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Metal hydride hydrogen and heat storage systems as enabling technology for spacecraft applications

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ABSTRACT

The next generation of telecommunication satellites will demand a platform payload performance in the range of 30+ kW within the next 10 years. At this high power output, a Regenerative Fuel Cell Systems (RFCS) offers an efficiency advantage in specific energy density over lithium ion batteries. However, a RFCS creates a substantial amount of heat (60–70 kJ per mol H_2) during fuel cell operation. This requires a thermal hardware that accounts for up to 50% of RFCS mass budget. Thus the initial advantage in specific energy density is reduced. A metal hydride tank for combined storage of heat and hydrogen in a RFCS may overcome this constraint. Being part of a consortium in an ongoing European Space Agency project, FOTEC is building a technology demonstrator for such a combined hydrogen and heat storage system.

1. Introduction

FOTEC is part of a consortium that is involved in the development of several critical components for a closed loop Reversible Fuel Cell System (RFCS) for satellite applications. The scope of project [1] is to exploit the potential of metal hydrides in a combined hydrogen and heat storage system. During an Eclipse, which is the time the satellite is in the Earth's shadow, the solar cells are not able to provide enough energy for continuous operation of the payload. In this time, the fuel cell would operate, generating a heat amount around 60–70 kJ per mol H_2. The thermal hardware required for dissipating this amount of heat can add up to 50% of the system mass. This is a major constraint to using a RFCS instead of a lithium ion battery onboard a satellite. Fig. 1 displays the specific energy density of a RFCS compared to a Li-ion battery with and without thermal hardware based on two independent studies. [2,3] It is apparent that a RFCS has a great advantage in specific energy density over Li-ion batteries if the thermal hardware is substantially reduced.

A possible way toward this end is a metal hydride storage system that can store both, heat *and* hydrogen. Instead of direct heat dissipation via a radiator, the waste heat from the fuel cell is at best completely absorbed by the metal hydride material and used for hydrogen desorption during the Eclipse. For the geostationary orbit, which is interesting for a large number of possible applications, there is a factor of about 20 in time between desorption and rehydrogenation which is quite different to most terrestrial applications. As can be seen in Fig. 2, the Eclipse is at maximum 72 min, while the rest of the 24 h day can be used for rehydrogenation.

The metal hydride has – apart from efficient hydrogen storage – the purpose to buffer the heat flows within the system over time. Since the peak heat flow from the fuel cell during Eclipse is substantially reduced, a radiator of lower performance, thus mass, can be used. The thermal hardware has a profound impact on system mass so any savings there will bring about a notable improvement in specific energy density. In this paper, we describe the development of such a Metal Hydride Reversible Fuel Cell System (MH-RFCS) within the Advanced Research in Telecommunications Systems program (ARTES) from the European Space Agency (ESA), specifically the development of a technology demonstrator for the combined hydrogen and heat storage system.

2. Theory

The model application for the MH-RFCS technology is a 39 kW telecommunication satellite. Key components of the tank system

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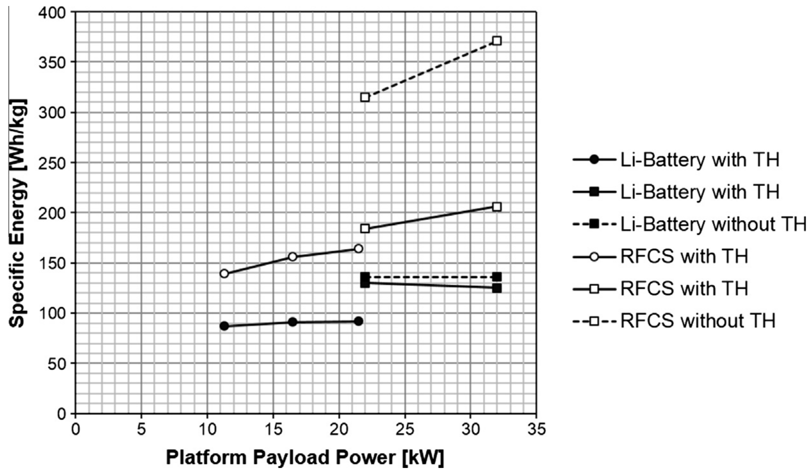

Fig. 1. Specific Energy of a reversible fuel cell system (RFCS) compared to those of a lithium ion battery with and without thermal hardware (TH). The figures are based on two independent studies [2,3] that virtually come to the same conclusion. Circles show the results from the study performed by Astrium [2] and boxes show the results from the study performed by Thales [3].

