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USE OF FUEL CELLS AND ELECTROLYZERS IN SPACE APPLICATIONS: FROM ENERGY STORAGE TO PROPULSION/DEORBITATION

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ABSTRACT

In this paper, two main groups of technologies and applications that can be distinguished regarding hydrogen field: gas production (hydrogen and oxygen), and power generation, are presented.

Firstly, for gases generation, reforming of bioethanol and PEM electrolysis are presented as possible choices for hydrogen production for terrestrial plants related to space activities. In the case of on board gases production, electrolysis is presented as the most suitable option.

Secondly, regarding power generation with fuel cells, different applications are presented (landers, aircrafts, stationary back-ups, APUs, UAVs, etc.).

Thirdly, two options of combination of power generation with fuel cells and gases production are shown: reversible fuel cell systems and regenerative fuel cell systems, and a comparison between the current batteries used and these regenerative fuel cell systems.

In the conclusion, two applications scales are presented: one for power generation depending of the level of power generated, and another one for gases generation depending of the gases production rate.

1. INTRODUCTION

The use of hydrogen as an energy carrier in space applications is growing day by day because of its advantages in comparison with other technologies and its environmentally friendly nature.

First applications of fuel cells were developed for aerospace sector. In the 1960s, General Electric developed the first Proton Exchange Membrane (PEM) fuel cell for Gemini missions (NASA), and, on the other hand, hydrogen is the main fuel for spacecrafts and oxygen is necessary for all manned missions, so the development of these technologies has an important impact in the aerospace sector.

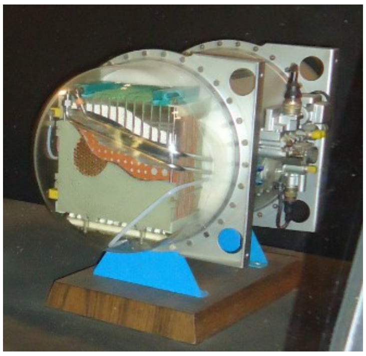

Figure 1. PEM fuel cell used in Gemini missions.

2. GASES GENERATION

Regarding gases generation there are many technologies to be used not only for spacecrafts but also for terrestrial plants related to space activities.

Reforming of any fuel or biofuel (in order of being more environmentally friendly) is one of the available technologies for hydrogen production for terrestrial plants to support spatial needs.

In case of, in example, bioethanol steam reforming, the overall reaction that occurs is:

$$CH_3CH_2OH\ (g) + 3H_2O\ (g) \rightarrow 6\ H_2\ (g) + 2CO_2\ (g)\ (1)$$

In this reaction, one mole of bioethanol reacts with three moles of steam water, producing hydrogen and CO_2. The aim of this process consists of maximizing the yield of hydrogen, limiting the formation of CO which is a catalyst poison. To achieve this goal, it is necessary to correctly choose operating conditions: temperature optimization, pressure and mole ratio of water/bioethanol and optimum choice of the catalyst.

Other possibility for hydrogen production is electrolysis process.

Proton exchange water (PEM) electrolysis is an electrochemical process in which pure water split up into hydrogen and oxygen by means of electricity using a polymer electrolyte membrane as a medium of transfer.

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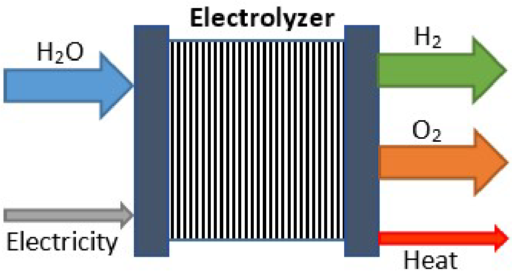

Figure 2. PEM Electrolyzer schema.

