Design and Fabrication of Hydrogen Generation System for Fuel Cell

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Abstract. Sustainable and low-emission energy source, such as hydrogen-based energy, will become available as fossil fuels are producing more harmful emissions. Given that hydrogen is extremely flammable and cannot be transported in a liquid state, this research is primarily focused on the application of hydrogen in drone systems. It is therefore intended to create a system that can produce hydrogen rather than store it. Since volumetric and energy density is an important phenomenon in selecting a suitable substance for hydrogen production, hydrogen production is done through the reaction of solid sodium borohydride ($NaBH_4$) along with hydrochloric acid (HCl) as a catalytic solution. A system is built with a reactor tank (1000 cm^3) and an active ingredient tank (423.73 cm^3) made of austenitic stainless steel with a storage capacity of 500 grams of HCl. A Peltier module with a fan maintains the temperature of the hydrogen and it is pumped into a tank using a centrifugal pump

Keywords: Chemical hydrides, hydrogen generation, sodium borohydride catalyst, sodium hydroxide, fuel cells.

Abbreviation:

Aqueous – aq

Density – D

Hydrogen Generation- HG

Mass – M

Polymer Electrolyte Membrane – PEM

Unmanned Aerial Vehicle – UAV

Volume – V

1. Introduction

Electricity is an extremely important source of energy that is used in many different contexts, such as homes, businesses, trains, airplanes, farms, schools, and automobiles. Energy is produced by solar thermal power plants, geothermal, hydroelectric, nuclear fission, biomass, petroleum, and natural gas. Despite being widely available and abundant, fossil fuels are rapidly running out on our planet [1]. Pollution is particularly significant while producing power from fossil fuels. Creating power utilizing renewable sources of energy to minimize pollution and providing ecologically friendly electricity from the sun, wind, and other sources. Automobiles, is an essential component of the daily lives of human beings, contributing significantly to pollute the environment on other side. Large corporations are attempting to reduce pollution. As contemporary automotive manufacturers produce energy from via hydrogen fuel cells and also drive automobiles on it, environmental damage is reduced [22].

Hydrogen fuel cell technology provides a high-density, energy-efficient source of energy. Over the years, the requirements for H_2 have been increasing steadily [2, 23]. Hydrogen energy could be created on an industrial scale without relying on the environment, in contrast to renewable energy sources like sun, wind, and tide energy which are dependent on weather conditions [3]. When compared to combustion engines, fuel cells emit little or no pollution. Hydrogen and oxygen gas are utilized as resources in hydrogen fuel cells to generate energy. Electricity can be produced in unmanned aerial vehicles (DRONEs) using hydrogen fuel cells. Hydrogen is nearly often found as a component of another substance, such as water (H_2O) or methane (CH_4), and must be purified into pure hydrogen (H_2) before it can be used in fuel cell. Through an electrochemical mechanism, hydrogen fuel mixes with oxygen collected from the air in a fuel cell to produce power and water. As a result, the energy generated by the hydrogen fuel cell may be implemented to power the UAVs' primary movers.

As part of a high-energy-density fuel-cell system for unmanned aerial vehicles, a hydrogen generator based on solid-state Sodium Borohydride ($NaBH_4$) was presented [4]. Comparative efficiency of hydrogen storage systems employing solid-state hydrogen storage materials are studied [5]. A study of recent advances in metal hydride materials for solid-state hydrogen storage applications is discussed [6, 18]. For portable power generators, a compact PEM fuel cell technology was designed. The power generator has a PEM fuel cell that uses a chemical hydride as a hydrogen source [7]. Categorization and analysis of hydrogen storage objectives for commercial viability based on US DOE is highlighted [8]. The results of the Ammonia Borane NH_3BH_3 (AB) confinement technique was reported to assist in comprehending the benefits and identifying the constraints, which are still not well characterized [9]. A review of novel ways to improve the characteristics of solid hydrogen storage materials based on hydrides via nano-confinement was performed [10]. UAV capabilities for extended flight durations through flight tests through fuel cell were validated. Hydrolysis of NaBH4 to produce pure hydrogen, essential for efficient UAV operation was investigated [11]. Design methods for fuel cell-powered unmanned aerial vehicles, highlighting the impact of design assumptions on power plant structure and aircraft performance is compared [12]. Hydrogen storage in solid compounds was considered a promising option for energy density enhancement; hence hydrogen storage materials were explored for improved hydrogen absorption properties [13]. Options for onboard fuel storage are examined: compressed hydrogen gas storage, metal hydride storage, and onboard reformer of methanol [14]. Data relating between pH of NaOH solutions and activation energy for NaBH4 hydrolysis, as well as the rate of hydrogen production at different pH levels was highlighted [15]. Importance of constructing demonstrators and prototypes to gain insight into the problems facing its applications as a fuel and hydrogen carrier are depicted [21].

