Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 126 (201709) 453–460

Energy Procedia

www.elsevier.com/locate/procedia

72nd Conference of the Italian Thermal Machines Engineering Association, ATI2017, 6-8 September 2017, Lecce, Italy

Preliminary design of a MW-class demo system for CO_2 capture with MCFC in a university campus cogeneration plant

Luca Mastropasqua[a,*], Maurizio Spinelli[a], Andrea Paganoni[a], Stefano Campanari[a]

[a]*Department of Energy, Politecnico di Milano, Via Lambruschini 4, 20156, Milan - Italy*

Abstract

One of the most promising, short-term options for efficiently capturing CO_2 from combustion exhaust gases – potentially from any combustion process source - is based on the operating principle of Molten Carbonate Fuel Cells (MCFC): their electrochemical reactions promote the transport of both CO_2 and O_2 molecules from the cathode side (which can be fed with combustion effluents) to the CO_2-rich atmosphere of the anode side (fed with internally reformed natural gas), by means of a CO_3^{2-}-ion conducting electrolyte. In the present work, the preliminary design of a 1 MW_{el} MCFC demo plant operating downstream a Combined Heat and Power (CHP) Internal Combustion Engine (ICE) installed at the Politecnico di Milano campus is investigated, with the aim of promoting a valid solution for high efficiency, de-carbonised heat and electricity production. The study envisages two purification strategies for the CO_2-rich stream at the MCFC anode outlet: i) the CO_2 is separated and compressed in a cryogenic unit and the unconverted fuel is either recycled at the anode inlet or burned and sent to the MCFC cathode inlet ii) the anode exhausts are burned in a catalytic oxy-combustor, increasing both the thermal energy available in the cogeneration unit and the CO_2 concentration in the stream sent to the storage site. Subsequently to a thermodynamic analysis carried out with a 0D model calibrated upon experimental data available for a commercial MCFC unit, the main components are designed by taking into account all the operating constraints of the machines and the CO_2 capture limitations associated to the size of the MCFC modules currently available on the market. Moreover, an economic analysis is performed in order to assess the feasibility of such an installation within the university campus cogeneration grid. As a main finding, the use of MCFCs to capture CO_2 at a distributed generation scale allows reaching interesting energy and environmental performances, highlighted by promising values of the Specific Primary Energy Consumption for CO_2 Avoided (SPECCA=0.9-1.9 MJ/kgCO_2) and Carbon Capture Ratios (CCR=68-84%). Within a mid-term perspective for MCFC specific cost, the economic analyses reveal acceptable values for the cost of electricity and the cost of CO_2 avoided, respectively close to 130 €/MWh_{el} and 100 €/tCO_2.

* Corresponding author. Tel.: +39 02 2399 3862
E-mail address: luca.mastropasqua@polimi.it

Peer-review under responsibility of the scientific committee of the 72nd Conference of the Italian Thermal Machines Engineering Association
10.1016/j.egypro.2017.08.213

Peer-review under responsibility of the scientific committee of the 72nd Conference of the Italian Thermal Machines Engineering Association

Keywords: MCFC; Carbon Capture and Storage; Distributed Generation; University campus; Feasibility study

1. Introduction

MCFCs are being extensively studied for post-combustion Carbon Capture and Storage (CCS) applications [1,2], thanks to their inner capability of transporting CO_2 and O_2 from the exhaust gas stream of a conventional power cycle (cathode side) as reactants to oxidise the fuel (anode side). Decarbonisation of the power generation sector is currently focusing also on small power units installed in medium scale communities supplied with local mini-grids. The novelty of the present work is to apply the MCFC-based post-combustion CCS configuration at a distributed generation scale (<10 MW) in a local Combined Heat and Power (CHP) grid which supplies a university campus, setting up the study of a potential demonstrative installation of this type of power plant.

The main targets of this study are summarised as follows:

- Calibration of a simulation model for a commercial MCFC power plant, taken as a reference for its possible adaptation to the CCS operation
- Design of possible layouts to implement post-combustion CCS to the CHP Internal Combustion Engine (ICE) unit installed at Politecnico di Milano campus, when combined with a commercial-scale MCFC unit
- Assess the energy balances and greenhouse gas emissions of the proposed solutions with respect to the current solution without CCS
- Introduce a techno-economic analysis in order to assess the feasibility of the new installation.

Nomenclature

MCFC	Molten Carbonate Fuel Cell
CHP	Combined Heat and Power
CCS	Carbon Capture and Storage
CCR	Carbon Capture Ratio
ICE	Internal Combustion reciprocating Engine
LHV	Lower Heating Value
PES	Primary Energy Saving
SPECCA	Specific Primary Energy Consumption per CO_2 Avoided

2. Plant modelling

2.1. Modelling methodology

In this study the system thermodynamic modelling is carried out employing an in-house modular simulation code called “GS”; the software has been developed at the Energy Department of Politecnico di Milano since the early 90’s [3]. The plant layout is built by assembling in a coherent network the different components selected in a library containing over 20 basic modules. The thermodynamic and chemical properties are internally calculated using the standards reported in [4,5] for ideal gases and water/steam.

Each component is modelled by means of 0D approach; in particular, the MCFC model performs the calculation of the stack operating conditions (i.e., average voltage, overpotential losses, power output) using the values of inlet pressure, composition, mass flow rate, temperature and average current density. The polarisation curve of the stack is