The reaction that occurs in the cell could be summarized as in Eq. 2:

$$\begin{aligned} &\text{Anode reaction:} \quad H_2O \rightarrow \tfrac{1}{2}\,O_2 + 2H^+ + 2e^- \\ &\text{Cathode reaction:} \quad 2H^+ + 2e^- \rightarrow H_2 \qquad (2) \\ &\text{Global reaction:} \quad H_2O + \text{electricity} \rightarrow H_2 + \tfrac{1}{2}\,O_2 \end{aligned}$$

The authors have experience on the design of this kind of plants because of their work in the "Environmentally Friendly Hydrogen Production" contract with ESA, where the identification of an environmentally friendly technology for hydrogen production and a techno-economical study for the implementation of a plant in Kourou to support Arianne 5 needs were carried out.

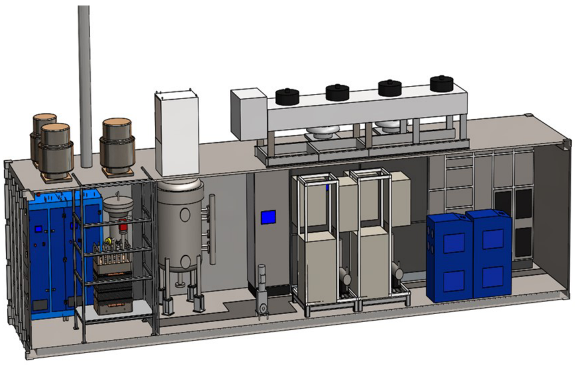

Figure 3. Example of PEM electrolyser.

Gases production is also relevant for space applications, where the applications of generation of hydrogen and oxygen can be distinguished.

Electrolysis process is the most suitable technology for gases production on board. Even if the overall electrochemical reaction is the same as for a terrestrial plant, some operational and design details have to be modified in order to fulfil with on orbit conditions.

Hydrogen produced by electrolysis is essential for space missions because it is the main fuel used for propulsion of spacecrafts during launch and it can also be used for on orbit propulsion and deorbiting at the end of the operative life of the spacecraft.

On the other hand, the other product gas of the electrolysis process, oxygen, is necessary for life support in manned missions, like in the International Space Station.

3. POWER GENERATION

Since the first applications of fuel cell were developed for aerospace sector, this technology has substantially improved.

From the alkaline fuel cell used in missions of Apollo program to the PEM (high and low temperature) fuel cell specially designed for space applications in our days, much knowledge and improvements in the technology and balance of plant for the operation has been achieved.

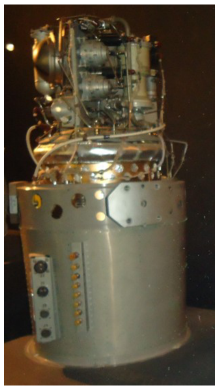

Figure 4. Alkaline fuel cell in Apollo missions.

The reaction (Eq. 3) for any of these fuel cell technologies consists of power generation by the electrochemical reaction of hydrogen and oxygen, becoming water as only product and avoiding any noxious product.

$$H_2 + \tfrac{1}{2}\,O_2 \rightarrow H_2O + \text{power} \qquad (3)$$

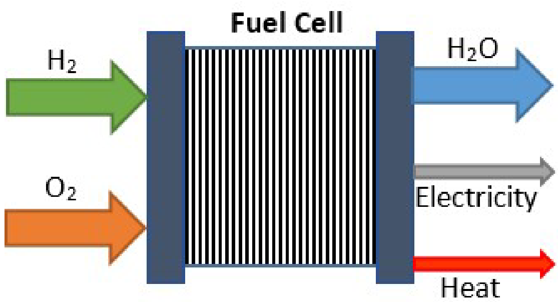

Figure 5. Fuel cell schema.

Power generated by fuel cell systems can be used for many aerospace applications:

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- Landers,
- Aircrafts,
- Stationary back –ups,
- Military/ Aeronautic auxiliary power units (APUs),
- Unmanned aerial vehicles (UAVs).

4. COMBINATION OF POWER GENERATION AND GASES PRODUCTION

The combination of the operation of a fuel cell and an electrolyzer working in a close loop can be used as an energy storage system [1].

3.1 Reversible fuel cell system

A reversible fuel cell system consists of a stack that operates in both ways:

- Fuel cell mode: the stack consumes hydrogen and oxygen and produces water and power.
- Electrolyzer mode: when power is supplied to the stack, it consumes water and produces hydrogen and oxygen.