With the help of the above-mentioned research papers, the research gap can be stated as, to increase the efficiency of flight time of UAVs, hydrogen fuel cells can be used instead of conventional batteries. Utilization of aqueous $NaBH_4$ in hydrogen storage system can replace hydrogen storage system with compressed or liquefied hydrogen, while giving the same amount of hydrogen output. From the literature reviews the main objective of this paper is confined as to generate hydrogen from Sodium Borohydride for fuel cells applicable to UAVs. This research paper gives a comprehensive overview of designing, fabrication, and production of a hydrogen storage system. The production of hydrogen storage system discusses about the reaction of $NaBH_4$ with metal hydride $NaBH_4$ [20] and the catalyst HCl [19] and some amount of NaOH. The content of this paper provides the fundamental understanding necessary to comprehend the basic chemistry of fuel cell as well as its terminology. The following section also discusses the basic characteristics of hydrogen, which are necessary for using it in fuel cells and the conditions required to store it.

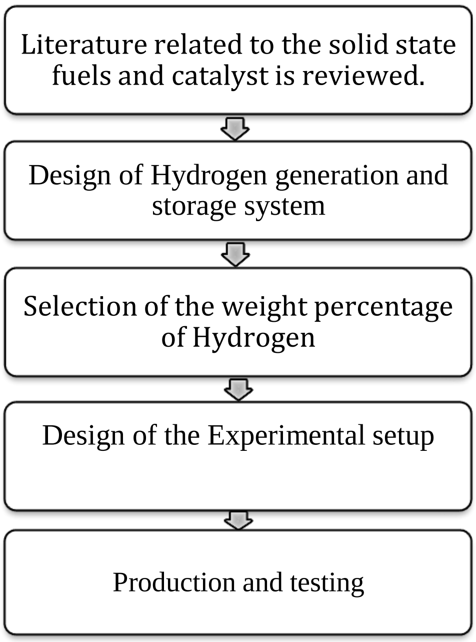


Figure.1. Methodology Flow chart

2. Methodology

Overall approach of the design, fabrication and testing of hydrogen generation and storage system of fuel cell is depicted in the flow chart as shown in the Figure.1. In order to obtain effective production of hydrogen above mentioned methodology can be used. The research work initiated with the identification of the research gap based on the literature review for the generation of hydrogen. Selection of the material is the most important and crucial part of the research investigation followed by the experimental setup and the testing. Using the chemical calculations the amount of compounds required is calculated.

3. Experimental Setup

Hydrogen generation system comprises of a fuel tank, fuel feeding pump, storage tank, and transparent pipe/tube, gas cooling fan, valves, mass flow meter, peltier module, Arduino board, computer, and power supply and the schematic diagram is shown in the Figure.2.

