LITERATURE REVIEW OF HYDROGEN PRODUCTION BY CSP AND ADVANTAGES OF LIQUID HYDROGEN STORAGE

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Abstract. *CSP plants proved to be applicable to produce hydrogen from different vias. Production of hydrogen from a renewable resource, in others words a free emission system, can be a potential energy carrier to support future energy demands or be applied as a backup system. This paper presents an overview about different approaches to produce hydrogen from CSP technologies that are already available. Furthermore the analysis presents some relevant aspects of the CSP through some studies from literature. A brief study of hydrogen storage is presented. Finally, liquid hydrogen and liquid organic hydrogen storage are presented as a better solution for mobile and stationary applications when compared to compressed hydrogen.*

Keywords: *CSP Technologies; Hydrogen storage.*

1. INTRODUCTION

In order to achieve the future demands of energy and reduce greenhouse gases, a mature stage of concentrated solar power plants (CSP) appears with potential between others renewable resources. The CSP principle is to warm a specific fluid that flows through a path in order to receive the heat that is reflected by the mirrors. The most usual configurations of mirrors are: the parabolic disk, the central tower and the parabolic trough.

In fact, CSP technology can be used to produce hydrogen, which is considered a promisor energy vector and storage of renewable energy to substitute fossil fuels. Hydrogen can be produced by different ways, such as: Electrolysis via electricity generation, or via high temperature, or by thermolysis.

The International Energy Agency (IEA) predicts an expansion of global energy consumption in 40% until 2030 (Shabani, 2010), some articles present that the world energy consumption will increase almost 70% before 2050 (Crabtree *et al*., 2004). Trying to solve this issue, the CSP technologies have been applied in many countries, such as Spain, Algeria, Morocco, and USA as an alternative to produce renewable energy (Coelho *et al.*, 2010). Also the scenarios for CSP applications in Brazil have already been done (Martins *et al*., 2012).

As a result of the maturity stage of CSP and the necessity of storing energy for long periods, the production of hydrogen by solar thermal energy has been studied (Koumingoh and Njomo, 2012). One possibility is to use the CSP with power towers configuration, which produce high temperatures and can produce electricity for lower cost than other CSP technologies, and then this energy is applied to produce hydrogen (Coelho *et al.*, 2010) and Joshi *et al.* (2010). Other study analyzed an integrated catalytic hydrothermal reforming process by production of hydrogen using parabolic trough and it appears promisor (Azadi, 2012).

Hydrogen is generally found in the world without regarding for national boundaries, but to use that like energy carriers is necessary to storage in high density energy. Hydrogen can be storage like compressed gaseous hydrogen CGH2, liquid hydrogen LH2 or using liquid organic carriers (Markiewicz *et al.,* 2015). The liquid organic hydrogen carriers LOHC is a carbon free energy route capable to store high energy content in contrast to compressed hydrogen (Teichamann *et al*, 2012).

Therefore this paper aims to present a review of the production of hydrogen by concentrated solar power in their many possibilities. In addition, it contains the advantages of storing energy in liquid hydrogen state besides the other ways.

2. METODOLOGY

In this paper it was made a literature review of several routes based on CSP technologies to produce hydrogen. These routes will be reviewed based on CSP function to production hydrogen. In the discussion section they are presented the characteristics of CSP technologies. Then the works already made about producing hydrogen from CSP are showed too, and in the last part of the discussion a brief analysis of possibilities to storage liquid hydrogen is presented.

3. DISCUSSION

As it has been said before, the basic principle of concentrated solar energy is to concentrate the normal direct solar irradiation (DNI) in a receiver with high absorption and reduces heat loss (Coelho *et al.*, 2010), (Desideri *et al.*, 2014), (Pereira, 2010). The absorber can reach temperatures around 4000 °C depending on the technology utilized. In fact, three principal technologies are: the parabolic disks, the central tower or central receivers (CRS), linear Frenel reflector (LF) and parabolic trough collectors (PTC). The last two are considered linear concentrators (Kvernevik, 2010), (Chen *et al.*, 2010).

