CONTROLLED, EFFICIENT HYDROGEN AND FUEL CELL DESIGN FROM SODIUM BORHYDRIDE WITH ACETIC ACID CATALYST IN POLYETHYLENE GLYCOL MEDIUM FOR FUEL CELL

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A R T I C L E I N F O

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A B S T R A C T

The aim of this study is to conduct controlled and efficient hydrogen production studies from sodium borohydride with acetic acid catalyst in polyethylene glycol medium for fuel cells. In this study, a literature review was conducted to collect data and the resources related to the subject were examined. Then, experiments related to the subject of the project were carried out. By analyzing the data and information we obtained during the project, controlled and efficient hydrogen production from sodium borohydride with acetic acid catalyst in polyethylene glycol environment for fuel cells was investigated.

Key Words : *Fuel Cells, Acetic Acid, Sodium Borohydride, Polyethylene Glycol, Hydrogen*

1. Introduction

1.1. Definition of Fuel Cell

Fuel cells are electrochemical devices that convert the chemical energy of the reaction directly into electrical energy. The basic physical structure of a fuel cell consists of a porous anode and an electrolyte layer in contact with the cathode on both sides. A diagram of the fuel cell with the reaction input and product gases is shown in Figure (1). Likewise, the flow directions of the ions through the fuel cell are also shown.

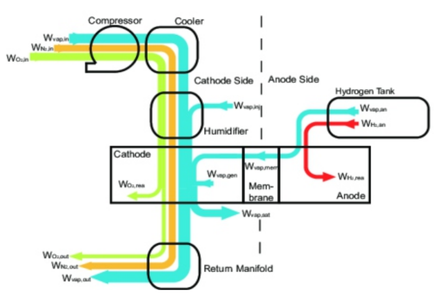

Fig. 1: The flow directions of the ions through the fuel cell

The components of a single-cell fuel cell module and fuel cell system are shown in Figure (2).

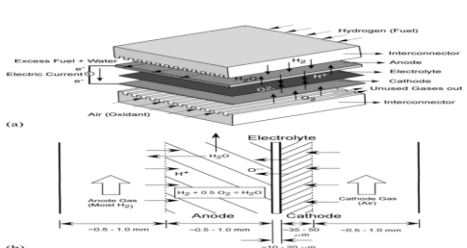

Fig. 2: Schematic representation of a single fuel cell and module

In a typical fuel cell, gaseous fuel is fed continuously to the anode (negative electrode), oxidizer (i.e. oxygen/air) to the cathode (positive electrode). In the fuel cell, while the reduction/oxidation reaction occurs between the fuel and oxygen, electric current (direct current) and heat are formed. At the cathode, protons combine with oxygen and produce only water vapor or water vapor and CO2, depending on the type of fuel used. A fuel cell is an energy conversion device theoretically capable of generating electricity as long as fuel and oxidant are fed to the electrodes. In fact, fuel cells also have a limited operating life (< 10 years for vehicles) due to degradation over time, corrosion, and component life.

1.2. Types of Fuel Cells

There are many types of fuel cells under development. These are the type of fuel and oxidizer it uses, the processing of the fuel outside (external reforming) or inside (internal reforming) of the fuel cell, electrolyte type, operating temperature, fuel supply type, etc. can be classified in many different ways. The most common classification of fuel cells is based on the type of electrolyte used in the cell. According to this classification, there are 6 types of fuel cells. These;

1. Polymer Electrolyte Membrane Fuel Cell (PEMYP)
2. Direct Methanol Fuel Cell (DMYP)
3. Alkaline Fuel Cell (AYP)
4. Phosphoric Acid Fuel Cell (FAYP)
5. Molten Carbonate Fuel Cell (EKYP)
6. Solid Oxide Fuel Cell (SFC)

In addition to its direct use in internal combustion engines, hydrogen is a fuel suitable for flameless combustion on catalytic surfaces. However, the development in the world is in line with fuel cell technology, where hydrogen is used as a fuel. Fuel cells were discovered in 1839, improved in 1932, and used by NASA as an energy provider in space studies in 1952. It was put into use in land transportation with the construction of the first fuel cell tractor in the 1960s, fuel cell train in the 1980s, fuel cell submarines and aircraft in the 1990s, it has been the subject of widespread research and application in land vehicles and power plants. Due to its high efficiency and low emissions, it has been successfully used in industry and service sectors, especially in the transportation (automotive) sector in recent years. Fuel cells are thought to revolutionize clean vehicle technology. Fuel cells can be designed to produce little power to meet the needs of mobile phones or enough to produce enough power for a city. Therefore, they have a wide usage potential from transportation vehicles to domestic and industrial applications. The size of the fuel cell market is expected to increase to 1-2 billion dollars in the next few years and to 20 billion dollars in the next decade.

Fuel cells are systems that convert chemical energy directly into electrical energy and use hydrogen as fuel. Fuel cells are energy conversion systems that are clean, do not harm the environment and work with high efficiency, in addition to their thermal efficiency over 60%, which is 2-3 times that of gasoline engines. In this system, electrical energy is produced directly without the use of a steam boiler or turbine by the electrochemical reaction between hydrogen (H2) and oxygen (O2) (the opposite of water electrolysis). Fuel cells are also known as continuously operating batteries or electrochemical machines.

