1 kW Hydrogen Generation System from Hydrolysis Reaction of Sodium Borohydride

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Abstract

This project is aimed to create a 1 kW hydrogen generation system from the hydrolysis reaction of sodium borohydride. The sodium borohydride was soluted in water with 10% by weight concentration. 3% by weight of sodium hydroxide was added to the solution in order to stabilize the solution. The ruthenium on alumina substrate was produced and used as the reaction catalyst. A hydrogen generation system, which is included of a reactor with the size of 34 mm in diameter and 290 mm in length, a separator, a solution feeder, and a dehydration system was built. The system was able to provide more than 1 kW of hydrogen supply at the solution feeding rate of 24 ml/min.

***Keywords**:* Hydrogen generation, hydrogen storage, sodium borohydride, hydrolysis reaction, and hydrolysis catalyst.

1. Introduction

H.C. Brown, a Noble prize in chemistry laureate [1] proposed the idea of hydrogen generation and storage by utilizing the hydrolysis reaction of sodium borohydride as in Eq. (1). The hydrogen generation rate is partly reduced from sodium borohydride and partly extracted from water. The reaction is not rigorous, thus easy to control. The fact that this hydrolysis reaction is exothermic reaction at atmospheric condition with no additional energy required to trigger the reaction draws out interest from many researchers [1] – [3].

$$NaBH_4 + 2H_2 \longrightarrow NaBO_2 + 4H_2 + 218\ kJ \quad (1)$$

In order to be able to control the reaction rate of chemical reaction in Eq. (1), sodium hydroxide is used as stabilizing agent added in the solution of sodium borohydride in water. Therefore, the reaction rate could be easily controlled by limiting the flow rate of the solution through reaction catalysts. J. Zhang et. al. [4] – [5] successfully developed a 1 kW hydrogen generation utilizing the chemical reaction between sodium borohydride and water. In their work, they used the ruthenium-on-carbon extrudate catalyst to stimulate the reaction. Kojima et. al. [6] – [7] worked on the similar idea, but with a 10 kW hydrogen generation system. In their work, Pt-$LiCoO_2$ on monolith alumina was selected and used as the reaction catalyst. Both mentioned works guarantee the successfulness, repeatability, reliability and safety of hydrogen generation utilizing the hydrolysis chemical reaction of sodium borohydride.

J. Wee et. al. [8] were successfully using sodium borohydride as the hydrogen supplier for a 12 kW proton exchanger membrane fuel cell (PEMFC), where the PEMFCs are well-known for their intolerable to impurity of hydrogen gases. Their work is a valuable reference, which confirms the perfect purity of hydrogen gas obtained from the hydrolysis reaction of sodium borohydride. K. Kim et. al. [9] went on further to utilizing the sodium borohydride as the hydrogen source for an on-board 100 kW PEMFC in an unmanned aerial vehicle. The propulsion system driven by PEMFC coupled with the hydrogen supply from hydrolysis reaction of sodium borohydride is superior to the propulsion system driven by electric batteries, due to the comparatively higher energy storage density per weight. The unmanned aerial vehicle produced by K. Kim et. al. [9] could easily cover longer distance flight than typical electric unmanned aerial vehicles. Anyone can observe and understand the benefits of performing at higher efficiency and energy storage capacity of hydrogen storage by sodium borohydride over electrical batteries.

2. Production of a 1 kW prototype hydrogen generation system

In this work, a prototype of 1 kW hydrogen generation system was built under financial support from the Electrical Authority of Thailand (EGAT). The proposes of the prototype were not only limited to the system demonstration, but also to create an experimental platform for testing the quality of sodium borohydride being under production at the research facilities in the department of mechanical engineering at King Mongkut's University of Technology Thonburi. The built system as in Fig. 1 is composed of a hydrogen feeding system, reactor, separator, and dehydration unit. Since the reaction is exothermic reaction, there would have water vapor evaporated from the solution surface, and thus the dehydration unit is required in order to control the humidity ratio of hydrogen gas released from the system. The humidity level of hydrogen gas is crucial to the performance of oxidation reaction devices such as in fuel cells. The reactor contains the catalyst to stimulate the hydrolysis reaction, where the separator increases the residual time of solution flow and allows the hydrogen gas to completely leave the solution.

Figure 1 the built 1 kW hydrogen generation system

Figure 2 shows the process schematic diagram of the built hydrogen generation system. The solution of sodium borohydride in water with 10% by weight was prepared and contained in the fuel tank; and 3% by weight of Sodium hydroxide was added to stabilize the solution. The solution flow rate through the system was controlled by the flow controlled pump in Fig. 2. The solution was pumped into the reactor, where the solution was in contact with catalyst and released hydrogen gas. The hydrogen gas was allowed to completely separate from the product solution in the installed separator. The product solution, which was the solution of sodium borate in water was returned to the discharge tank. The humidity of hydrogen gas was then controlled by the heat exchanger and chiller. The desiccant dryer was used to remove moisture from the produced hydrogen gas. The high purity of hydrogen gas from the system, according to the chemical reaction in Eq. (1) could be used as cleaned energy in any preferable choices of usage without causing harmful damage to environment.