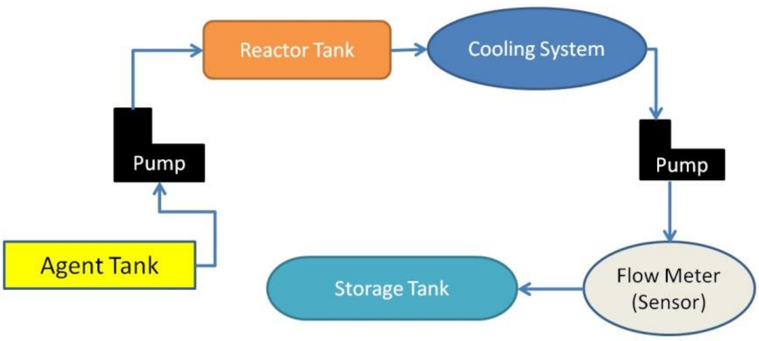


Figure.2. Schematic Diagram

The fabricated experimental setup with the components is shown in Figure.3 and its detailed specifications are tabulated in Table.1. The design of the experimental setup is carried out in such a way that the hydrogen product that is produced will be stored in a hydrogen storage tank. Austenitic stainless steel (SS304) material is used for the fabrication of the fuel tank to store $NaBH_4$ to prevent the hydrogen embrittlement process. Cooling fan is connected to cool the heating process; peltier module is a thermal control which has both ‘warming’ and ‘cooling’ effects. Two pumps are utilised, one at a location of between the agent and reactor tank, other one after the cooling system before the storage tank. A flow-meter is utilised for recording the mass flow rate, and it is stored in a computer. Power supply of 14 volts is supplied to run the pumps, peltier module and the cooling fan. Flow meter is connected to an Arduino board which record the flow-rate received from the flow meter, transparent pipe/tube are used to connect the whole setup. The computer provides the information that is recorded through Arduino. Valves are attached to regulate the flow as well as for opening and closing purpose.

Table.1. Specifications of the components

Sr.no	Components	Specifications
1	Reaction tank	150 mm x 85 mm x 85 mm Volume - 1000 cm^3
2	Pump	100 mm x 100 mm x 100 mm Outlet diameter - 7.5 mm Inlet diameter - 5 mm Weight - 70 gram
3	Cooling system	95 mm x 95 mm x 25 mm 2000 RPM
4	Peltier module	150 mm x 100 mm x 55 mm Weight - 25 gram
5	Flow meter	115 mm x 104 mm x 307 mm Weight - 40 gram Outlet/Inlet diameter - 20 mm Flow range - 1-30 ml/min
6	Storage tank	240 mm x 80 mm Weight - 350 gm Austenitic Stainless Steel Material

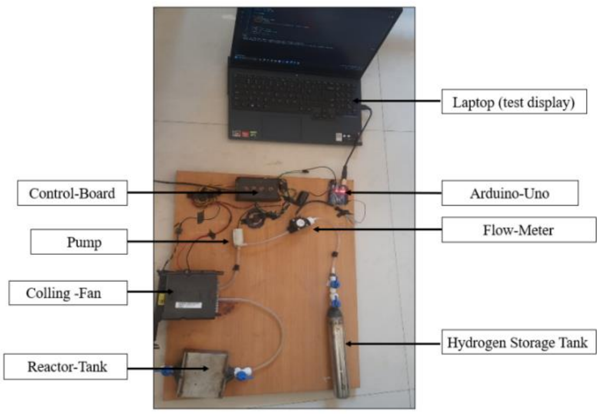


Figure.3. Experimental setup

3.1 Catalyst Preparation

In the present investigation, 500ml of diluted HCl with a concentration of 2.74 was obtained from the addition of 390ml of water to 110ml of 37% concentrated HCl.

Concentrated HCl (aq) + H_2O → Dilute HCl (aq)

Other concentration weight percentage of chemicals is considered as tabulated in Table.2.

Table.2. Concentration wt %

S.No	Chemicals	Concentration (wt %)
1	HCl	2.74
2	$NaBH_4$	74
3	NaOH	50.5

3.2 Chemical reaction of HCl over $NaBH_4$

Hydrochloric acid (HCl) can act as a catalyst in certain chemical reactions, involving sodium borohydride ($NaBH_4$) as metal hydride. Sodium borohydride is a common reducing agent used in various chemical processes. HCl can activate $NaBH_4$ by protonating the hydride ion (H^-) in $NaBH_4$, making it more reactive. The protonation of borohydride ions increases their susceptibility to nucleophilic attack, facilitating the reduction of targeted functional groups in organic compounds. HCl is often used in catalytic role, by participating in multiple reaction cycles, making it an efficient catalyst.