Fuel cells are classified according to operating temperature, electrolyte type and fuel type. If the operating temperature of the fuel cell is lower than 150 °C, it is called "low temperature fuel cell", and if it is between 500-1000 °C, it is called "high temperature fuel cell". Whereas low temperature fuel cells require simple fuel like hydrogen and good and expensive catalyst like platinum, high temperature fuel cells have the potential to use hydrocarbon fuel and cheaper catalyst. The electrolyte used can be acidic or basic. Fuel cell fuels are generally hydrogen, natural gas (methane), methanol and propane.
Figure 1.3 shows a schematic of a fuel cell using ambient air and hydrogen. In the battery, potassium hydroxide (KOH) solution is used as the electrolyte and the battery mainly consists of two interlocking porous carbon tubes. As soon as the hydrogen flow from the inner tube starts, electricity production starts in the battery. As it passes through the outer tube in contact with the air, the oxygen separates from the air and enters the battery.

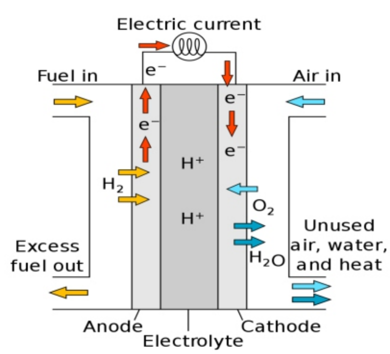

Fig. 3: Fuel cell using ambient air and hydrogen

Fuel cells are small in size, work with high efficiency, can achieve higher conversion than fossil fuels and waste heat can be used, as well as being portable, not containing moving parts, being built close to the user and in a short time, requiring very few environmental restrictions in the area to be built, fuel cells In addition to pure hydrogen, natural gas, methanol or gas produced from coal can be used, quiet operation, not causing environmental and noise pollution, and no solid waste problems.

1.3. Sodium Borohydride and Fuel Cells

The role of sodium borohydride in energy production, which is a boron compound used as a hydrogen supplier in fuel cells and on which the world works intensively, is gradually increasing. In fuel cells, sodium borohydride can be used in two main ways: 1. In hydrogen production other than the fuel cell, 2. In the fuel cell directly. Apart from the fuel cell, the catalyzed sodium bohydride solution is converted into hydrogen by passing through the hydrogen generation unit and this hydrogen is used in low temperature fuel cells. In this system, sodium borohydride catalytically gives hydrogen in aqueous medium. This technology is especially important in applications where hydrogen transport and storage is a problem such as weight, volume and safety. In direct sodium borohydride fuel cell, on the other hand, sodium borohydride is directly used as fuel without hydrogen production intermediate stage and electrical energy is produced. Direct sodium borohydride fuel cell is especially suitable for portable civilian (telephone, radio, small television, hand vacuum cleaner, etc.) and military (local lighting, mobile radio, telephone, electronic warfare devices, radio, personnel heating, unmanned vehicles, sensor etc.) is important in applications.

The advantages of producing hydrogen from sodium borohydride can be summarized as follows:

1) As a result of NaBH4-acetic acid reaction, controlled hydrogen release can be achieved.

2) The reaction occurs at room temperature and pressure and is exothermic.Therefore, no additional energy is required for the hydrogen to be released.

3) The NaBH4-acetic acid-PEG system can be an alternative system to other methods for hydrogen production.

4) The reaction products and solvent are harmless to the environment.

5) NaBH4 is safe as a hydrogen source, non-flammable and non-hazardous.

6) NaBH4 solution can stand for months without decomposition even in open air.

7) Since the freezing point of polyethylene glycol (PEG400) is -10°C, using polyethylene glycol in environments where water cannot be found in liquid form can also provide hydrogen at low temperatures.

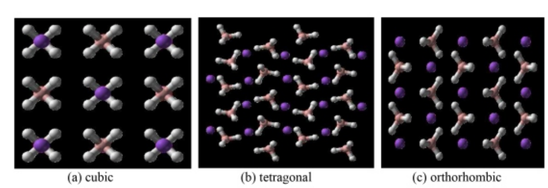

Fig. 4: Crystal structures of sodium borohydride

1.4. Fuel Cell Applications

Studies on the use of fuel cells as an automotive energy source are intensifying, especially within the scope of research for solutions to clean transportation. The proposed sodium borohydride fuel cell system for automotive applications is schematically given in Figure(4).

The first vehicle that uses fuel cells and is manufactured for research purposes is a hybrid vehicle that uses fuel cells and batteries. In this vehicle, the fuel cell and the battery are connected in parallel. While the fuel cell is used for stable driving power supply and battery charging; The battery temporarily provides additional power for starting and acceleration. The phosphoric acid (H3PO4) electrolyte fuel cell, shown schematically in Figure (5), has been defined as the most technologically advanced fuel cell today. The battery uses ambient air and hydrogen from fuels such as methanol. It is stated that the weight of the 15 kW battery is 237 kg, the volume is 0.25 m3, it gives 181 amps at 87 volts at atmospheric pressure and 177 °C operating temperature, and the power level of the battery can be changed by the number of elements or the active surface area.

