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MOLTEN CARBONATE FUEL CELLS TO IMPROVE THE PERFORMANCE OF CHP IN WASTEWATER TREATMENT FACILITIES

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ABSTRACT

The concern about environmental sustainability brought about by global warming in the last decades along with the scarcity of fossil fuel resources has fostered the research in renewable energies, high efficiency power generation systems and carbon dioxide capture and storage opportunities. The present work shows the performance of a system closely related to these three research areas. It focuses on a hybrid system composed by a reciprocating engine set (ICE) fuelled with biogas (BG) and a bottoming molten carbonate fuel cell network (MCFC) for active CO_2 capture purposes.

The proposed hybrid system constitutes the cogeneration unit of a wastewater treatment plant (i.e., driven by renewable energy) where electricity is generated efficiently and environmentally harmlessly thanks to the smart integration of two dissimilar subsystems in one of which CO_2 is captured. In addition, the system has the potential to be economically interesting for various reasons. First, it is possible to enjoy more favourable market conditions (special regime in Spain) by using the heat rejected by the ICE to generate additional power and control the production of biogas. On top of this, there is a new business opportunities in the International Emissions Trading Market where CO_2 can be traded. Despite these gains, there are also important economic drawbacks to be considered, mostly due to the added investment costs of the MCFC and the corresponding operating and maintenance costs: timely overhauls and the need to back up the fuel cell with a certain amount of natural gas (NG) limited to 10% of the annual heat input from fossil fuels.

INTRODUCTION

The first task of this work is to analyse the performance of the reference plant (without fuel cell) from real operation data recorded over a year. Then, after evaluating the sensitivity of fuel cell performance with respect to the most relevant operating parameters (fuel and carbon utilisation, current density, steam to carbon ratio and operating temperature), two different hybrid designs are developed. Finally, a project appraisal is presented aiming to find the break-even-cost of MCFC technology.

DESCRIPTION OF HYBRID FACILITIES

The BG produced by a water treatment plant is injected into an ICE whose exhaust gases feed the fuel cell cathode. This electrode captures a fraction of the CO_2 content in the engine exhaust gas stream whereas NG is injected into the anode (Project A). Alternatively, part of the BG can be premixed with NG before feeding the anode (project B) in which case one of the three ICEs available is put off service.

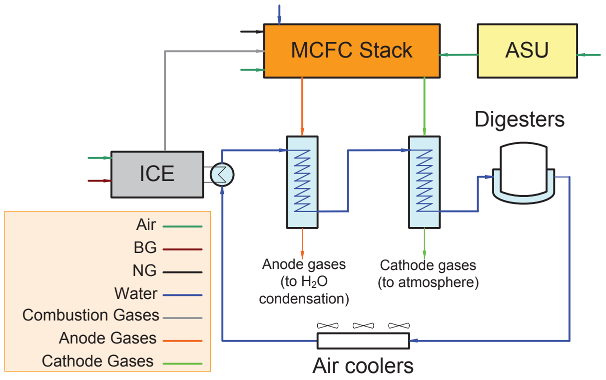

Figure 1: Block diagram of the hybrid facility.

MODEL AND ASSUMPTIONS

The performance of the ICEs is modelled as per the available operating data of the plant: BG is burnt stoichiometrically with a 31.9 electric efficiency (2), heat

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losses of 5 % are considered and the ratio from available thermal heat to electric power output is 436 kWt /426 kWe for each engine. The exhaust gases from the engine feed the fuel cell cathode (with additional air being added for the reducing half reaction) whereas a fuel-steam mixture is supplied to the internal reformer before flowing into the anode where oxidation takes place. The MCFC behaviour is modelled as described in reference (3).

The excess fuel in the anode exhaust is burnt separately from the cathode exhaust in order not to dilute the already captured carbon dioxide. To this aim, an Air Separation Unit (ASU) produces 98% pure oxygen (4).

HYBRID CHP SYSTEM PERFORMANCE

The afore described hybrid systems make use of atmospheric fuel cells operating at 650 ºC with 1100 A/m^2 current density and 3:1 SCR. Their performance is summarised in Table 1 where the information of the reference facility (base case) is also given. These data correspond to rated operation where *EEE* stands for the equivalent electric efficiency and CCR is the Carbon Capture Ratio:

$$CCR = Carbon\ captured / Carbon\ in\ fuel$$

Subscripts *e*, *th* and *CHP* indicate electric, thermal and combined heat and power respectively.

