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Thermo-economic analysis of a hydrogen production system by sodium borohydride ($NaBH_4$)

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ABSTRACT

In the spectrum of current energy possibilities, hydrogen represents a solution of great interest toward a future sustainable energy system. No single technology can sustain the energy needs of the whole society, but integration and hybridization are two key strategic features for viable energy production based in hydrogen economy.

In the present work, a hydrogen energy model is analyzed. In this model hydrogen is produced through the electrolysis of water, taking advantage of the electrical energy produced by a renewable generator (photovoltaic panels). The produced hydrogen is chemically stored by the synthesis of sodium borohydride ($NaBH_4$). $NaBH_4$ promising features in terms of safety and high volumetric density are exploited for transportation to a remote site where hydrogen is released from $NaBH_4$ hydrolysis and used for energy production.

This model is compared from an economic standpoint with the traditional hydrogen storage and transportation technology (compressed hydrogen in tanks).

This paper presents a thermodynamic and economic analysis of the process in order to determine its economic feasibility. Data employed for the realization of the model have been gathered from recent important progresses made on the subject.

The innovative plant including $NaBH_4$ synthesis and transportation is compared from an economic standpoint with the traditional hydrogen storage and transportation technology (compressed hydrogen in tanks). As a final point, the best technology and the components' optimal sizes are evaluated for both cases in order to minimize production costs.

Introduction

The increasing stringency of environmental rules set in the last years has prompted the research to study innovative fuels with low environmental impact. In this context, hydrogen is becoming more and more interesting because it is a clean fuel, with zero CO and CO_2 emissions during its combustion [1]. Hydrogen can be produced by several methods such as steam reforming, coal gasification and water electrolysis. In particular, electrolysis of water is a well-known process that requires electricity, which can be provided by clean and renewable energy sources [2–17] and, in this case, hydrogen production is completely a sustainable process from the environmental standpoint. Hydrogen storage and transport are critical issues involving intense researches. The problem is related to the low density of hydrogen gas (0.09 kg/m^3 in standard conditions, that is 8 times lower than methane),

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therefore, hydrogen storage is mandatory in order to allow its transportation [18–22]. The most common method consists in H_2 compression and storage in high-pressure tanks (at least 200 bar), however despite the technology is well known, this method still presents disadvantages, related to high energy consumptions and to safety, since H_2 has a very wide range of flammability in air (from 4% to 75%).

The aim of this paper is to consider H_2 storage by chemical hydrides (sodium borohydride $NaBH_4$) [23–25] and to analyze it from both energetic and economic standpoints, comparing it to the traditional state of the art storage method of pressurized tanks in order to evaluate its feasibility and implementation in the low-to-midterm future.

$NaBH_4$, in standard conditions, is a solid powder with a density of 1070 kg/m^3 and 11% in weight of hydrogen that can reversibly absorbed and released. Furthermore, $NaBH_4$ safety issues for manage and transportation are significantly reduced in comparison with pressurized hydrogen. The use of $NaBH_4$ has promising perspectives, however drawbacks have to be carefully considered for its application. Among these there are i) the necessity to develop a plant for its production, ii) the production needs a expensive reducing agent, iii) hydrogen is released by a hydrolysis process. This paper focuses on the main aspects that determine the feasibility of H_2 storage and release by $NaBH_4$ analysing a scenario common in several applications in the hydrogen economy and using existing technologies.

Plant description

The idea of the thermo-economic analysis of this specific hydrogen production plant aims to evaluate the practical applications of the emerging storage technology for sodium borohydride, with particular attention to the economic feasibility, the main problem of this specific project. Fig. 1 shows the scheme and the energy flows for the system under analysis. PV panels have been connected to an alkaline electrolyzer, which has been designed for a nominal input power of 1 MW. With this input, the electrolyzer produces hydrogen (pressure 30 bar) which is sent to the regenerator reactor of the sodium borohydride (see Section Plant description). In order to provide the necessary thermal power for this latter component, an electric furnace alimented by renewable energy is considered. Once the reaction temperature is reached, it can be maintained also thanks to the exothermicity of the reaction which takes place once the gaseous hydrogen stream is fed [26].

The produced $NaBH_4$ powder is distributed via trucks, then hydrogen is made available in the local usage zone through a $NaBH_4$ hydrolysis reactors (see Section Plant description).

The hydrogen flow produced by the hydrolysis reactor is about twice the amount restrained in the borohydride. An estimate of H_2 production cost has been carried out considering the total annual cost of the plant operation and the produced H_2.

Considering the features of this system, which depend on the availability of the solar energy source to feed the electrolyser for H_2 production, a time-dependent analysis is mandatory to provide a reliable thermo-economic analysis. Therefore, the tool W-ECoMP [27] (Web-based Economic Cogeneration Modular Program), developed by Thermochemical Power Group (TPG) at University of Genoa for time-dependent thermo-economic optimization of energy systems is employed to determine the best configuration, in terms of the optimal size of the system's components, to minimize annual costs. The parameters for the different processes represented in Fig. 1 are described in the paragraphs below: these data have been employed for the thermo-economic analysis with the W-ECoMP tool, described in the second part of the paper.

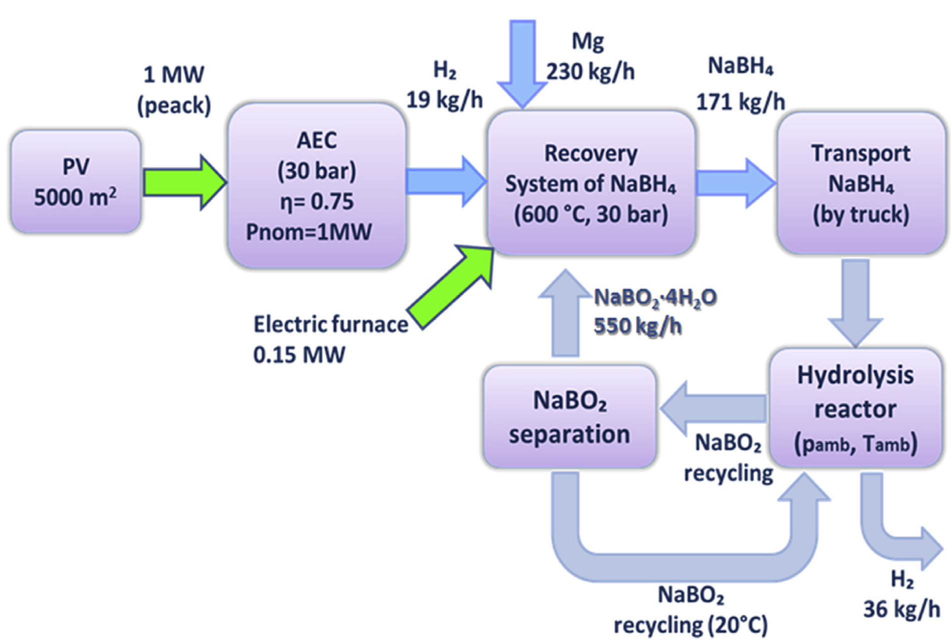

Fig. 1 – Energy balance of the process.