Generation of Hydrogen as alternate fuel from Aluminium with Gallium in Aqueous Solution

N.Nandakumar [1], M.Arularasu[2]

[1]Asst. Professor of Mech. Engg., Government College of Technology, Coimbatore, India
[2]Principal, Thanthai Periyar Government Institute of Technology, Vellore, India

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Abstract - ***Hydrogen is produced from the various renewable sources of energy such as hydroelectric power, wind, and geothermal energy. But when generated through these processes, they release a significant amount of carbon dioxide, and other greenhouse gases. On the other hand the generation from solar power and the chemical reactions remain expensive. In order to overcome these difficulties we suggest a cost effective, efficient and eco-friendly method. In this method hydrogen can be produced by the alloying of Aluminium with Gallium. Hydrogen produced through this method might be employed to power fuel cell devices for portable applications such as emergency generators, laptop, and computers. And also the waste products obtained from the reaction between alloyed aluminium and water is alumina and gallium, where alumina can be recycled to obtain aluminium and it can also be used as a desiccant. In addition, the reaction of water with molten aluminum alloys such as aluminum-lithium and aluminum-gallium has been studied***

Key Words: *Hydrogen, gallium, emissions, fuel cells*

1. PREAMBLE

The demand for energy is growing and the raw materials for fossil fuel economy are diminishing. Oil, coal and natural gas supplies are not replenished as it is consumed, so an alternative must be found. Emissions from fossil fuel usage significantly degrade air quality all over the world. The resulting carbon by product is a greenhouse gas which substantially changes the world climate. These concerns create an incentive to switch to clean and efficient alternative fuel. Hydrogen is an ideal alternative fuel, because unlike fossil fuel that can be mined or extracted, hydrogen must be produced. And also hydrogen is the cleanest fuel available whose only by-product on combustion is water.
Hydrogen is considered as an alternative fuel for two reasons. One, it is renewable and other; it is abundant on the earth. Hydrogen comprises more than 75% of the environment so if it becomes a primary fuel, dependence on natural sources of fuel would be eliminated, which in turn would avoid the emissions of toxic gases such as carbon dioxide, carbon monoxide etc., Hence it is believed that hydrogen will within a few years become the fuel that powers most reliable and portable devices, however for hydrogen to be useful as a fuel; it must exist as free hydrogen. An important application would be as a movable energy source in automotive transport, where hydrogen fuel cells now operate with an efficiency of about 50%, and perhaps 60% in the near future, while gasoline- or diesel-operated internal-combustion engines have efficiencies of 25%-30% under real driving conditions [2].

2. REVIEW OF LITERATURE

The concept of producing hydrogen by the reaction of certain metals with water was first proposed in the late nineteenth century [1]. For several years, aluminium alloys with gallium and indium have been studied which is a highly reactive materials in the aluminium-water reaction, as the minor-metal combinations cause embrittlement of the metal and destruction of the intergranular bonds and passivating aluminium oxide film. The activation of aluminium powders by grinding or milling of various compositions, Ga-In (70:30), Ga-In-Zn (70:25:3), Ga-In-Sn (62:25:13), Ga-In-Sn-Zn (60:25:10:5), leads to significant rates of hydrogen gas evolution on water contact [5] [6].
It has been shown that mixtures of aluminum and aluminum oxide (Al_2O_3) powders are reactive with water in the pH range of 4-9 [7] [8] and at temperatures of 10-90° C. These Al- Al_2O_3 powder mixtures must be heavily ball-milled together in order to produce hydrogen reactions. Hydrogen can be evolved at room temperature using essentially neutral water, although the hydrogen evolution rate increases with increasing temperature.

3. HYDROGEN PRODUCTION

A definite method in the new developments of energy technologies is played by hydrogen. It has to be considered an energy vector, a material produced by an endergonic chemical process starting from hydrogen-containing compounds, and whose chemical potential can in turn be converted to other forms of energy, by combustion in air, through fuel cells, or by other means [2] The aluminium-water reaction produces energy in different forms, all of which are potentially usable: heat, water vapour, and hydrogen gas.