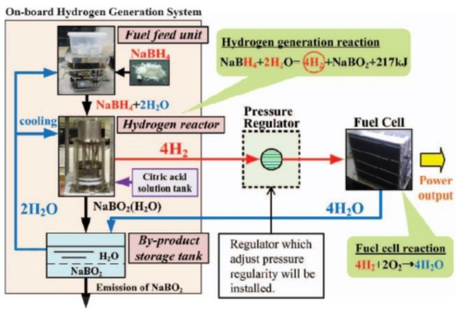

Fig. 5: The use of the H2 storage system in vehicles via NaBH4

Fig. 6: Two cars powered by a fuel cell

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1.5. Hydrogen Energy

In the last 100-150 years, the main energy sources have undergone a partial transformation from solid (coal) to liquid (petroleum) and from liquid to gas (natural gas, LPG) in recent years. This transition is expected to continue with hydrogen. Hydrogen is the simplest and most abundant element in the universe, discovered in the 1500s. It is a colorless, odorless, 14.4 times lighter than air and non-toxic gas. The fuel of the heat given by the sun and other stars through the thermonuclear reaction is hydrogen, and it is the main energy source of the universe. At normal pressure, its boiling point is -252 °C, its critical temperature is -234 °C, its critical pressure is 12.8 atm, and its critical density is 0.031 gcm^{-3}. The volume of liquid hydrogen is 1/700 of its gaseous volume. Hydrogen has the highest energy content per unit mass of all known fuels (heat of combustion = -242 $kJmol^{-1}$ = -121 $MJkg^{-1}$). The energy of 1 kg of hydrogen is equivalent to the energy of 2.1 kg of natural gas or 2.8 kg of oil. However, the volume per unit energy of hydrogen is high. Hydrogen is not found in free form in nature, it exists in the form of compounds. The most well-known compound is water. It is clean and easy to use in any area that requires heat energy. During the generation of energy from hydrogen,

$$H_2 + O_2 \rightarrow H_2O$$

Except for water vapor and partially nitrogen oxides (NO_x), no gas and harmful chemical substances (such as CO, CO_2, C_nH_m, SO_x) that pollute the environment and increase the greenhouse effect are produced. Research shows that under current conditions, hydrogen is about three times more expensive than other fuels and its use as a common energy source will depend on cost-reducing technological advances in hydrogen production. However, the inability to store electrical energy keeps hydrogen on the agenda as a storage medium. As a matter of fact, countries such as Canada and New Zealand, which have abundant hydroelectric energy resources, have started programs in this direction. This approach is based on the continuous operation of hydroelectric power plants at a certain intensity, and the excess energy is evaluated in the production of hydrogen by electrolysis of water and energy is stored in this way.

1.6. Hydrogen Production and Storage

t is accepted that the most advanced technology that can provide the world's increasing energy needs without polluting the environment and sustainably is the hydrogen energy system. Every year, 500 billion m^3 of hydrogen is produced, stored, transported and used in the world. The chemical industry, especially the petrochemical industry, has the largest share of users. In our country, gas or liquid hydrogen is produced in pressurized cylinders to be used in the artificial fertilizer industry (25000 m3), vegetable oil (margarine) production (16000 m^3), oil refineries (1200 m3), the petrochemical industry (30.000 m3) and in various places. There is no commercial hydrogen production for power generation purposes. Production sources of hydrogen are plentiful and diverse. It can be obtained from fossil fuels such as coal and natural gas, as well as by using renewable energy sources such as solar, wind and hydraulic energy, it is possible to produce from water electrolysis, biomass and biotechnological processes. Today, hydrogen is mainly obtained from the reaction of natural gas with water vapor. Perhaps the most important feature of hydrogen is that it is storable. As it is known, there is still no suitable method for storing large amounts of energy today. If it were possible to store the energy obtained from hydroelectric power plants today, it would be possible to solve the energy problem to some extent. However, the best known storage method for electrical energy is still accumulators. Hydrogen can be stored in pure form as a gas or liquid in tanks, as well as physically in carbon nanotubes or chemically in the form of hydrides. The advantages of sodium borohydride over other hydrogen transport media are summarized below:

- ü It can store 20% hydrogen by weight,
- ü It is not flammable/explosive,
- ü The reaction can be easily controlled,
- ü Catalyst and sodium metaborate are reused.

1.7. Development of Hydrogen Energy Technology in the World

Fuel cells have proven their role in space, as they have safely provided electricity (and water) on shuttle missions. These achievements led to predictions that fuel cells could be the solution to all of the world's energy problems in the 1960s, and in the 2000s, they started to take an important place in the energy policies of countries. America is marketing the phosphoric acid type fuel cell that provides 200 kW of energy. The 11 MW power plant in Japan meets the electricity and heat needs of Rokko island, and 40000 kW of the city's electricity needs in Tokyo are provided by hydrogen energy systems. Canada has offered generators with 250 kW of electricity and 230 kW of thermal power, using PEM type fuel cells.

