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PRODUCTION OF HYDROGEN USING ALUMINUM AND ALUMINUM ALLOYS: A REVIEW

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ABSTRACT

Due to depletion of fossil fuels and the pollution caused by their burning, there is a pressing need for renewable, clean fuel alternatives for our future energy source. Scientists have been paying close attention to hydrogen, a regenerative and ecologically benign fuel with a high calorific value. The hydrogen economy idea proposes that, rather than fossil fuels, hydrogen fuel would be used to provide the majority of future global energy needs. Hydrogen production should be properly developed initially in order for the technology to be deployed in a sustainable, clean, and cost-effective way for a smooth transition to the hydrogen economy.The hydrogen industry has been recognized as a viable replacement for the non-sustainable fossil fuel economy. The development of ecologically safe and cost-effective hydrogen manufacturing techniques, which are critical for the hydrogen economy, is now ongoing. Using aluminum and its alloys to convert water or hydrocarbons to gas is one of the most promising methods to generate hydrogen. This article provides a review of aluminum-based hydrogen generation techniques, as well as their limits and commercialization difficulties. A recently developed idea for hydrogen and electromagnetic energy co - generation is also addressed.

KEYWORDS: *Aluminum, Aluminum Alloys, Alcohols, Hydrogen Production, Electricity Generation.*

INTRODUCTION

Aluminum and its alloys are regarded as one of the most appropriate metals suited for future hydrogen generation for specific metal reactants that may cause hydrogen developing chemical processes, and there is a tendency to use them as an energy source, particularly in recent years.

Furthermore, metal usage has been found as an efficient, user-friendly, and safe method for both hydrogen generation and energy storage. The goal of this article is to provide an overview of the current techniques for generating hydrogen utilizing aluminum and its alloys, as well as their limits and commercialization difficulties. These techniques are divided into two categories: aluminum–water reactions and aluminum–alcohol reactions, which convert water and hydrocarbons into hydrogen, respectively. In addition, a relatively new potential idea, hydrogen and electrical energy cogeneration, will be addressed in the next section[1][2].

1. Production and storage of hydrogen are now at a standstill:

Despite the fact that hydrogen is the most common element in the cosmos, it is seldom found on Earth. As a result, hydrogen must be extracted from either water or hydrocarbons, both are plentiful on the planet. Biological mechanisms, electrochemical water electrolysis, and chemical techniques are now used to produce hydrogen.[3] Chemical techniques control the industry for commercial hydrogen generation, owing to the poor conversion efficiency of biological systems and the high cost of hydrogen production. Steam or partial oxidation reforming of natural gas, coal gasification, biomass reforming, water photolysis, and other methods may all be used to physically extract hydrogen from its sources. Currently, steam/partial oxidation reforming of natural gas and coal gasification produce about 95 percent hydrogen. Despite the fact that these methods are mature and then have the lowest prices, they cannot be utilized as a long-term plan for the hydrogen fuel cell since the raw materials required are all derived from fossil fuels, which are neither renewable nor clean. Although biomass reforming, a plentiful and renewable resource, may be considered a sustainable method to generate hydrogen, its carbon dioxide (CO_2) neutrality remains a point of contention. Furthermore, the poor hydrogen production and energy content of biomass severely limit this method. Furthermore, the conversion of syngas to hydrogen through the water–gas shift process will need extra energy. Another drawback of biomass use is the high expense of producing, collecting, and transporting biomass. Water photolysis, a potential advanced chemical technique, is still under research, and technical challenges keep it from reaching commercial applications.[4]

2. Aluminum and its alloys are used to make hydrogen:

Aluminum and its alloys have a variety of mechanical, electrical, and thermal characteristics that make them useful. They're extensively utilized in a variety of industries, including transportation, construction, electrical engineering, and packaging. Because of its high energy density of 29 MJ/kg , there has been a growing worry in recent years about utilizing aluminum-based materials as an energy storage or converter medium. Aluminum is considered a "viable metal" since it is the most plentiful crustal metal on the planet and can be completely recycled. Its use corresponds to today's subject of creating sustainable energy. Aluminum's low weight is another benefit. Aluminum is the lightest of all widely used metals, with a density of 2700 kg/m^3. Its various alloys have densities ranging from 2600 to 2800 kg/m^3. A feature like this may enable a system's overall weight be reduced significantly. Aluminum's usage in batteries is a good illustration of how it's used in the energy sector. The potential for the discharge reaction of pure aluminum in a highly alkaline electrolyte (pH 14) may be as low as 2.33 V compared to the typical hydrogen electrode. Aluminum also has a high electrochemical equivalency of 2.98 Ah/g due to its tri-valence and low weight.[5]

Aluminum is a good anode metal for hundreds of years because of all of these characteristics. Li and Bjerrum looked examined a number of different aluminum batteries in depth. The aluminum–air battery, which consists of an aluminum anode, a gas permeation cathode, and an aqueous alkaline (sometimes neutral) electrolyte, was said to be the sole battery system that could provide an electric vehicle with a range and resupply time similar to internal-combustion-engine vehicles.