Furthermore, the CSP have been used to produce electricity energy with Rankine power cycles using steam turbines, or with the Brayton cycle, or Stirling engines. On the other hand, some of these systems can be implemented in thermochemical applications using the energy to enable endothermic reactions. A third possibility uses this high temperature in the absorbers to produce direct reactions of thermolysis. Some authors consider all of these ways high temperature applications (Shabani, 2010), (Martins *et al.*, 2012).

3.1 The CSP to produce hydrogen

Concentrated solar energy is a renewable resource and it is linked to the future of “hydrogen economy”. This happens because hydrogen is energy carrier indeed renewable produced hydrogen for transportation fuel is one of the most popular hydrogen economy goals (Martins *et al.*, 2012).

Tab. 1 presents the main routes to produce hydrogen from CSP systems.

Table 1 - Principle routes to produce hydrogen from CSP systems

RESOURCE	ROUTES TO PRODUCE
Biomass	Gaseification
Water	Solar thermolysis; Solar thermochemical cycles
Electricity and steam	Electricity, electrolysis
Fossil fuels (natural gás; oil; coal)	Solar reforming, solar cracking; solar gasification

Production from fossil fuels could evolve sequestration of CO2 and C.

3.1.1 Production Via Solar Thermolysis

Thermolysis is a single-step dissociation of water, one of the most direct methods to produce hydrogen. The reaction is show in Eq. (1). A study of thermolysis of water is conducted in two principle ways, first with hydrogen or oxygen separation at reaction temperature and second with separation after the reaction (Baykara, 2004).

$$H_2O \rightarrow H_2 + 1/2O_2 \tag{1}$$

The temperature of reaction is limited around 2200 °C, where about 25% of water is dissociated at atmospheric pressure (Coelho *et al.*, 2010). This high temperature requires the use of high concentration systems, such as the central towers or parabolic trough collectors. It is possible to increase the rate of dissociation by enhancing the pressure of reaction and consequently the temperature in the absorber. After the dissociation is necessary to separate the hydrogen from products, being possible to use semi-permeable membranes based on ZrO2 (Coelho *et al.*, 2010), (Joshi *et al.*, 2011). Other separation systems are described, such as: by microporous refractory membranes, by metallic membranes, by centrifugation, and supersonic jets (Chen *et al.*, 2010).

3.1.2 Production Via Solar Thermochemical

The water thermochemical cycles has been studied since 1960. The temperature of this process can occur below than 900°C, lower than for direct water thermolysis. Then it is possible to use the same systems that are used in thermolysis, but with a smaller scale. Parabolic disks and tower systems are the most common devices to use in thermochemical cycles (Koumingoh and Njomo, 2012). These reactions happen in two steps, in the first step the CSP system supports the energy for the reaction and in the second step it happens an exothermic reaction, (Coelho *et al.*, 2010).

The thermochemical cycle can be combined with steam cycle, such as the dissociation of ammonia in endothermic reactor heated by a parabolic dish solar plant coupled with an exothermic reactor. The endothermic reactor is placed at the focal point of the parabolic dish. Part of the product of hydrogen and nitrogen can be transferred and stored in a liquid form, the other part is transferred to an exothermic reactor where the ammonia is reproduced and the heat transferred to a fluid in steam cycle to produce electricity energy (Kvernevik, 2010).

A hydrogen sulfide splitting using concentrated solar energy had already been studied. It was proved that this system is able to produce hydrogen at a lower cost than a hybrid system (natural gas coupled with solar plant), what could be explained because of the high cost of hybrid reactors. Other unique advantage of solar plant is that it is free from CO2 emissions (Villasmil and Steinfeld, 2010).