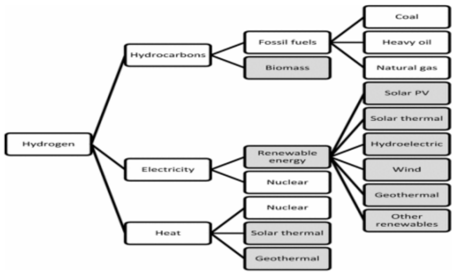


Fig. 7 : Production sources and methods of hydrogen

In the transportation sector, the development of fuel cell-powered vehicles will not only reduce oil consumption, but also minimize air pollution caused by vehicles. In addition to Canada, which produces fuel cell buses, the world's leading automotive companies are trying to commercially produce cars powered by fuel cells. A large number of sample vehicles have been produced since 1993. A new bus running on hytane, a mixture of 15-20% hydrogen and 80-85% natural gas, has been trialled since 1993 in Montreal (Canada). In addition to vehicles, Locomotives for the Canadian railways and submarines for the German, Australian and Canadian navies have also been manufactured for the use of hydrogen through internal combustion engines or fuel cells. Generally, in these vehicles, the system moves with an electric motor, there is no engine, piston, crank and gearbox. Hydrogen has been used as an unrivaled fuel in space shuttles and all other rockets for many years.

1.8. Hydrogen Energy and Turkey

Turkey is a country with the richest and highest quality boron minerals reserves in the world with a share of approximately 65%. In order for Turkey to transform its richness of boron ores into added value and to reach a position compatible with this richness in the world boron market, it is necessary to start the production of boron compounds that can be widely used in large quantities. Turkish Boron Research Institute carries out and coordinates R&D activities for the production of boron compounds with high added value and their use in critical technology areas. The production of sodium borohydride and its use in fuel cells are good examples of these compounds. Two projects on "Sodium Borohydride Synthesis and Production" and "Direct Sodium Borohydride Fuel Cell Production and Integration" supported by the Boron Research Institute are carried out at TÜBİTAK MAM. Another pleasing development regarding Hydrogen and Hydrogen Energy is the establishment of the "United Nations International Center for Hydrogen Energy Technologies (ICHET)" in Istanbul. The agreement regarding this Center was signed between Turkey and the United Nations on 21 October 2003 in Vienna. The main purpose of the Istanbul Center for hydrogen energy, which is called the energy of the future, to which the international energy circles attach great importance, together with our country, is to carry out all kinds of research and development activities related to hydrogen and hydrogen energy, to ensure coordination among investor institutions, to determine the application areas of the future hydrogen technology and industry .

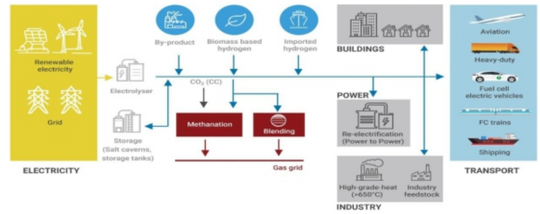


Fig. 8: Hydrogen energy system

1.9. Acetic Acid and Polyethylene Glycol

Acetic acid, also known as ethanoic acid or acetic acid, is an organic acid with open formula $CH3COOH$ and closed formula $C2H4O2$. It is the acid that gives vinegar its pungent smell and sour taste. It is the most important and smallest of the carboxylic acids. It is obtained by oxidation of carbohydrates in nature. It can be obtained biologically and synthetically in the industrial sector. The salt and ester of acetic acid, completely soluble in water, is called "acetate". It is referred to as ethanoic acid in the chemical industry. Pure acetic acid has a sharp, colorless, acrid odor and boils at 118 degrees Celsius and freezes at 16.7 degrees Celsius. When mixed with water, it absorbs water, irritates the skin and corrodes metals. The main ingredient of vinegar, which is obtained by fermenting wine or yeast, is acetic acid. Acetic acid, which has a wide use in industry, is evaluated as a raw material in the production of chemicals. It is used extensively in the production of vinyl acetate. Wood glue is obtained from this. It is also used in the production of acetic ester and acetic anhydride. It is also used as a solvent. It is used as a solvent in the production of terephthalic acid, which is used in pet plastic production. This accounts for about 5-10% of the use of acetic acid. Since it has a buffer feature in the food industry, it is used as an additive as E260. Its derivatives are also used in different fields. Sodium acetate is used as E262 in the weaving industry and as a food additive.

Polyethylene Glycol (400) (PEG) is colorless, odorless, viscous. Polyethylene Glycol is the most important glycol commercially available and produced in the world. It can be used in the production of an antifreeze and coolant, hydraulic fluids and low-freezing dynamites and resins. Polyethylene glycol is a polyether compound with many applications. It can be used in industrial and pharmaceutical production. Polyethylene glycol is produced through the interaction of ethylene oxide with water, ethylene glycol or ethylene glycol oligomers. PEG is used as an excipient in many pharmaceutical products. Low molecular weight variants of Polyethylene Glycol are used as solvents in oral liquids and soft capsules. Solid variants of Polyethylene Glycol are used as ointment bases, tablet binders, film coatings and lubricants. It can be used to create very high osmotic pressures with the flexible, water-soluble polymer property of Polyethylene Glycol. There is no possibility of specific interaction with biological chemicals in Polyethylene Glycol.