The water vapour and hydrogen gas formed can be used to power a turbine, and the hydrogen gas furthermore represents an energy reservoir to be used by high-temperature combustion or to feed fuel cells. Such systems have been quantitatively modeled [3]. The second output of an energy conversion system based on the aluminum combustion with water is the heat released by reaction. The aluminum oxidation with water generates an amount of heat equal to 17.6 MJ per kilogram of aluminum; thus, it is possible to vaporize the water exceeding the chemically correct value required for the Al–H_2O oxidation. Therefore, superheated steam can be created and employed in a steam cycle system to produce mechanical work by means of a steam turbine, or in an external combustion engine, such as a Stirling engine, or in another heat recovery system based on superheated steam. Hydrogen can be produced from a variety of renewable sources of energy such as hydroelectric power, wind, solar power, geothermal energy and by chemical reactions. These methods are either expensive or it results in the emission of greenhouse gases. In order to overcome these difficulties we suggest a new method of production of hydrogen from the alloying of aluminium.

4. CHEMICAL REACTION.

Aluminium has a strong urge to react with oxygen. The aluminium thus extracts the oxygen from water and frees up hydrogen from the water molecule. Because of its low equivalent weight, aluminium is an excellent potential producer of hydrogen by weight, Due to its highly negative potential, aluminium should react easily with water, producing hydrogen gas and $Al(OH)_3$ according to the equation

$$2Al + 3H_2O = 3H_2 + Al_2O_3 \qquad (1)$$

Aluminum has always been an extremely favorable anode material, given its high electrochemical potential and low equivalent weight, which produces a theoretical energy density of 8.1 kWhlkg AI. Another important issue relating the energy conversion and hydrogen production system based on the Al–H_2O oxidation concerns the water supply requirement. In fact, even though we can consider aluminum in a closed lifecycle via the alumina recycling, a large amount of water is still needed, i.e. approximately one kg. of water is consumed for each kilogram of oxidized aluminum and therefore more than 8 kg of water is necessary to produce 1 kg of H_2.

4.1 Reactions of Aluminium with water

This passivation of the aluminium also interferes with the aluminium-water reaction at the interface between metal and liquid. Surface oxidation of the aluminium also comes about as a result of the aluminium-water reaction itself, and may also constitute a limitation to the rate and yield of the reaction.

$$2Al + 6H_2O = 2Al(OH)_3 + 3H_2 \qquad (2)$$

At 280 degree C

$$2Al + 4H_2O = 2AlO(OH) + 3H_2 \qquad (3)$$

At 280 - 480 degree C

$$2Al + 3H_2O = 2AlO_3 + 3H_2 \qquad (4)$$

At above 480 degree C

The first reaction forms the aluminum hydroxide ($Al(OH)_3$) and hydrogen, the second reaction forms the aluminium oxy-hydroxide (AlO(OH)) and hydrogen, and the third reaction forms aluminum oxide and hydrogen. All these reactions are thermodynamically favorable from room temperature past the melting point of aluminum (660°C). All are also highly exothermic. From room temperature to 280°C, $Al(OH)_3$ is the most stable product, while from 280-480°C, AlO(OH) is most stable. Above 480°C, $Al2O_3$ is the most stable product.

4.2 Hydrogen Reaction promoters.

The reaction is promoted by,

Hydroxide promotes such as NaOH

Oxide promoters = $Al2O_3$

Salt promoters = NaCl

In addition, the reaction of water with aluminium alloys such as aluminium-lithium can promote the reaction between aluminium and water. But in all these cases formation of a coherent and adherent aluminium oxide layer is formed which prevents the further reaction. Theoretically, the reaction of 1 g of Al with water produces 1.245 L of H_2[2]. But this reaction has a limitation, due to the passivation of the Aluminum surface caused by the dense film of Aluminum oxide which prevents further reaction. However, recent studies show that, with the help of Gallium-based alloys, the reaction could be quite efficient due to the prevention of the passivation of Aluminum surface.

4.3 Hydrogen activation.

There are commonly two ways of using Ga-based alloy as a catalyst on the reaction between aluminum and water: The first method is to initially mix all the metals including Al and Ga and then heat them at high temperature in a vacuum or inert gas atmosphere, making a bulk alloy as a whole that contains Al. After that, the bulk of alloy could be directly put into water and generate hydrogen gas in the required situation.