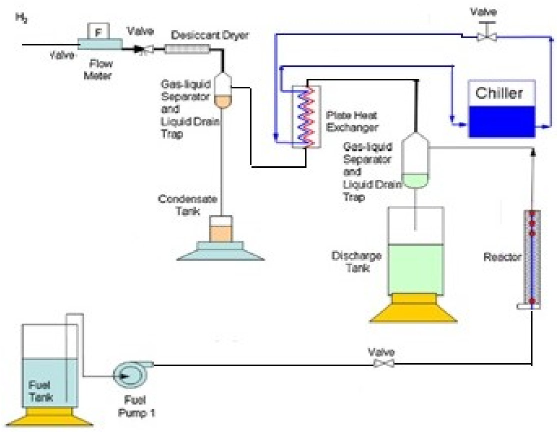

Figure 2 Schematic diagram of hydrogen generation from hydrolysis reaction of sodium borohydride.

3. Preparation of reaction catalyst

Catalyst is the most crucial to the effectiveness of the system. In this work, we chose to use the ruthenium-on-alumina catalyst due to our accessibility and comparatively cheap production price. Alumina has been used as the perfect catalyst substrate, due its excellent reactive area per weight (about 200 m^2/g). The catalyst was basically prepared by the so-called, "impregnation-reduction method". The ruthenium on alumina substrate was prepared as reaction catalyst by these following steps:

Step 1: Dehydrate alumina at 600 °C for two hours,

Step 2: Soak alumina in solution to $RuCl_3$ in water for 24 hours,

Step 3: Dehydrate the soaked alumina at 120 °C for 2 hours,

Step 4: Reduce chloride by baking at 550 °C under nitrogen environment.

and Step 5: Reduce the oxide of ruthenium by baking the catalyst at 700 °C for 6 hours before being used.

By following all the presented 5 steps, the effective catalyst was ready to be installed in the system reactor.

4. System test results

A 1 kW hydrogen generation system was successfully created and tested to verify the target of 1 kW hydrogen release rate or 6 g/min of hydrogen release. The solution feeding rate was varied until the target was achieved. As seen in Fig. 3, the hydrogen production rate at the solution flow rate of 13 mL/min, 19 mL/min and 24 mL/min was reported, respectively.

The system could provide the hydrogen release rate greater than the 1 kW target demand at the solution feeding rate of 24 mL/min, as reported in Fig. 3. The hydrogen production rate was measured by the MV-194-H2 MASS VIEW Hydrogen flow meter. The test results are valuable for creating the relation between hydrogen production rate and the solution flow rate. Such relation is important to create the controlled algorithm of the system. The built hydrogen generation system could also provide higher and lower rate of hydrogen release from the hydrolysis reaction of sodium borohydride; and the rate of hydrogen release could be simple controlled by limiting the feeding flow rate of solution.

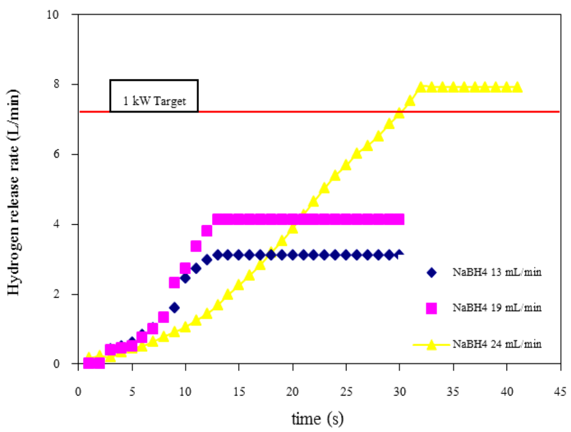

Figure 3 Hydrogen release rate according to the solution feeding rate

5. Conclusion

Hydrogen is the most cleaned energy source and has true tremendous potential for usage. Its energy density, especially when stored in the form of matter compound such as sodium borohydride is far better than any electrical batteries. In the 30% by weight of sodium borohydride in water solution could store hydrogen of about 63 grams per liter, while storing hydrogen gas in compressed tank at 5,000 psi (344.7 bar) and 10,000 psi (689.4 bar) could store hydrogen of only 23 grams per liter and 39 grams per liter, respectively. Storing hydrogen in matter compound such as sodium borohydride at atmospheric pressure diminishes the leakage problems as well as the necessary of having high strength storage tanks.

The prototype 1 kW system confirms the reliability of the proposed hydrogen production process by utilizing the hydrolysis reaction of sodium borohydride. The system proves the controllability, effectiveness and purity of produced hydrogen gas.

6. References

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