1.10. Problem Status

In the research, during the interview, the problem situation was determined as follows:

In this study, "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells" constituted the problem of this research.

1.11. Purpose of the Research

The aim of this study is to conduct "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells". In this study, a literature review was conducted to collect data and the resources related to the subject were examined. Then, experiments related to the subject of the project were carried out. By analyzing the data and information we obtained during the project, "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells" was examined.

1.12. Importance of the Research

It is seen that there is limited research in our country and internationally on the subject of "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells". For this reason, it was found important to conduct a research on this subject. The findings of this research,

1. The importance of "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells" will be revealed,
2. "Controlled, Efficient Hydrogen Recovery and Fuel Cell Design from Sodium Borohydride with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells" will help to be more constructive and permanent,
3. It will provide opportunities for reflection, discussion and new research on "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells",
4. It will provide preliminary information to the persons or organizations that will carry out the studies to be carried out on the "Controlled and Efficient Hydrogen Recovery from Sodium Borohydride with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells",
5. "Controlled, Efficient Hydrogen Recovery and Fuel Cell Design from Sodium Borohydride with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells" will be beneficial to the industry and economy of our country,
6. "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells", it would be beneficial to use polyethylene glycol instead of water as a solvent,
7. In addition, the findings obtained, educators who are interested in this subject; It is thought that it will be useful to researchers who will do research and develop projects in this field.

1.13. Counts

While conducting the research, the following assumptions were made:

1. Experiments of "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells and Fuel Cell Design" within the scope of the research accurately reflect the findings.
2. The experiments of "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells" are of the nature to serve the purpose of the research.

1.14. Limitations

The research is limited to the following dimensions in terms of the area it covers and the data it benefits from:

1. This research, with the data of the literature review and experiments conducted in 2021,
2. With the generalization included in the research from the internal and external factors affecting the experiments,
3. The research is limited to the findings of the experiments of "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells".

2. Method

In this section, information about the research model, universe and sample, data collection tool, data analysis and interpretation are given.

2.1. Research Model

In this research, which aims at "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells", a literature review has been made and resources related to the subject have been examined. Then, experiments related to the subject of the project were carried out. The data and information we obtained during the project were analyzed and the information obtained from "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells" was analyzed and analyzed. The results were edited and evaluated using Microsoft Office programs.

2.2. Universe and Sample

The universe of this research is "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells". Examples in the research universe are "resource scanning" and "observation, experiment and content analysis/text analysis etc." selected by methods.

2.3. Data Collection Tool

In this study, "resource review" and "observation, experiment and content analysis/text analysis etc." were used to collect data. used. The works related to the subject and the libraries where these works are located have been determined.

2.4. Analysis and Interpretation of Data

In order to collect data that will answer the problem and sub-problems of the research, "resource scanning" and "observation, experiment and content analysis / text analysis, etc." The obtained data were collected by the researcher. The results were edited and evaluated using Microsoft Office programs.

3. Findings

3.1. Materials

All materials used for this experiment were purchased commercially:

NaBH4, Polietilen Glikol 400 (C16H34O9), CH3COOH Hcl, C7H6O2, CH2O2, Schlenk Tube, 50 ml Burette, Micro pipette, Septum, Magnetic heater stirrer, Magnetic fish, Precision balance, Silicone hose, Stopwatch

Fig. 9: Experimental Setup

3.2. Experimental Studies

* NaBH4 was weighed with a precision balance at the appropriate rates determined in terms of hydrogen yield.
* 3 mL of Polyethylene Glycol measured with a pipette was added into the Schlenk tube.
* NaBH4 was also added to this tube and attached to the assembly with a clamp and placed on the magnetic stirrer.
* The burette device in the water has been prepared.
* The burette and the schlenk tube were connected with a silicone hose.
* Acid was added to the tube closed with a septum at the specified molar ratio.
* With the added acid, the stopwatch and magnetic stirrer were operated at 500 rpm.
* The volume of hydrogen released was measured over time.
* In this study, polyethylene glycol was used as a solvent.
* The main purpose of this selection is to facilitate the use of PEG in low air temperature environments.
* NaBH4, which reacts very slowly in the alcohol environment, reacts rapidly in the presence of acid and releases hydrogen gas.
* In the study, the effect of different acids was tested at room temperature.
* In the research, the effect of acetic acid (CH3COOH), hydrochloric acid (HCl), formic acid (CH2O2) and benzoic acid (C6H5COOH) on the reaction of obtaining hydrogen gas from NaBH4 was investigated.
* Depending on the ratio of the acid used in the reaction of the proton (hydrogen) of the acid used with NaBH4, it combines with the proton in BH4- to form hydrogen gas and sodium acetoxyboron hydride (NaBH3(OAc), NaBH2(OAc)2, NaBH(OAc)3, or NaB (OAc)4 sodium mono, di, triacetoxy borohydride and sodium tetraacetoxy boron) compounds are formed.
* The boron compound reacts (alcolysis) with the PEG used as a solvent to form hydrogen gas.