The second method for preparing Ga-based liquid alloy excludes the involvement of Aluminium at the beginning. After the amalgamation, alloy is formed; it could be mechanically mixed with fine Aluminium powders. This indicates that all the energy stored in the Al metal can be released locally into hydrogen energy through reaction with water with the help of Gallium based alloys.

4.4 Hydrogen formation.

In this process the formation of aluminium oxide layer is prevented by the alloying of aluminium with gallium, which in turn promotes the following reaction. The energy stored in the Al metal can be released locally into hydrogen energy through reaction with water with the help of Ga-based alloys.

$$2Al + 3H_2O = Al_2O_3 + 3H_2 \quad (5)$$

Pellets of aluminium and gallium are put together. Hydrogen is generated naturally when water is added to these pellets. Gallium is critical to the process, because it obstructs the formation of film normally created on aluminums' apparent after oxidation.

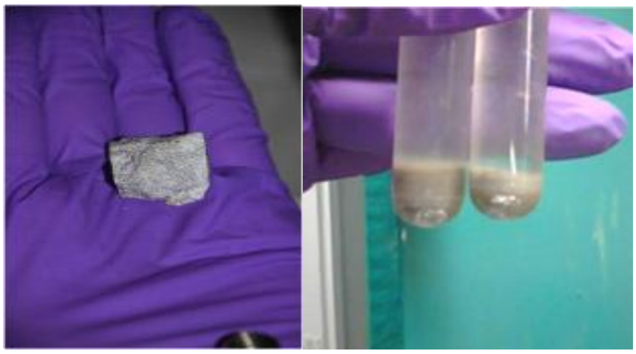

Fig. 1 Aluminium reaction process

In the hydrogen production process, the gallium would be essentially an inert type that could be reused. Ga-In-Sn liquid alloy was prepared using 65 wt% of gallium, 25wt% of indium and 10wt% of tin. Initially, physically mixed gallium and indium was heated to 150 °C until the phase changed to homogeneous liquid form. This designates that all the energy stored in the Al metal can be released locally into hydrogen energy through reaction with water with the help of Ga based alloys.

Gallium has an atomic number of 31, an atomic weight of 69.737, and melting point of 29.78 DC. The Al - Ga binary phase diagram shows gallium to be soluble in aluminum up to a maximum of 21 wt% at 26.4 DC. However the solubility of aluminum in gallium is very low. It has been reported that the lattice parameters for an Al - 0.53 at% Ga alloy were practically the same as those of pure aluminum.

5. TESTING OF HYDROGEN FUEL CELL

The hydrogen (H_2) gas used in fuel cell has to be free of impurities in order to make the fuel cell as efficient as possible and so quality thresholds have been set in legislation. Such legislation as SAE J2719 provides hydrogen fuel quality standards for proton exchange membrane (PEM) fuel cell vehicles. If impurities above these thresholds are present in the H_2 fuel then there is a risk of not only making the cell inefficient, but also unrecoverable back to its peak operating voltage as the fuel cell electrode becomes poisoned.

6. CONCLUSIONS

Both the hydrogen production reaction from Al-water reaction and the activation process between Al and Gallium based liquid alloy were observed. An attractive feature of the aluminium-water reaction as a way to produce hydrogen gas on demand is essential for the greenhouse environment. Large-scale application of the aluminium-water reaction appears less promising and is unlikely to replace to any significant extent the more established modalities, e.g. energy storage in battery banks. The reaction rate is sturdily affected by temperature and the concentration of alkali, which acts as catalyst. Additionally, high yields are acquired that come close to the exact prediction under some conditions. The speed of aluminum consumption might be easily controlled by connecting a system to a fuel cell or another device able to burn hydrogen to generate energy, especially for portable and small electric devices. The main purpose of this work is signifying the possibility of using renewable aluminum as source of hydrogen. A complete analysis on the cycle is still under study in order to optimize hydrogen production, minimize energy costs and greenhouse gases emissions.

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