International Journal of Greenhouse Gas Control 91 (2019) 102818

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

Review and techno-economic assessment of fuel cell technologies with CO_2 capture[☆]

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ARTICLE INFO

Keywords:
CO_2 capture
Fuel cell
Techno-economic
Solid oxide
Molten carbonate

ABSTRACT

The concept of using Fuel Cells (FCs) within large scale power generation cycles for CO_2 capture has been studied over the last decade. Two types of FCs, Solid Oxide Fuel Cells (SOFCs) and Molten Carbonate Fuel Cells (MCFCs) have emerged as promising CO_2 capture systems, with the added advantage of additional power production. Although promising, neither SOFCs nor MCFCs are commercially available for CO_2 capture applications, primarily due to low technological maturity, lack of large demonstration projects, and significant associated costs.

In this work, the aim is to provide a comprehensive literature review of Fuel Cell technologies with CO_2 Capture and a techno-economic analysis of five selected cases utilising SOFCs and MCFCs as CO_2 capture systems in power plants. Economic parameters were homogenised to enable a fair comparison between the technologies. Results show that Cases 1 and 5 which consider MCFCs as CO2 concentrator's in Natural gas and super critical pulverised coal cycles respectively give the best LCOE performance. The LCOE is comparable to current state-of-the-art CO_2 capture technologies applied to large-scale power plants.

1. Introduction

In 2016, the IEA estimated that CO_2 emissions from the production of energy represented 42% of the total global emissions. To limit the increase of the Earth's temperature to 1.5 °C above pre-industrial levels in the framework of the Paris agreement, more than 1950 GW_e must be decarbonised within the power sector (International Energy Agency (IEA), 2016).

Currently, the most advanced CO_2 capture technologies applied to large-scale power plants are post- and pre-combustion capture and oxyfuel combustion, with post-combustion capture the most advanced in terms of demonstration at a significant scale. However, the main drawback of these technologies is the energy penalty, and consequent efficiency loss, which leads to a high Levelized Cost of Electricity (LCOE). As a result, novel energy systems, which promise high efficiency and low CO_2 emissions, such as fuel cell (FC) hybrid power cycles with CO_2 capture merit research, development and detailed analysis of their potential economics (Adams et al., 2013).

SOFCs and MCFCs have emerged as potential technologies in CO_2 capture systems, with the added advantage of providing additional power production. Although promising, neither SOFCs nor MCFCs are commercially available for Carbon Capture applications (Adams et al., 2013; Campanari et al., 2010).

FCs convert the chemical energy of a gaseous fuel directly into electricity and heat. Fuel is oxidised electrochemically, which leads to lower exergy losses compared to direct combustion. FCs consist of an electrolyte layer between an anode and a cathode, functioning as a membrane permeable for ions. The anode and cathode are connected in such a way that electrons generated at the anode flow to the cathode thus creating a closed circuit. In general, FCs are classified by the electrolyte material and their operating temperature (US DoE, 2004). Low-temperature FCs include the alkaline FC (AFC), phosphoric acid FC (PAFC) and proton exchange membrane FC (PEMFC). Molten carbonate FCs (MCFC) and solid oxide FCs (SOFC) are high-temperature FCs. Due to the high temperature at which MCFCs and SOFCs operate, natural gas reformation and the subsequent shift reaction can be performed in the FC itself. MCFCs and SOFCs are most appropriate for stationary power production at scales ranging from a few hundred kW up to a few MW, due to their high electrical efficiencies and the ability for co-generation of electricity and heat (US DoE, 2004). The efficiency of SOFCs and MCFCs can be further increased by integration with gas turbines, as will be reported later in this study.

When FCs produce the entire electrical power output electrochemically, the advantage is the elimination of the Carnot-efficiency limitation (Hassanzadeh and Mansouri, 2005). This fact, in parallel with environmental advantages (almost zero NO_x and particulate matter

☆ The work reported in this paper is part of the IEAGHG technical study "Review of Fuel cells for CO_2 capture".

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https://doi.org/10.1016/j.ijggc.2019.102818
Received 3 October 2018; Received in revised form 1 August 2019; Accepted 19 August 2019
Available online 14 November 2019