3.3. How does it work?

Fuel cell, with supplied fuel (anode side) and oxidizer (cathode side). When these react in an electrolyte environment, it produces electricity. This reaction takes place with the effect of a catalyst. The reacting fuel is split into electrons and positively charged ions (anions). Electrolytic material allows anions to pass to the cathode, but does not allow electrons to pass, so electrons are forced to flow through an electronic circuit (electric current (DA) Electrons recovered by another catalytic process combine with anions and oxidizer to produce waste products (e.g. water, carbon dioxide). With these two catalytic processes, the interior of the fuel cell remains stable, unlike the cells, and they can generate electricity as long as the required material flow is provided.

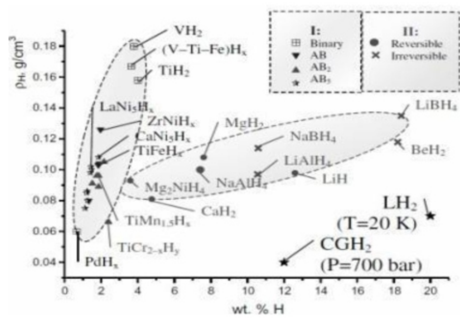


Fig. 10: Hydrogen storage capacities of metal hydrides

4. Results

Effect of different acids:

In the study, the hydrogen gas output as a result of the acid reaction with sodium borohydride was measured volumetrically and the results are given in Figure 3.6. The effect of different acids in this reaction was investigated and although formic acid, which provides the highest hydrogen gas output among the acids used, acetic acid was used in the studies because it was more economical in terms of cost.

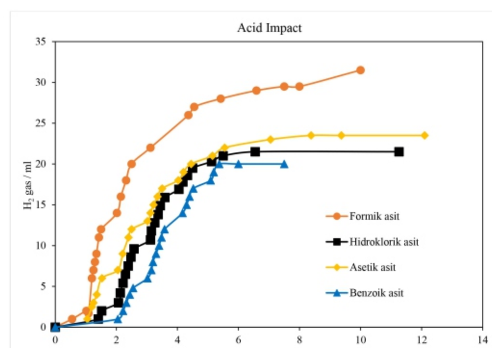


Fig. 11: Different Acid Impact

Reaction Conditions: 20 mg (5.2x10-4 mol); NaBH4; 5.2x10-4 moles (30 µL) Acid; 3 mL of PEG; P=1 atm; T=19 °C; mixing speed = 600 rpm

Effect of water-PEG mixture:

The acid reaction with NaBH4 in the medium of water-PEG mixture at different ratios was examined and the graph drawn using the results is given in Figure 3.7. Although the H2 gas output is higher in volume in the presence of water under the studied experimental conditions, the use of PEG provided the regulation of the reaction. In the presence of water, H2 gas was obtained uncontrollably and rapidly in a short time.

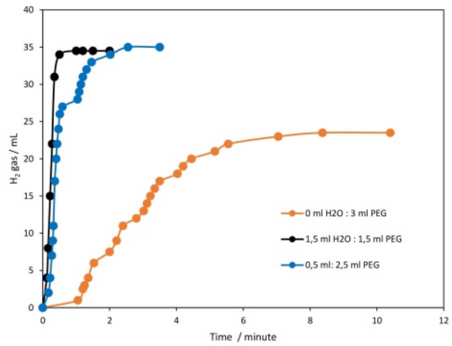


Fig. 12: Obtaining H2 gas in the presence of water

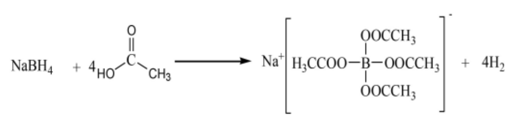
Reaction Conditions: 20 mg (5.2x10-4 mol); NaBH4; 5.2x10-4 moles (30 µL) Acetic Acid; 3 mL of PEG + H2O; P=1 atm; T=19 °C; mixing speed = 600 rpm

Effect of the amount of acid:

Figure (13) shows the graphs showing the time-dependent pleasure outputs in the results of the experiment performed by changing only the acid ratios and keeping the other parameters constant.

The reaction requirement shown below is that when NaBH4 and acetic acid react in a 1:4 mole ratio, 4 moles (50ml) of H2 gas is theoretically released.

NaBH4-acid reaction:



As a result of the experiments, more gas was released than expected in the experiments performed at 1:0.33, 1:1, 1:1.7 and 1:6.7 NaBH4:Acid ratios. On the contrary, less gas output than expected was observed in the experiment performed at a ratio of 1:6.7. As a result of these observations, it was decided that an alcoholysis reaction took place between polyethylene glycol and NaBH4.

Since the substance that bonds with the hydrogen atom in the structure of NaBH4 and provides gaseous release is both acetic acid and polyethylene glycol, no definite information about the percent efficiency of the experiment has been reached. However, it was determined that the efficiency of the experiment performed with a ratio of 1:6.7 was not 100%.