	Base Case	Project A	Project B
q_{NG} / q_{BG} (Nm^3/ h)	0 / 628	43.6 / 628	43.6 / 628
$\dot{W}_{ICE}$ / $\eta_{e,ICE}$ (kW$_e$ / %)	1242 / 31.87	1242 / 31.87	828 / 31.87
$\dot{W}_{MCFC}$ / $\eta_{e,MCFC}$ (kW$_e$ / %)	-	205 / 47.43	580 / 37.06
$\dot{W}_{TOTAL}$ / $\eta_{e,TOTAL}$ (kW$_e$ / %)	1242 / 31.87	1447 / 33.22	1408 / 32.53
Heat (kW$_{th}$)	**-**	**1426**	**1426**
Engine jackets	-	*1271*	*847*
Anode gas heater	-	*35*	*0*
Cathode gas heater	-	*120*	*579*
η_{th} (%)	-	32.95	32.95
η_{CHP} (%)	-	66.17	65.48
EEE (%)	-	62.76	61.46
CO$_2$ captured			
CCR	-	0.2208	0.3747
kg CO$_2$/MWh[1]	-	-1318	-1698
Emissions			
kg CO$_2$/MWh	598	336.4	317.1

Table 1: Performance comparison.

ECONOMIC ANALYSIS

The assumptions for the economic analysis are:

- Reciprocating engine**:** capital cost: 1021 €/kW; O&M cost: 16 €/MWh (6).
- Fuel cell: O&M cost: 38 €/MWh (6).
- Natural gas: 3.37 c€/kWh (7).
- Electricity price: 9.68 c€/kWh for the first 15 years; 6.51 c€/kWh afterwards (1).
- Carbon credit: 15 to 40 €/ton CO$_2$ (5).
- External funds (debt/equity): 100-0 %.
- Inflation/discount: 1.90 /7.50 %.

These conditions yield the results plotted in Figure 2. Regardless of the project lifetime, the break-even MCFC capital cost is close to 3000 €/Kw, corresponding to a carbon credit of 32 €/ton of CO$_2$. As expected, higher carbon credits yield higher break-een MCFC cost to still make the system economically interesting.

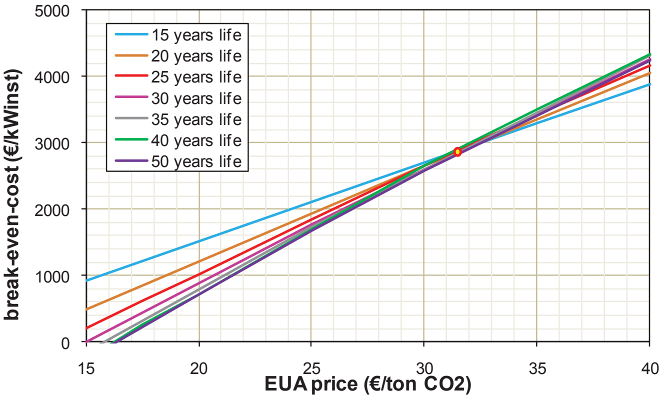

Figure 2: MCFC break-even-cost vs. life & EUA price.

CONCLUSIONS

The main conclusion drawn from this work is that the proposed system is not economically interesting presently due to the very high cost of fuel cells. Nevertheless, a reduction in the MCFC capital cost to below 1500 €/kW or an increase in the price of carbon credits to above 40 €/ton CO$_2$ would change the situation completely and make the system profitable. Both of these changes are likely to become a reality in the mid-term.

With regard to the two alternative projects, A and B, it is worth noting that a very optimistic combination of the economic boundary conditions (2400 €/kW MCFC installation cost and 30 €/ton CO$_2$) would make Project A feasible in spite of the statement given in the previous paragraph. On the contrary, Project B is always penalised by a larger and costlier MCFC whose efficiency decreases dramatically due to the need to recycle part of the anode gases to the cathode in order to provide it with enough CO$_2$.

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[1] CO$_2$ captured over MWh consumed by the capturing system. It value is negative because the capturing process generates energy. This parameter would be positive for conventional systems based on chemical absorption.

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