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Study Of A Basic Mcfc Unit For Modular Multi-Mw Systems

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In recent years Molten Carbonate Fuel Cells (MCFCs) have received a great deal of attention due to their high efficiencies, low emissions, suitability for co-generation purposes and low sensitivity to contaminants, and they are now at a pre-commercial stage.
In this work the process analysis of a reference 500 kW MCFC power system will be presented with reference to the simulation experience of the Department of Civil, Environmental and Architectural Engineering (DICAT) of the University of Genoa.
Taking into account the new philosophy of distributed energy supply for the production and distribution of electrical energy that focuses its attention on plants with a power size in the range of 1 – 10 MW, the simulation of a 1 MW MCFC system will be considered. For this analysis a 500 kW plant configuration will be adopted as a reference system scheme; then some modifications for improving plant performance will be evaluated. The results of the simulation, mainly in terms of plant efficiency, will be discussed.

1. Introduction

In recent years, a great deal of attention has been focused on fuel cells, which represent one of the most promising technologies for the production of clean distributed energy, to meet growing demand. MCFCs occupy an important position in this field of development thanks to their low level of pollutant emissions and the interesting possibility of coupling their technology with the use of renewable sources, in particular biomass, and they are now at a pre-commercial state.
In this work we will consider the process analysis of a reference 500 kW MCFC hybrid plant; then we will focus on the development of a 1 MW system considering the above reference module and some modifications based on worldwide experience (Hishinuma and Kunikata, 1997; Mugitani, 2003).

2. Analysis of 500 kW configuration

2.1 The plant

The 500 kW MCFC hybrid system is considered suitable for the basic module of a modular multi-MW plant. It has been developed by Ansaldo Fuel Cells S.p.A. (AFCo), it is called "Serie 2TW" and it has maximum electrical power of 500 kW. Figure 1 shows the scheme of the reference 500 kW plant (www.ansaldofuelcells.com).

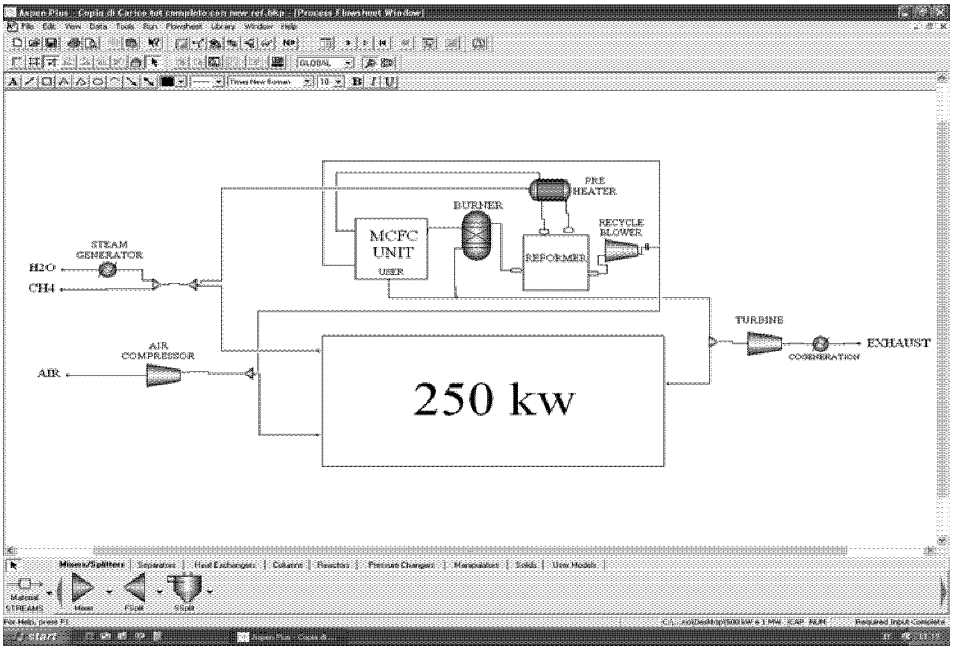

Figure 1: Scheme of the reference 500 kW plant.

The reference module is fed by methane and consists of two 250 kW sub-units, a gas turbine, a cogeneration system and a unit for the pressurisation of the feeding air and steam. Each 250 kW sub-unit is placed in a vessel and contains a reformer that converts methane into hydrogen, a fuel pre-heater, a burner, a recycle blower and two 150-cell MCFC-stacks that guarantee the production of the main electrical energy. The feeding methane is diluted with steam at a steam-to-carbon ratio of 3.5; in order to feed the two 250 kW sub-units, this fuel and the fresh air feed, both at 3.6 atm, are divided into two equal streams. The fuel is pre-heated, reformed and sent to the anodic side of the MCFC of each 250 kW module; the cathodic side is fed with air mixed with the anodic and part of the cathodic exhaust gases burned together. The remaining part of the hot pressurised cathodic exhaust expands to atmospheric pressure in the gas turbine that produces additional electrical energy and provides energy for the air compressor. By cooling these gases to 90 °C, it is possible to recover the thermal energy utilised for the production of the steam and for cogeneration.