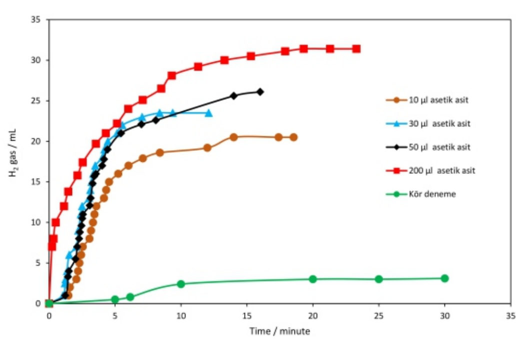


Fig. 13: Effect of the amount of acetic acid

Reaction Conditions: 20 mg (5.2x10-4 mol); NaBH4; 5.2x10-4 moles (30 µL) Acetic Acid; 3 mL of PEG; P=1 atm; T=19 °C; mixing speed = 600 rpm

Table 1: Theoretical and experimental hydrogen gas outputs in sodium borohydride-acid reaction

$NaBH_4$: Acetic acid (mol)	H_2(mL) (THEORIC)	H_2(mL) (EXPERIMENTAL)
1:0,33	4,17	20,5
1:1	12,5	23,5
1:1,7	20,9	26,0
1:6,7	50,0	31,0

Temperature influence:

NaBH4-acid reaction was investigated at two different temperatures (O °C and 19 °C). In these experiments, other reaction parameters except temperature were kept constant. (Fig. 3.9). Although the efficiency of the reaction is higher at room conditions, the reaction takes place at 0 °C, albeit at a slow rate.

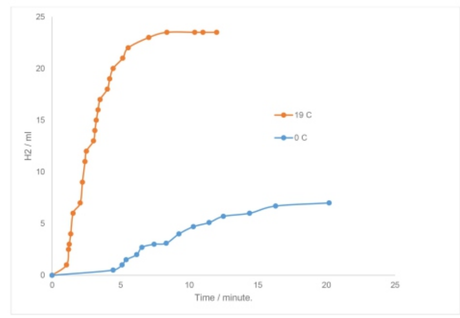


Fig. 14: Hydrogen yield of acetic acid at different temperatures

Reaction Conditions: 20 mg (5.2x10-4 mol); NaBH4; 5.2x10-4 moles (30 µL) Acetic Acid; 3 mL of PEG; P=1 atm; mixing speed = 600 rpm

5. Conclusion and Discussion

In this section, the results obtained from the findings related to the research questions are given. Then, the findings and results revealed in the research were discussed by considering the relevant subject. Apart from these, explanations about the theoretical dimensions, method and findings of the study and suggestions for similar researches to be made in the future are included.

5.1. Conclusion

The advantages of producing hydrogen from sodium borohydride in a PEG medium can be summarized as follows:

1. As a result of NaBH4-acetic acid reaction, controlled hydrogen release can be achieved.
2. The reaction occurs at room temperature and pressure and is exothermic. Therefore, no additional energy is required for the hydrogen to be released.
3. NaBH4-acetic acid - PEG system can be an alternative system to other methods for hydrogen production.
4. The reaction products and solvent are harmless to the environment.
5. NaBH4 is safe as a hydrogen source, non-flammable and non-hazardous.
6. NaBH4 solution can stand for months without decomposition even in open air.
7. Since the freezing point of polyethylene glycol

(PEG400) is -10°C, using polyethylene glycol in environments where water cannot be found in liquid form can also provide hydrogen at low temperatures.

As a result;

Electric energy is obtained from hydrogen with fuel cell technology.

In the transportation sector, the development of fuel cell-powered vehicles will not only reduce oil consumption, but also minimize air pollution caused by vehicles.

In addition to Canada, which produces fuel cell buses, the world's leading automotive companies are trying to produce cars powered by fuel cells commercially. Our domestic and national fuel cell, which we developed in our project, can be used in the domestic and national automobile (TOGG) to be produced in our country. (https://www.togg.com.tr)

A large number of sample vehicles have been produced since 1993. A new bus running on hytane, a mixture of 15-20% hydrogen and 80-85% natural gas, has been trialled since 1993 in Montreal (Canada).

In addition to vehicles, Locomotives for the Canadian railways and submarines for the German, Australian and Canadian navies have also been manufactured for the use of hydrogen through internal combustion engines or fuel cells.

Generally, in these vehicles, the system moves with an electric motor, there is no engine, piston, crank and gearbox. Because the most important factor that determines the competition in electric cars is not design, but also production. It is “Fuel Cell” technology.

Hydrogen has been used as an unrivaled fuel in space shuttles and all other rockets for many years.

In the last 100-150 years, the main energy sources have undergone a partial transformation from solid (coal) to liquid (petroleum) and from liquid to gas (natural gas, LPG) in the last years. This transition is expected to continue with hydrogen.

Fuel cells are systems that convert chemical energy directly into electrical energy and use hydrogen as fuel.

Fuel cells are energy conversion systems that are clean, do not harm the environment and operate with high efficiency, in addition to their thermal efficiency over 60%, which is 2-3 times that of gasoline engines.

In this system, electrical energy is produced directly without the use of a steam boiler or turbine by the electrochemical reaction between hydrogen (H2) and oxygen (O2) (the opposite of water electrolysis).