DISCUSSION

3. Production of hydrogen from aluminum–water interactions:

3.1 Aluminum–water reaction with alkali aid:

In highly alkaline conditions, hydrogen ions (OH) may dissolve the oxide layer on the aluminum surface, producing AlO_2. As a consequence, even at ambient temperature, aluminium alloys dissolve easily in a highly alkaline, resulting in hydrogen generation. Sodium hydroxide (NaOH) is the most frequently encountered alkali, and it undergoes the following sequence of reactions

This hydrogen production process is thought to include the two stages indicated in the equations above. The NaOH that was depleted for hydrogen production will be replenished by the $NaAl(OH)_4$ breakdown. As a result, if the reaction is correctly regulated, only water is used during the operation. The total reaction despite the fact that this is a well-known parasitic reaction that is undesired in alkaline–aluminum–air batteries, it does offer a small supply of hydrogen. This process has been used to create a variety of hydrogen production devices. However, generating hydrogen via this reaction has the drawback of being highly corrosive, making it unsuitable for hydrogen generation in cars or home power systems.[6]

Other hydroxides were employed as the reactive base for hydrogen generation in addition to NaOH. By raising temperature and basic concentration at same time in potassium hydroxide (KOH) solution, a synergistic impact on hydrogen liberation performance was discovered. Unfortunately, due to its interaction with CO_2 in the air, KOH was consumed, slowing down the reaction rate. A recent research evaluated the performance of three distinct hydroxides in hydrogen generation: NaOH, KOH, and $CaOH(OH)_2$. Aluminum consumption in NaOH solution was observed to be faster.[7]

4. In a neutral state, the interaction between aluminum and water:

4.1 without using alkalis, aluminum may react directly with water:

According to the preceding equation, the predicted hydrogen output of this reaction for a molar ratio combination of aluminum and water is only 3.7 weight percent, although it is still greater than other metals like Mg and Zn (3.3 wt. percent and 2.4 wt. percent , respectively). If the water generated by the driven fuel cell is fully recovered again for aforementioned process, the potential hydrogen yield rises to 5.6 wt.%, nearing the 6.0 wt.% goal established by the US Department of Energy for hydrogen storage devices.

This technique is found more safer than alkali-assisted reactions, although surface passivation in aqueous electrolyte is much easier to achieve, and metal activity with water is very low. As a result, increasing aluminum activity in water may be a critical job in this situation. The chemical activity of a freshly exposed metal surface is greater. Cutting, drilling, or grinding aluminum and its alloys in water, with the fresh surface of the metal exposed in water, resulted in the emission of hydrogen gas. Grinding produced the greatest amount of hydrogen per unit volume of metal removed. However, owing to the fast passivation of the metal surface, the reaction ceased soon after the machining stopped. Metal particles of tiny diameters, which enhance the particular exposed surface area of metals, are preferable for continuous hydrogen production. High-energy ball milling, a technique in which materials are broken into tiny particles by ball-powder impacts, is one method to create fine metal powders. Ball milling size reduction is highly dependent on the mechanical characteristics of metals.[8]

4.2 At high temperatures, an aluminum–water interaction occurs:

Apart from the above-mentioned aluminum corrosion processes in water under moderate circumstances, a combination of aluminum and water vapor may react (burn) at high pressure and temperature, resulting in the reaction:

Because of its potential use in propulsion systems, this response has gotten a lot of attention. Nano-scale aluminium with strong chemical activity, similar to alkaline metals, was used to promote this reaction. Water-soluble polymers, such as polyacrylamide, were also added to the water to prevent water evaporation during the combustion process and enable the reaction to proceed in a layer-by-layer fashion. Recent research found that this extremely exothermic combustion process (heat release of 15.4 MJ/kg) may boost hydrogen generation from $NaBH_4$ hydrolysis without using precious metal catalysts. In contrast to the realistic hydrogen production of 5 wt. percent for hydrolyzing $NaBH_4$ alone, burning of $NaBH_4/Al/H_2O$ mixtures yielded a hydrogen generation efficiency of percent and a hydrogen yield of 7 wt. percent.[9]

5. Cogeneration of hydrogen and electrical energy is a concept:

Aluminum, as previously stated, has long been a popular material for battery anodes. The aluminum–air battery was shown to be the best option for powering cars among a range of aluminum batteries. However, one serious issue with aluminum–air cells is that a parasitic reaction, occurs at the anode in conjunction with the current-generating reaction, significantly reducing the batteries' coulombic efficiency. The following two elements are the focus of efforts to inhibit this unwanted reaction: I high purity aluminum or aluminum alloys doped with these elements, and (ii) corrosion inhibitors added to the electrolyte. Both of the aforementioned methods, however, substantially raise the battery prices. Instead of inhibiting this reaction, Zhuk et al. suggested that it be used to produce hydrogen in a positive way. Calculations based on actual experimental results confirmed the viability of this concept. When the energy stored in the liberated hydrogen is taken into account, the fuel efficiency of commercially available aluminum alloys, which are more vulnerable to parasitic corrosion, is similar to that of special anode alloys in a combined system.[10]