The authors [2] have worked in the development, tests and integration of a reversible fuel cell system for a picosatellite.

This reversible fuel cell system is composed of a stack where reactant gases and product water are contained in. There are no storage independent parts. Hydrogen, oxygen and water are adsorbed in the membranes of the stack and circulate in close loop during its operation. Water produced by the fuel cell is then used as reactant in electrolyzer mode; and gases produced by the electrolyzer are used as reactants in fuel cell mode.

This system has successfully passed vibration, thermal and vacuum tests and has overcome 50 operation cycles. Its reliability has been demonstrated and it presents several advantages as:

- Possible increase in available power,
- Reduction of the energy storage system mass (possibility to increase payload),
- Compact energy generation and storage systems on board.

3.2 Regenerative fuel cell systems (RFCS)

On the other hand, a regenerative fuel cell systems consist of two different stacks (one fuel cell and one electrolyzer) connected to three storage tanks (for hydrogen, oxygen and water) that operate in a closed loop [3].

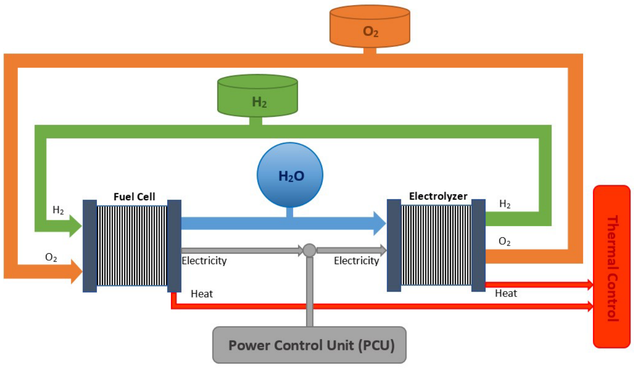

Figure 6. Regenerative fuel cell system schema.

This kind of systems can be used as auxiliary power supply for spacecrafts (satellites, rovers, etc.). There are three possible operational modes of the system:

- Discharge mode: when the spacecraft needs power (i.e. shadow periods), the fuel cell operates using hydrogen and oxygen stored in the tanks (discharge process of gases storage tanks) and producing the demanded power and water to be stored in the water tank.
- Charge mode: when there is available power from the spacecraft (light periods), the electrolyzer operates using water from the water tank and recharging the gases tanks with the oxygen and hydrogen generated.
- Idle mode: no stack is operating but fuel cell is ready to supply power when the spacecraft requires it and tanks are plenty of gases. The fuel cell and the electrolyzer cannot operate at the same time.

The authors have evaluated the feasibility of this system collaborating with the main suppliers of fuel cells and electrolyzers for space, identifying issues and solutions:

- Thermal control solutions identified to reduce mass,
- Water management in space conditions,
- Fast response for power supply,
- Passive system design to avoid maintenance and failures.

The feasibility of this regenerative fuel cell system has been demonstrated. It could be a possible substitute for current batteries presenting a mass saving and higher energy density that improves with the increase of the power level.

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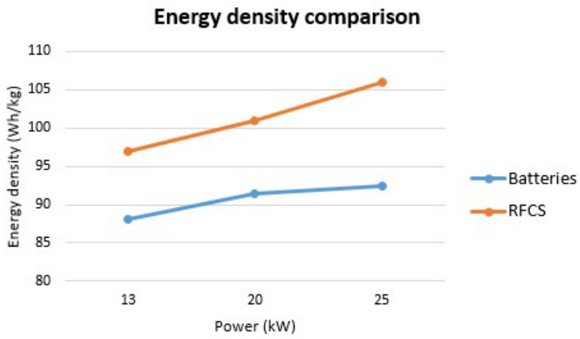

Figure 7. Energy density comparison. RFCS vs batteries.

5. CONCLUSIONS

The use of fuel cells and hydrogen production technologies in the aerospace sector is becoming more important day by day.
Its advantages in comparison with other technologies have great impact for different spatial activities and its development for different applications is a fact.

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