2.1 The results

The analysis of this system has been developed using Aspen Plus© software that not only allowed the study of all the standard components of the plant, but also let us integrate innovative components modelled using specific Fortran language codes, such as the MCFC stacks that were simulated using the detailed proprietary 3D model MCFC-D3S© (Bosio and Arato, 2005).

In table 1 the main bonds for the appropriate utilisation of the MCFC unit (Scattolini and Bosio, 2005) are summarised.

Table 1: Typical values for the appropriate utilisation of the MCFC unit.

Maximum temperature inside the stack	680 – 690 °C
Minimum O_2 at the cathodic inlet	8 %
Minimum CO_2 at the cathodic inlet	5 %
Steam-to-carbon ratio	≥ 3.5
Fuel utilisation	≤ 75 %

In this analysis we referred to an innovative compact methane steam-reforming reactor, based on an AFCo configuration for which a patent is pending, which was designed to optimise the thermal management of the system, integrating the endothermic (reformer) and exothermic (MCFC stack and burner) units. This reactor was simulated, thanks to standard Aspen modules, using a series of heat exchangers and ready-to-use reforming reactors where thermodynamic equilibrium was achieved for the reforming and water-gas shift reactions (Bosio et al., 2001).

The other auxiliary components were simulated as ideal modules where efficiencies are constants despite the treated flows. Moreover we considered the plant without thermal dissipations.

Table 2 summarises the main results of the simulations.

Table 2: Main results of the simulation of the reference 500 kW plant.

	Load			
	100 (%)	75 (%)	50 (%)	25 (%)
Fuel				
Q (kg/h)	347	266	184	97
T (°C)	191	191	191	191
Air				
Q (kg/h)	2750	2120	1530	885
T (°C)	203	203	203	203
Fuel cell				
Current density J (A/m^2)	1547	1160	773	386
T_{MAX} (°C)	686	682	685	679
Power (kW_{el})	504	395	273	141
Turbine				
Net power (kW_{el})	59	44	32	17
Thermal recover				
Power (kW_t)	412	314	226	125
Efficiencies				
Reduction of $\eta_{EL,PLANT}$ respect to 100% load	-	0.0	3.0	7.5
Net power				
Net electrical power (kW_{el})	522	403	268	134
Net thermal power (kW_t)	197	149	112	65

We have considered four different types of efficiency: stack electrical efficiency (η_{STACK}), electrochemical module efficiency (η_{ELECTR}), plant electrical efficiency

($\eta_{EL,PLANT}$), global plant efficiency ($\eta_{TOT,PLANT}$) (Marra and Bosio, 2006). The absolute values of the MCFC efficiencies are bout 45-55% for the $\eta_{EL,PLANT}$ and 75% for the $\eta_{TOT,PLANT}$ (De Simon et al., 2003; Tomasi et al. 2006). We have conducted further simulations on the relative values of these efficiencies with respect to the base simulation analysed in this paragraph and the results are presented below.

Our analysis has been developed for the full load and for three partial loads of 75%, 50%, 25% respectively.

The simulations show that the η_{STACK} remains roughly constant despite the reduction in the load: its variation with respect to the full load is always less than ±2%. We have observed that the $\eta_{TOT,PLANT}$ does not change with the load, while the $\eta_{TOT,PLANT}$ decreases with a decreasing load. This fact is mainly due to the recirculation blowers that, having to supply roughly the same amount of energy independent of the load, lower the net electrical power, which shows a bigger reduction than the net thermal power. In fact, the ratio between the net electrical power and the net thermal power decreases from a value of 2.6 for a 100% load to a value of 2 for a 25% load.

3. Development of 1 MW system

3.1 The plant

On the basis of the previous results, we extended our work to an MCFC system with a nominal power of 1 MW. The starting point for our detailed analysis was the identification of an ideal configuration composed of two of the 500 kW modules previously described, which could be considered a reference for the solution described below. Then we modified the plant scheme to improve reliability and global performance.

First of all we adopted both a single heat exchanger for steam production and a single air compressor and gas turbine for the entire plant. This compressor was assumed to work with a constant air flow of 6000 kg/h: the air not required inside the MCFC stack, a function of the utilisation level, was preheated by the plant exhaust and bypassed to the turbine that, following the manufacturer's indications, had to work with a constant flow of 6000±20% kg/h at a temperature of 700 °C. For this reason the exhaust gases were burned with a proper methane quantity before entering the turbine.

Moreover, we considered a single reformer, burner, fuel preheater and recycle blower for the whole system.

We also took into account the thermal dissipations of the vessels where the stacks were placed: to do this for each 250 kW module, we concentrated these dissipations in a pipe (with a thermal exchange coefficient equal to 0.53 W/m^2K, on a base of insulation material) with the same dimensions as the vessel themselves.

Then we added a water recovery system (WRS) to our plant to condense the hot gases coming from the hot side of the reformer, recover the water necessary for the methane steam-reforming, and reheat them before they entered the blower so that the temperature inside the MCFC unit was lower than 680 °C.