3.3 Hydrogen Generation Rate

In the reaction of generation of hydrogen, $NaBH_4$ reacts with diluted HCl vigorously and produces, sodium chloride NaCl, hydrogen H_2, and boric acid H_3BO_3, and its chemical reaction is as follows

$NaBH_4 + xHCl + 3H_2O \rightarrow x\,NaCl + xH_3BO_3 + 4H_2$

For production of 53.21 gm of hydrogen the required 'X' gm of $NaBH_4$ is calculated based on weight percentage of hydrogen as follows

Weight percentage of hydrogen in $NaBH_4$= 10.6%

Also, H_2 wt% in $NaBH_4$ = $\frac{H2\ output\ mass}{NaBH4\ mass}$

10.6% = $\frac{53.21}{X}$

X= $\left(\frac{53.21}{10.6}\right)$ x 100

X= 501.98 gm of $NaBH_4$

3.4 Calculation for HCl Required:

To generate 53.21 grams of hydrogen the amount of HCl required will be calculated using the steps shown below.

$NaBH_4 + x\,HCl + 3H_2O \rightarrow x\,NaCl + x\,H_3BO_3 + 4H_2$

Here, 2.74 M of HCl is used to produce 4 M of H_2

Molecular mass of HCl = 36.458 g/mol

The molecular mass of H_2 = 2.016 g/mol

Hence, 100 g of HCl is required to produce 8.054 g of H_2.

2971g of HCl produces 238g of H_2

100g HCl→ 8.064 g H_2

2971g HCl→ Y

$$Y = \left(\frac{(2971 * 8.064)}{100}\right)$$

Y = 239.8 g

Hence, to determine the grams of HCl is required to produce 53.21g of H_2 is calculated based on the following calculations

100 g HCl→ 8.064 g H_2

X → 53.21 g H_2

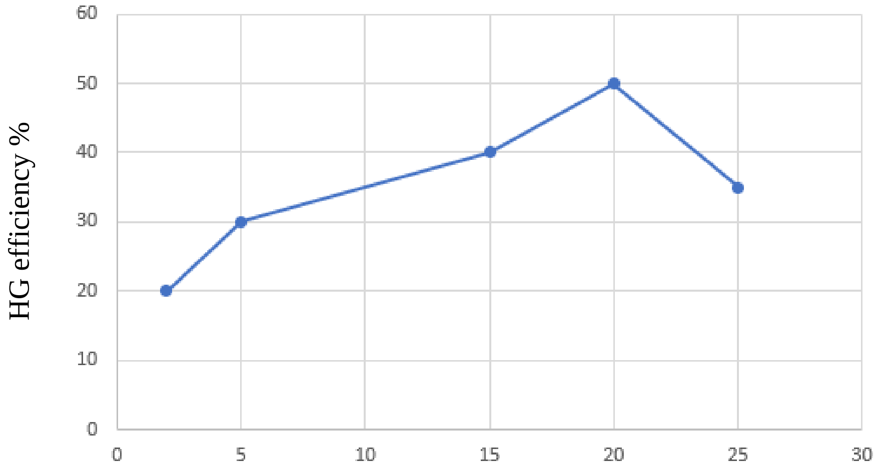
$$X = \left(\frac{(100 * 53.21)}{8.064}\right)$$

X = 659.85 g HCl

Approximately 659.85 g of HCl is required to produce 53.21 g of H_2.

