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On-board hydrogen production for auxiliary power in passenger aircraft☆

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ABSTRACT

This paper presents the potential of a method for on-demand hydrogen generation from the reaction of activated aluminum powder and water for commercial aircraft applications. The hydrogen produced on-board during flight can be used in a fuel cell to generate electric energy. Results of an investigation of the reaction between aluminum and urine show that, in addition to fresh water, the waste water available on-board the aircraft can be used for hydrogen generation. High reaction rates producing about 200–600 ml/min/g Al of hydrogen at a high yield of about 90% was demonstrated. The possibility to use the available waste water leads to high specific electric energy of up to about 850 Wh/kg. In addition, the aluminum–water reaction enables safe use of hydrogen. A comparison to the traditional hydrogen storage methods is also presented.

Introduction

Future aircraft design tends to be more electric and less polluting. As part of the transition towards more electric aircraft (MEA), current hydraulic and pneumatic systems are converted to electric operation [1,2]. The need in additional clean sources of electric power can be addressed by Proton Exchange Membrane (PEM) fuel cells which are non-polluting, as they produce electric energy using hydrogen (stored) and oxygen (from the air), with only water as a byproduct. In addition, they are relatively lightweight therefore enabling high specific energy (energy per unit mass) storage. Moreover, PEM fuel cells are characterized by quiet operation at low temperatures (typically 20–100 °C) and high efficiency (about 50%) of power generation.

One of the main challenges associated with the use of PEM fuel cells on-board an aircraft is the hydrogen fuel storage due to hydrogen's extremely low density (gaseous state: 0.089 kg/m^3, liquid state: 71 kg/m^3). It implies storage as hydrogen gas at very high pressures (350–700 bar) or as liquid at very low temperatures (~20 K). Furthermore, central storage and long pipelines of elemental hydrogen within the aircraft involve safety issues due to its high flammability and explosion hazards.

A novel method for in-situ and on-demand hydrogen production was developed and patented at the Faculty of Aerospace Engineering of the Technion – Israel Institute of technology [3], based on activation of aluminum powder to react spontaneously with any type of water at room temperature. The hydrogen produced on-board the aircraft, during

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flight, can be channeled to a fuel cell for electric energy generation. This technology offers a good solution to the challenges mentioned above, namely, high specific energy storage with no actual storage of gaseous or liquid hydrogen. Only activated aluminum powder should be stored, producing hydrogen gas only when needed, according to the rate of its use. Furthermore, fuel cell units with their assigned hydrogen source may be located at the points of need on-board the aircraft.

The objective of this paper is to present and investigate this method of activated aluminum–water reaction for hydrogen production on-board an aircraft, using fresh and waste water already existing in the aircraft, and to introduce the application of this method in fuel cells for electric energy generation. Comparison to other hydrogen storage methods is presented as well.

Hydrogen and fuel cells on-board commercial aircraft

Applications of fuel cells

In the last several years the application of fuel cells in commercial aviation has been drawing much attention, and various researches (including by Boeing, Airbus, and DLR) have been conducted in order to integrate fuel cells in future aircraft. Various applications have been investigated, including on-board power systems for electricity supply during routine flight, emergency power systems, and ground auxiliary power systems in airports. For example, Boeing has investigated the integration of PEM fuel cells in the 787-8 aircraft which represents a state of the art electric airplane; its electric generation capacity is 1.5 MW, almost an order of magnitude larger than previous designs [4,5]. The fuel cells will provide power during flight to the galleys (60 kW rear galley, 40 kW forward galley, 20 kW mid galley) and entertainment system (maximum of 20 kW, active for all phases of flight) as well as an alternative power source used for peak electrical loads during descent and landing (two 75 kW fuel cells, one for each engine). As a first step, Boeing performed the first manned flight with fuel cells, in 2008, with a modified two-seater motor glider [6]. Airbus and DLR are cooperating in investigating fuel cell applications in aircraft, including PEM fuel cells testing in ATRA research aircraft (A320) as an emergency power system of 20 kW, and in Antares DLR-H2 research aircraft, the first manned fuel cell powered aircraft demonstrating long distance capabilities as well as take-off using fuel cells as the only power source [7–9].

Fuel cells can play an important role also in airports, by providing on-ground auxiliary power, since it is expected that in the future there will be regulations for limiting emissions from aircraft while they are on the ground [10]. Higher taxes and airport tariffs are expected according to ground emissions [7]. The main functions of the ground auxiliary power unit (APU) include engine start, avionics systems, environmental control systems (air conditioning), de-icing devices, and taxiing. Gas turbine APU's operate at less than 20% load cycle efficiency contributing 20% of the airport ground emissions. Using fuel cell APU's will dramatically decrease emissions and noise, and could reduce aircraft fuel consumption [1,11]. In June 2011, DLR demonstrated successfully electric taxiing of the ATRA research aircraft (A320) using PEM fuel cells in the nose wheel drive [9]. In addition, fuel cells can be used in aviation ground support equipment (GSE), as was demonstrated in the hydrogen fuel cell mobile light tower (H_2LT) project that is described in detail in Ref. [12]. In this project a 5 kW PEM fuel cell has powered mobile lighting towers at San Francisco airport reducing emission and noise.

The main advantages associated with the use of hydrogen fuel cells in commercial aircraft are:

- **Emission reduction** – drastic reduction in CO_2 and nitrogen oxides (NOx) emission.
  The European vision for future aviation (2050) states its goals regarding environmental protection. The targets include 75% reduction in CO_2 emissions and 90% reduction in NOx emissions per passenger kilometer [13].
  Global aviation is responsible for about 2% of the global anthropogenic CO_2 emissions. International aviation accounts for about 60% of those emissions [14]. In addition, by the year 2030 air traffic is expected to increase substantially with continued growth to 2050. Therefore, an increase in aircraft noise and emissions that affect local air quality and global climate is expected [14].
  A research conducted by Sandia laboratories [4,5] found that the use of PEM fuel cells have the potential to decrease the amount of fuel used to generate electricity by 30%; it means that a fleet of 1000 airplanes equipped with fuel cells can lead to a reduction of more than 20,000 tons of CO_2 annually.
  The DOE has published that the use of fuel cells for auxiliary power unit (APU) in aircraft could result in a 2–5% reduction in the total amount of aircraft fuel used by the U.S. Air Force, saving 1 million to 3 million barrels of jet fuel [10].
- **Quiet operation** – fuel cell operation is quiet, and can reduce the noise in airports which is being restricted [5,7].
- **Electric power generation efficiency** – PEM fuel cells exhibit high efficiency of electric energy generation, about 50% of the HHV (High Heating Value) of the chemical reaction between hydrogen and oxygen. In comparison, the efficiency of current electric energy supply by the generators of the main engines is about 30–40% during flight, and about 10–20% when idling [7].
- **Thermal efficiency** – The heat generated by the fuel cells can be used for de-icing [7], heating water and food at the galleys, and moreover for heating the jet fuel, increasing the engine efficiency [5].
- **Wiring reduction** – When using fuel cells as a power source, multiple fuel cells can be located at the aircraft, near their point of use. Unlike the traditional design where power is generated near the engines and the APU. The shorter distance between power generation and use increases the power distribution efficiency [2,5].
- **Inert gas generation** – The exhaust gas produced at the fuel cell cathode is an oxygen depleted air (ODA) that can be transformed to an inert gas, channeled to the jet fuel tank during flight, reducing the fraction of flammable vapors and increasing safety [7,8,11].

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