3.1.3. Production Via Biomass Gasification

Biomass gasification appears with positive perspective in relation to production cost. Literature agrees that this technology is the cheapest via to produce hydrogen (Coelho *et al.*, 2010). Furthermore, one experimental analysis has been made with biomass gasification by concentrating solar energy. It was used corn meal and wheat stalk. This study used a special CSP with a toroidal surface heliostat and a secondary concentrator with cone surface. This experiment also investigated the relation of direct normal solar irradiation on gasification process. Then an increase in DNI results in gain of gasification efficiency and carbon efficiency. The experimental results confirmed the feasibility of gasification by this processes (Coelho *et al.*, 2010).

3.1.4. Production Via Electricity and Steam

CRS plants for electricity generation are currently in the commercialization phase and can be competitive with the other renewable technologies, for example: photovoltaic plants. Central tower presents produces electricity at lower cost when compared to other concentrated power plants (Coelho *et al.*, 2010). Here the plant is used to heat a specific fluid, for instance: molten salt. This fluid is applied in a Rankine cycle to produce electricity, for example, and then it is utilized to produce hydrogen (Joshi *et al.*, 2010). Thermal heat storage can be applied to support energy when direct solar irradiation is not enough to generate power. The direct electrolysis via electricity shows an efficiency of 14% (Coelho *et al.*, 2010).

3.2. The liquid hydrogen storage

Hydrogen economy presents a way to carried energy produced from other sources, preferably renewable resources. The most considerable world's hydrogen production is from natural gas, around 48% (Koumingoh and Njomo, 2012).

The first two ways of storing hydrogen are by using cylinders of liquid and high compressed gas. Liquid hydrogen LH2 requires temperatures below to -253 °C and the compressed system CGH2 requires pressures up to 700 bar for mobility applications (Teichamann *et al*, 2012). These options can be applied to stationary consumption in plants with a large area for these cylinders. In high compressed system the hydrogen losses by diffusion may lead to an important energy loss.

Liquid storage and liquid organic hydrogen carriers present better conditions to improve the transportability and storage conditions for hydrogen, because of their bigger volumetric energy density in these physical states.

Liquid systems have already been applied with some plants that generate tons of hydrogen with a density energy of 2,3 kWh/l (Teichamann *et al*, 2012). The liquid hydrogen has a density of energy 71.2 kg/m³ (Teichamann *et al*, 2012), (Markiewicz *et al.*, 2015). However the literature shows that liquefaction process is very energy intensive and around 30% of energy can be consumed (Crabtree *et al.*, 2004), (Coelho *et al.*, 2010), (Markiewicz *et al.* (2015).

Liquid organic hydrogen carriers are systems formed by pairs of organic compounds, to attend the demand hydrogen can be obtained via dehydrogenation. Considering an energy consumption of 0.21 kWh of electrical energy per kWh of liquefied hydrogen and 0,035 kWh for compressed hydrogen. Besides that, for a LOHC system it is assumed 0,011 kWh of electrical energy per kWh Consumption of electric energy. Then with this conditions the LOHC presents the less energy consumption, a total of 1,1% for energy consumption, while 21% for liquid hydrogen and 3,5% for compressed hydrogen (Teichamann *et al*, (2012)

4. CONCLUSION

Different routes to produce hydrogen are possible. The link between two renewable resources turned this interesting to produce and storage energy. Therefore it could attend future demand of energy according to different conditions of each country. Of course it is necessary to study the best option of CSP to each environmental condition for normal direct solar irradiation and the availability of primary sources to produce hydrogen, such as water for thermolysis and thermochemical cycles, or biomass to thermochemical cycles.

Storage hydrogen appears with potential to support the increase in energy consumption. Then liquid hydrogen and liquid organic hydrogen carriers are energy vectors that can be used in stationary conditions or transported by ship, truck, or with some technological advantages that utilize the infrastructure of liquid fuels to handle the LOHC. Furthermore, development of new materials can improve the storage.

The improvement of production of hydrogen from CSP technologies followed by efficient hydrogen storage is dependent on advantages in new materials for tanks, absorbers, and physical structure of CSP plants.

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