4. Results and discussion:

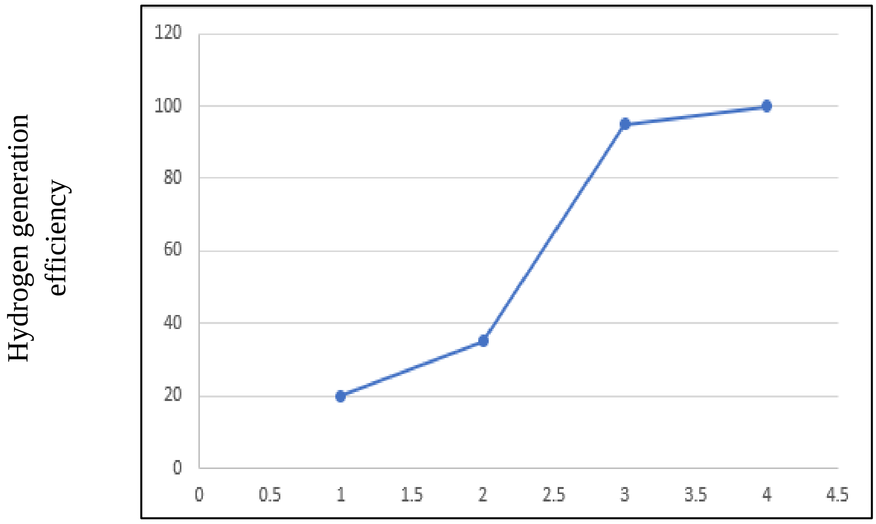
The concentration of $NaBH_4$ is a key parameter that determines the hydrogen production rate. $NaBH_4$ concentrations of 2.8, 10, 18, 20, and 25 wt% were tested in the present investigation to obtain different hydrogen production rates. All other parameters were kept constant, including NaOH concentration at 1 wt% solution of $NaBH_4$ and the feeding rate of 1 g/min HCl catalyst. Experimental results of the hydrogen generation rate and efficiency as a function of $NaBH_4$ concentration are shown in Figure 4. The by-product of the reaction, that is, $NaBO_2$, would precipitate on the catalyst surface therefore reducing the activity of the catalysts. Therefore, if the concentration of $NaBH_4$ is too high, the hydrogen generation rate of the system may decrease. From the graph it is noted that optimal hydrogen generation rate of 0.45 L/min was obtained at 20 wt% of $NaBH_4$, whereas the rate of hydrogen generation declined to 0.43 L/min when concentration of $NaBH_4$ was increased to 25 wt%. The hydrogen generation efficiency for the 20 wt% $NaBH_4$ concentration case could be up to 50% maximum value obtained. Further, increasing the concentration of NaBH4 could lead to decrease in the Hydrogen generation efficiency [16]. In theory, a system with a high $NaBH_4$ concentration, which may have a high hydrogen yield, is desirable. However, because the viscosity of the solution increases as $NaBH_4$ concentration increases, the hydrogen generation rate may slow down as a result. Therefore, considering the hydrogen content of the solution and the hydrogen generation rate by catalytic hydrolysis, the 20 wt% $NaBH_4$ concentration is ideal for practical applications.



$NaBH_4$ concentration weight %

Figure.4. Hydrogen generation rate

It is known that the $NaBH_4$ solution becomes very unstable when the solution reaches pH < 9; at a lower pH value, the hydrolysis reaction may occur spontaneously. The addition of NaOH into the $NaBH_4$ solution helps to reduce such a reaction. Although NaOH can be a stabilizer for the $NaBH_4$ solution, it inhibits the hydrogen generation rate of the hydrolysis reaction; hence both the stability of the $NaBH_4$ solution and the hydrogen generation rate of the hydrolysis reaction in the experiments are considered [16, 17].



NaOH weight %

Figure.5. Effect of NaOH concentration on hydrogen generation rate

Conclusion:

The above highlighted results and conclusion is dependent on the work performed in this research. Based on the investigation performed, the following salient points are accomplished.

● By adding specific weight percentage of NaOH in the Chemical reaction, the exothermic rate decreases and same amount of Hydrogen is also obtained.

● Comparing the experimental and theoretical values the optimal Hydrogen generation with 50 % efficiency obtained for 20wt % of $NaBH_4$.

Acknowledgement:

Specially thanking our friends Sushruti Karhade, Indresh, Sweet, Anchal and Akash who motivated us throughout this project and thanking our institution and department for giving this opportunity to perform this research project.

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