The replacement of the oxygen diffusion anode in the aluminum-air batteries with a hydrogen-evolution cathode is an alternate approach for the co - generation of electricity generation and hydrogen. The neutral NaCl solution has been used as the electrolyte in recent experiments on this approach. The cathodic process generates the majority of the hydrogen in this approach, with the self-corrosion reaction just at anode contributing a little amount. Figure 1 depicts the structure of a combined system developed by Zhang et al. A reactor, an electrolyte reservoir, and mechanisms for electrolyte flow and hydrogen flow rate control make up the system architecture. To meet certain electrical output requirements, a number of aluminum alloys cell units that may be mechanically charged are linked in series or in parallel inside the main reactor.[11]

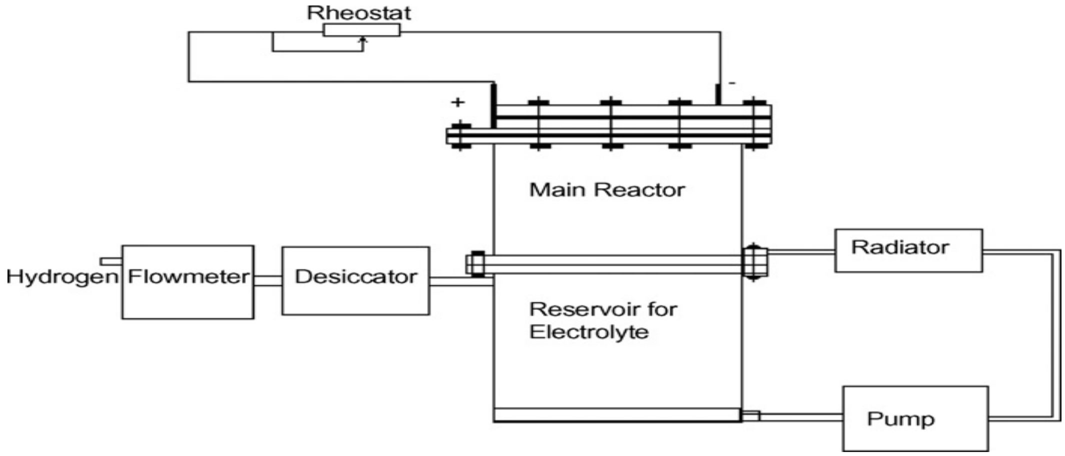

Figure 1: Structure of Aluminum water Hydrogen generator[1]

When the system is in stand-by mode, the electrolyte is stored in the reservoir underneath the main reactor. The electrolyte will be injected into the primary reactor from the reservoir to start the reaction by touching the electrodes, and the free space in the reservoirs will be utilized for hydrogen collection while the reactor is in operation. Excess electrolyte in the main reactor will flow back into the reservoir via a top-of-the-reactor exit. This kind of electrolyte circulation also aids in the removal of precipitated $Al(OH)_3$ as well as the heat produced during the reaction. The rate of hydrogen production is controlled by changing the battery's discharging density using an auxiliary rheostat. A maximum open-circuit voltage of 19.8 V and a maximum short-circuit current of 7.8 A were reported in a series of experiments on a system with the configuration shown in Figure 1 utilizing Ni nets as the cathodes. The system provided a steady power supply at a voltage of 0.45 V and a current of 7.5 A throughout the 180-minute testing period, while the hydrogen production rate remained at 1.0 L/min and above. Because the cathode activity determines the hydrogen production characteristics as well as the battery capacity of a combined system, considerable effort has gone into developing novel cathode materials with strong electro-catalytic activity at cheap prices.[12]

CONCLUSION

Aluminum alloys are very helpful in the generation of hydrogen. Aluminum's strong activity allows it to extract hydrogen from a variety of sources, including water or hydrocarbons. Aluminum–water interactions in either alkaline or neutral circumstances are the most often used reactions, whereas metal combustion and metal–alcohol reactions have received less attention. Despite significant attempts to address this issue, metal surface passivation remains a serious stumbling block. Although a theoretical hydrogen conversion yield may be achieved using difficult treatments such ball milling and specific metal doping, further study is required to improve cost efficiency and fully use the energy contained in aluminum-based materials. Systems for co - generation of hydrogen with electrical energy were suggested, inspired by aluminum batteries. Its viability, on the other hand, has to be investigated further. Aluminium alloys will play a significant part in hydrogen generation as a result of continuous research and development.

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