy penalty and consequent power generation efficiency reduction, which leads to a high ‘Levelised Cost of Electricity’ (LCOE). As a result, novel energy systems which promise high efficiency and low CO₂ emissions, such as fuel cell hybrid power cycles with CO₂ capture, merit research, development and detailed analysis of their potential economics.

The concept of using Fuel Cells (FCs) within large scale power generation cycles for CO₂ capture has been studied over the last decade [1, 2]. Two types of FCs, Solid Oxide Fuel Cells (SOFCs) and Molten Carbonate Fuel Cells (MCFCs) have emerged as promising CO₂ capture systems, with the added advantage of additional power production. SOFCs are considered among the most promising fuel-to-electricity conversion units, while they also allow for an easy integration with CCS by using either pre-anode or post-anode CO₂ capture configurations. For the first option, a pre-anode syngas clean-up stage is required resulting in a H₂-rich fuel fed into the fuel cell, whereas the second option operates in a similar manner to the oxyfuel combustion concept, aimed at removing the CO₂ after the partial fuel oxidation in the SOFC. SOFCs generally require a customised integration with gas turbine cycles (SOFC-GT hybrid cycles), often operating at unconventional turbine inlet temperatures (>1050°C) and pressure ratios (15-18). In the case of MCFCs, one of the most favourable configurations is acting as CO₂ concentrators. The MCFC receives flue gas from a power plant at the cathode inlet and concentrates CO₂ at the anode. In this configuration, the MCFC operates as a post-combustion CO₂ capture approach, whilst it also oxidises a minor portion of additional fuel with the same ‘oxyfuel’ features discussed above for SOFCs.

Although promising, neither SOFCs nor MCFCs are commercially available, primarily due to low technological maturity and high associated costs. Additionally, the authors have identified the need for an updated and normalised approach to assess the techno-economic performance of SOFCs and MCFCs as CO₂ capture systems in power plants.

1. Methodology

The paper will discuss the techno-economic status of large scale integrated SOFC and MCFC power plants as emerging CO₂ capture systems and the range of potential applications. An update on the
Technology Readiness Levels (TRLs) of different available configurations will be presented. Improvements on current CO₂ capture rates, overall plant efficiency and associated costs will be reviewed, using LCOE as the key metric. Additionally, key performance parameters, including process parameters (e.g. fuel utilisation factor, internal/external fuel reforming and CO₂ capture approach), operating conditions (e.g. cell voltage, stack pressure and stack temperature) and feed stream compositions, will be assessed. A sensitivity analysis on the most important performance parameters will be presented and an optimised configuration in terms of cost, LCOE and overall plant efficiency will be identified.

Based on the outputs of the techno-economic review, an analysis of potential economic improvements, such as increasing the FC production volume, cell power density, or the cell stack scale and applying advanced cell manufacturing technologies, will be discussed. Considerations on power plant performance, such as thermodynamic enhancements, innovative configurations and novel power plant concepts will be presented. In conclusion, a list of challenges and barriers to commercialisation will be included, together with the most promising configurations for future deployment at large scale.

2. References


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