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Hydrogen generation from aluminum composites hydrolysis for space propulsion

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Abstract

Hydrogen is a green energy source, largely used in space propulsion, but its extraction is still an environmental problem since 96% of it comes from hydrocarbon reforming, and only 4% from electrolysis. Other major drawbacks that limit hydrogen energy economy on a large scale are its difficult transport and storage due to safety and volumetric reasons. These problems can be solved by aluminium hydrolysis. Indeed, aluminium exothermically reacts with water to produce hydrogen and non-toxic Al hydroxides and oxides. It is known that the reaction between Al and water is prevented by the oxide layer around the metal particles. However, this layer can be removed by chemical or physical activation processes. Once the aluminium is activated, the Al-water reaction satisfies the requisite of an in-situ and on demand hydrogen production method, overcoming the storage and handling issues.

This paper debates the activation of aluminium powders and its effects on the Al-water reactions. The initial morphology of the powder is modified by ball milling with activation metals that fractures the aluminium oxide passivation layer, promoting the galvanic activity. The Al-water reactions, focusing on the hydrogen generation rate, yield and catalytic effects, are examined and discussed. Microstructure, surface area of the active Al composite particles, Al-water reactions, hydrogen generation rate and catalytic effects are investigated and discussed, supported by experimental tests performed through SEM analysis and XRD measurements. A special focus is directed on the energy efficiency of the process and on the recovery of activation metals and Al hydroxides produced during the oxidation reaction.

In particular, the behaviour of aluminium hydrolysis vs water temperature and pressure is investigated. A 90 wt% Al - 5 wt% Bi - 5 wt% NaCl composite powder is activated mechanically by ball milling, using a planetary ball miller. Bi acts as a catalyst in the aluminium oxidation, while NaCl is an assisting agent of the milling process. To preserve and handle the produced powder in an easier way, tablets of 0.5 grams are then formed by compression at 100 bar. The tablet reacts with tap water in an airtight and watertight apparatus, that does not permit mixing of the generated hydrogen with gases in the external environment. The experiments are conducted changing water temperature and pressure, in the range 20 – 70°C and 1 – 4 bar respectively, repeating each combination three times to validate the reliability of the results. Typical trends, for the mentioned operating conditions, are shown in Figure 1.

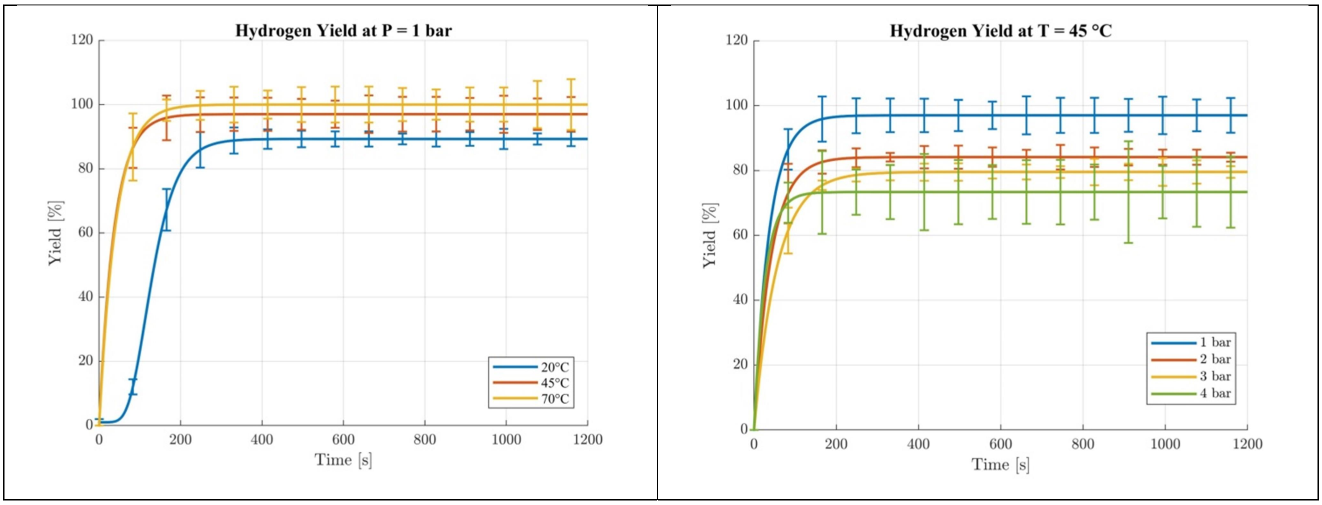

Figure 1.

Left: Trend of hydrogen yield vs. time at p = 1 bar and different temperatures, for the composition taken as reference composition in the paper. The temperature increase points out the significant change in the reaction induction time, the change in the reaction rate, the hydrogen yield.
Right: Trend of hydrogen yield vs. time at T = 45 °C and different pressures, for the composition taken as reference composition in the paper. The pressure increase shows a reduction in the hydrogen yield.

In the second section of the paper, hydrogen production by Al-water reaction is used to fuel a small propulsion unit. As small satellites are becoming popular and increasingly powerful, the attention on new strategies to provide efficient in-space propulsion systems increases. In the framework of this trend, a study is performed for the exploitation of this propulsion system, beneficial for the creation of smaller and lighter propulsion units which do not require the pressurization of hydrogen tanks.

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