Considering the boron ore potential of our country, the importance of sodium borohydride fuel cells in our country's energy production increases even more.

As a result of our project work on obtaining controlled and efficient hydrogen from acetic acid and sodium borohydride for fuel cells, it will be a very important guide in future project studies.

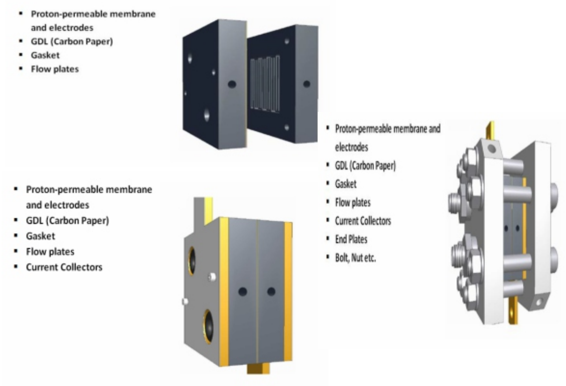
5.2. Argument

In the research, “Problems in fuel cells; in hydrogen energy; Hydrogen production systems that are economical, controlled, efficient, can be obtained even at low temperatures and do not harm the environment are still the subjects of intensive research. We have contributed to this field with the work we have done, and from the results obtained, it is understood that our work is open to development and that it should be continued and developed.

5.3. Suggestions

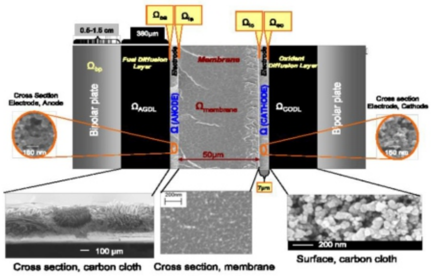
1. Since the biggest problem of the last century, which emerged as a result of developing technology and increasing population, will reduce the energy problem, systems for "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells" should be established.
2. Since fossil fuels will be depleted in the near future and the main cause of environmental pollution is largely due to the use of fossil fuels, systems for “Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells” should be developed.
3. Since the use of fuel cells is seen as the most appropriate solution within the scope of finding new, renewable energy sources that are harmless to the environment and developing new technologies, the systems for "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst for Fuel Cells in Polyethylene Glycol Environment" The financial and moral support needed for the establishment should be provided.
4. The regional and national reasons for “Controlled, Efficient Hydrogen Recovery from Sodium Borohydride with Acetic Acid Catalyst and Sodium Borohydride for Fuel Cells in Polyethylene Glycol Environment and Fuel Cell Design” should be revealed and studies should be carried out to eliminate these reasons.
5. This study will make a positive contribution due to the lack of such studies on "Controlled, Efficient Hydrogen Recovery from Sodium Borohydride and Fuel Cell Design with Acetic Acid Catalyst in Polyethylene Glycol Environment for Fuel Cells".
6. With the development of fuel cells, types that use hydrocarbon fuels and air, which still meet the power needs in some limited areas, it can be a serious competitor to today's traditional power sources in automotive and other fields in the near future, "For Fuel Cells Controlled from Sodium Borohydride with Acetic Acid Catalyst in Polyethylene Glycol Environment" Our “Effective Hydrogen Recovery and Fuel Cell Design” project should be evaluated carefully as it will provide added value to our country.
7. In order for Turkey to transform its richness of boron ores into added value and to reach a position compatible with this richness in the world boron market, it is necessary to start the production of boron compounds that can be widely used in large quantities.
8. R&D activities should be carried out on the production of sodium borohydride and its use in fuel cells.
9. It is thought that carrying out our project work at the national and international level will produce beneficial results.
10. Our domestic and national fuel cell, which we developed in our project, can be used in the domestic and national automobile (TOGG) to be produced in our country. Because the most important factor that determines the competition in electric cars is not design, but also production. It is “Fuel Cell” technology. (https://www.togg.com.tr)
11. With these suggestions, the results of our project work can be evaluated.

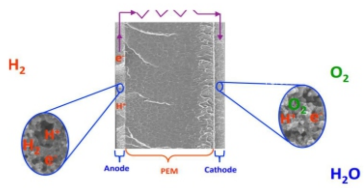
5.4. Design of Fuel Cell

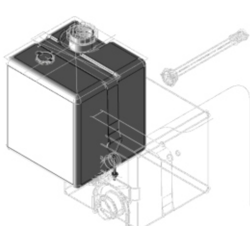


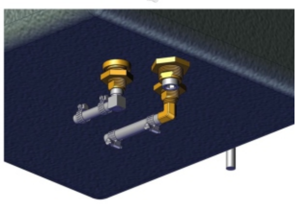
5.5. 3D Modeling of Fuel Cell Design

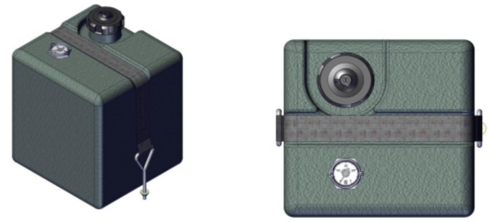
5.6. Structure of Fuel Cell











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