The last modification, in order to keep the blower temperature below 680 °C, was to bypass the feeding air through it before it entered the stacks.

The scheme of this new 1 MW system configuration is shown in Figure 2.

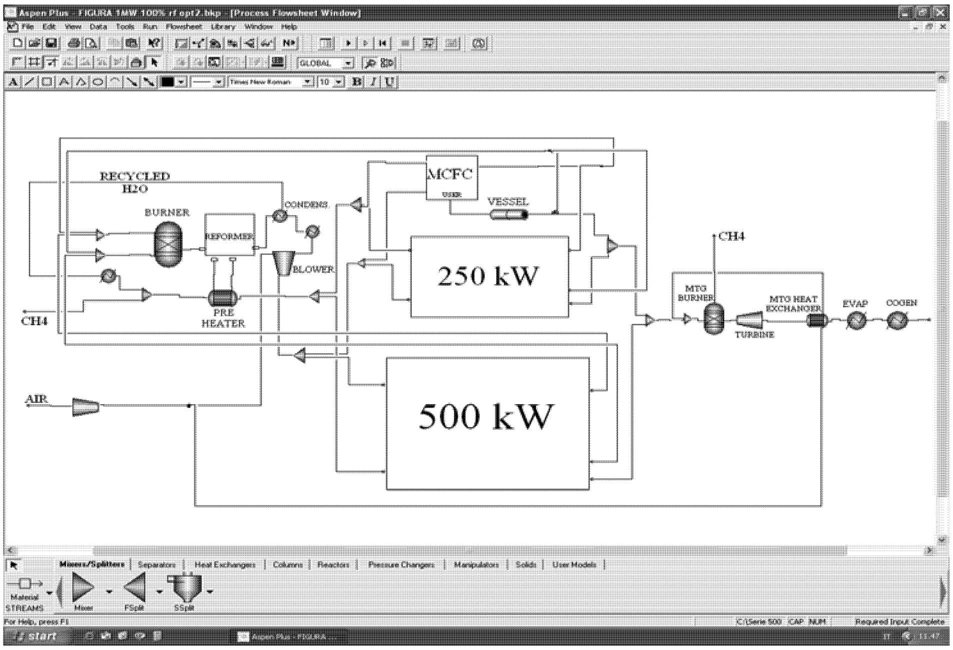

Figure 2: Scheme of the 1 MW system.

3.2 The results

We found that, in terms of plant efficiency, the reference configuration was the same as that of the 500 kW: this is because the plant flow scheme was not changed by the coupling of the two modules.

We should underline that all the modifications to the innovative configuration were analysed singly in order to identify how and how much each of them affected the plant performances.

It is interesting to observe, from Figure 3 (which shows the efficiency variations with respect to the ideal configuration as a function of the load), that the global plant efficiency, for the full load, is roughly 20% higher than in the ideal configuration: this is mainly due to the WRS that also enabled us to recover the vaporisation heat (as can be observed in Figure 4) that could be used for cogeneration. It can also be noted that the electrical efficiency is lower than in the reference case and it decreases with a decreasing load: this is mainly due to the smaller flow that passes through the turbine, due to the lack of water, and to the roughly constant flows, despite the load, which have to be treated by the blower and the air compressor.

We found that the thermal dissipations reduce the $\eta_{TOT,PLANT}$ by about 5% and 10% respectively for the full and 25% load. Moreover we observed that for the full load the percentage of the heat dissipated by the vessel was almost negligible (14%) with respect to the heat necessary for the steam generator (86%) while for the 25% load the two contributions were comparable (37% and 63%).

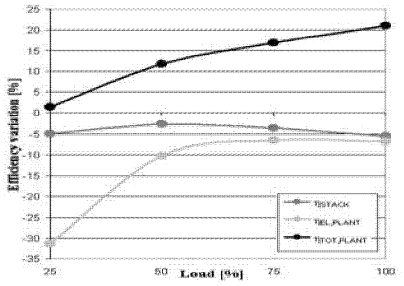

Figure 3: Efficiency variation with respect to the ideal configuration as a function of the load for the 1MW plant.

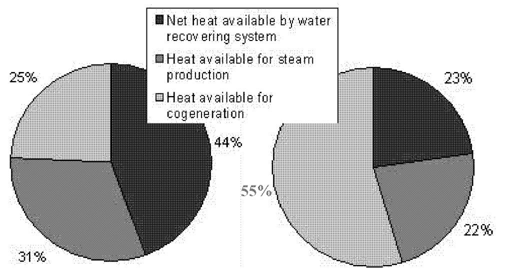

Figure 4: Energy contribution of the WRS, the heat exchangers for the steam production and cogeneration, for the full and 25% loads (full load on the left, 25% load on the right).

4. Conclusions

This simulation work proposes the development of an innovative 1 MW MCFC hybrid-plant: starting with the process analysis of a 500 kW system, considering some modifications necessary for improving its performance (first of all a single reformer for the entire plant and a water recovery system) we found an optimised configuration that could be considered as a basic module for a modular multi-MW plant.

5. References

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