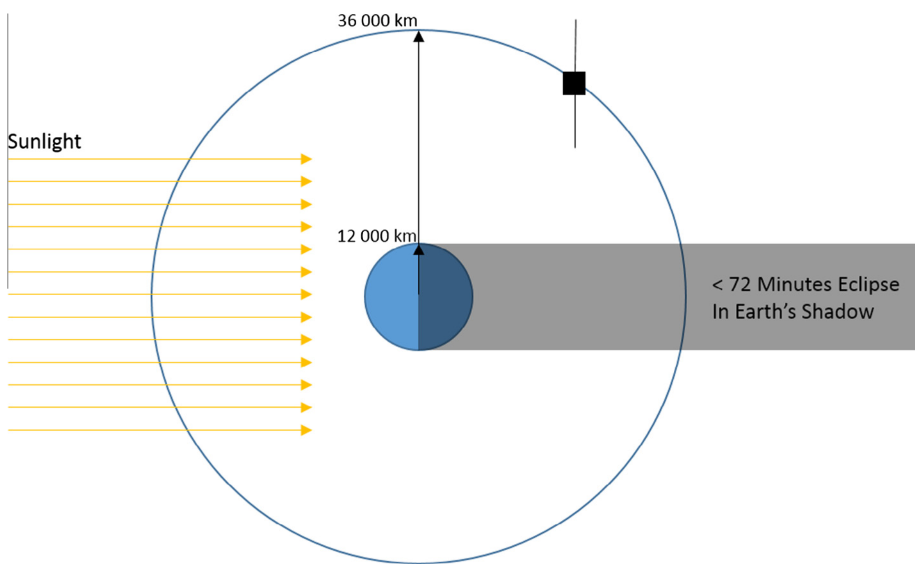

Fig. 2. A satellite orbiting Earth in geosynchronous orbit. In this particular orbit the satellite stays always above one specific location at the Earth's surface, thus the total orbit period is 24 h.

are the metal hydride (MH), the pressure vessel and the heat exchanger. A RFCS is a highly integrated array of components so the requirements for the metal hydride properties are set by those of the fuel cell. Since the fuel cell generates a heat of 60–70 kJ per mol H_2 at an operation temperature around 200 °C the ideal metal hydride for this application matches these figures by a slightly lower decomposition enthalpy ΔH_d and desorption temperature. A high gravimetric hydrogen content toward 10 wt.% in the metal hydride material is desired for high tank performance. The rehydrogenation pressure is below 100 bar. Another important mark set by the fuel cell for the metal hydride is an equilibrium pressure well above 5 bar at the decomposition temperature of about 180 °C since this is the maximum back-pressure to be expected from the fuel cell. There is no available material that meets all these requirements of this application case, but Li–Mg–N [4] or Li–Mg–N–B [5] systems are promising candidates for amendments and meeting most out of many requirements. Although the properties of the metal hydride are vital for final systems performance, they are secondary to technological system implementation since one metal hydride can be readily substituted for another as long this creates no conflict with system parameters. For that reason, we implement the system with 2.5 mol% titanium trichloride doped sodium alanate because the thermal properties of this material are well known and its high cyclic stability has already been demonstrated on various similar applications [6–9]. However, in order to have a significant advantage over next generation batteries at system level, the cyclic gravimetric hydrogen storage capacity of Ti-doped $NaAlH_4$ of $3 \cdot x$ wt.% should be exceeded as far as possible. Contrary to a high pressure gas tank where the pressure vessel accounts for the largest share of the mass budget, the MH tank efficiency is dominated by the gravimetric storage density of the metal hydride. Fig. 3 shows the mass distribution within the MH tank system for sodium alanate according to our simulations and the potential mass savings if a 10 wt.% material can be used instead of a 4 wt.% material. Note that the very low contribution of the pressure vessel results from the fact, that the heat exchanger is designed as a structural part of the tank. This results in an overall contribution of the tank mass of about 15% of the hydride material. Two recent comprehensive assessments of metal hydride storage systems for passenger vehicles