Hydrogen Storage from the Result of Reactor ACE (Aluminum Corrosion and Electrolysis) Production by Pysisorption Method

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Abstract. Hydrogen is one of promising renewable energy and has potential as an alternative energy source to replace fossil fuel. In its application as a fuel, hydrogen still has deficiencies in terms of storage. If stored in the gaseous form, hydrogen has a very low energy ratio to its volume, so it is necessary to conduct various studies related to methods and materials for storing hydrogen. So far the method of storing hydrogen with the adsorption principle using activated carbon as an adsorbent is very promising because it can lower the pressure in the tank with relatively equal storage capacity. The data collection process is done by gravimetric method and the type of adsorption used is physisorption. The results of this study are indicated hydrogen storage capacity at 2.5 bar pressure using 8.42% activated carbon adsorbent while using zeolite adsorbent by 20.42%. Based on variations in the ratio of the adsorbent mixture obtained the maximum hydrogen storage capacity at a ratio of 2:3 by 4.54%.

1. Introduction

Energy is a primary need for development towards a modern society. In Indonesia, it currently requires energy that is still possible in the use of fossil fuels such as petroleum, coal and natural gas. In the combustion process, fossil fuels will produce CO$_2$ emissions that can cause global warming. Besides that, fossil fuels are energy that cannot be renewed. The global warming and energy crisis issues are pushing various energy experts to develop more renewable energy which is abundant in nature. One of alternative energy that can replace the function of natural gas is hydrogen gas. Hydrogen gas does not produce pollution if it is burned and has a high energy density, where energy is generated from three times the product [1].

The Obstacle of using the hydrogen as fuel now is storage and distribution of hydrogen gas. The purpose of the development of technology today is to produce high efficient hydrogen storage. There are three methods storing the hydrogen, in the form of gas, liquid and solid. The first two methods are in the form of gas (at the height of 700 bar) and liquid (the temperature must be stable between -240 to -259ºC in terms of security, it is not sufficient. The state of the art storage system currently actively studied is using solid storage technology (solid hydrogen storage). In this dense system, the H atoms are in the lattice material, where hydrogen is "inserted" in certain material [2]. During this time hydrogen storage uses a strong tank construction to save up to 2000 psi. Hydrogen storage by adsorption can reduce hydrogen up to 0.1–4 Mpa [3].

According to Froudakis [4], materials that have a high surface area, high porosity, and strong interaction are very potential materials for use as hydrogen storage materials with relatively high hydrogen storage capacity; With this method, gas storage will be developed with an adsorption system on porous materials such as activated carbon, zeolite, and mixing carbon with zeolite at certain ratios. This study will focus on the content of gas and gas entering storage for storage in storage, good energy, and energy ratios, and the amount of energy stored in the storage.

Adsorption is a process of absorbing particles of a fluid (liquid or gas) by a solid to form a film (thin layer) on the surface of the adsorbent. Solids that can absorb fluid particles are called adsorbents
or adsorbents. While the absorbed substance is called adsorbate. Adsorption is divided into two types, namely, first, physical adsorption is the interaction process between adsorbent and adsorbate caused by Van Der Waals force. Second, chemical adsorption is a reaction that occurs between solids and adsorbed solutes reference.

Hydrogen storage on porous material is carried out through the adsorption method, where porous material acts as an adsorbent and hydrogen gas act as the adsorbate. The mechanism for storing hydrogen in porous material involves the physical process. The physisorption process is a mechanism of absorption of hydrogen gas molecules on the surface of porous material that occurs reversibly with relatively large adsorp speeds. In this process, hydrogen molecules can be easily absorbed and released repeatedly without losing energy and generally there is no activation energy involved in the hydrogen adsorption process. This causes the process of adsorption and desorption of hydrogen to take place quickly [5].

Absorbent material or adsorbent is a substance or material that has the ability to bind and retain liquid or gas in it. The adsorbent used can be grouped into two, namely polar and non-polar groups [6].

1. The polar adsorbent is also called hydrophilic. The types of adsorbents included in this group are silica gel, active alumina, and zeolite.
2. Non polar adsorbents are also called hydrophobic. The types of adsorbents included in this group are adsorbent polymers and activated carbon.

The activated carbon material is one of the candidates for hydrogen storage because it has high absorption capability, high specific surface area, porous microstructure, low mass density, and low cost to be one of the very interesting studies. Activated carbon which is used as a good adsorbent for gas storage must have a high adsorption capacity on a volumetric basis. To achieve this condition activated carbon must have a large amount of micropore, because micropore is a component that absorbs many small molecules. It has a very compact shape, this will increase bulk density and finally also volumetric storage capacity, has a pore size that matches the diameter of the adsorbate molecule, which will optimize the amount of substance adsorbed, has relatively low mesoporosity, because mesopores have a small contribution to adsorption capacity and reduce bulk density, has a high enough global heat and mass transfer from carbon materials.

Zeolite is a unique adsorbent because it has a very small and uniform pore size when compared to other adsorbents such as activated carbon and silica gel, so the zeolites is only able to absorb molecules with a diameter equal to or smaller than the diameter of the cavity gap, while molecules with a diameter larger than the pore of the zeolite will be retained and only cross between particles [7]. The ability of zeolites to adsorb depends very much on the Si/Al ratio. The Si/Al ratio is low, zeolites are hydrophilic having a high affinity for water and other polar compounds. Conversely, if the Si/Al ratio is high, then zeolites are hydrophobic and adsorb non-polar compounds [8].

Considering the structure of natural zeolites that vary as well as the magnitude of possible impurities, before using natural zeolites requires an initial treatment which is often referred to as an activation process. This activation process is needed to improve the specific nature of zeolite as an adsorbent and eliminate impurity [9].

X-carbon zeolite material is a mixture of zeolite adsorbents and activated carbon with a comparison of certain compositions. The use of X-carbon zeolite for hydrogen storage has been carried out, the average hydrogen absorption capacity of X-carbon zeolites after several measurements up to 1.66% by weight. This number is greater than pure zeolite, which is reported to be between 0.4% wt. up to 0.9% by weight at 30°C and 100 bar, but smaller than activated carbon, which is reported to be 3% by weight at 298K and 100 bars [10].

2. Method
This research uses a physisorption method to determine hydrogen storage capacity by the adsorbent. The adsorbents used are a zeolite, activated carbon and a mixture of zeolite and activated carbon.
(zeolite X-carbon). The adsorbent used will be carbonized and activated which aims to remove gases in activated carbon and zeolite and aims to increase the pore surface area.

Adsorbent will be made into pellet form by using an adhesive mixture. The purpose of forming the adsorbent into a pellet form is to increase the mass of the adsorbent. Thus, the adsorbent does not participate when it mixes with hydrogen which has pressure. In addition, it can make it easier to remove hydrogen when it will be reused.

The stored hydrogen is the product of ACE reactors, by reacting aluminum and KOH solutions using electrolysis methods. The ACE tool can be seen in Picture 1 and Figure 1.

Hydrogen is stored in modified storage from refractory used tanks. The storage valve is added to the safety valve, and there are 3 holes. The first hole to insert hydrogen in storage, the second hole functions as a hydrogen output place, while the third hole is used as a place to insert and remove the adsorbent. The output of the tank is coated with glass wool, aluminum foil, and a blanket tank that serves to maintain the temperature in the storage so that it is not affected by ambient temperature. As seen in Picture 1, storage is also equipped with a pressure gauge that serves to facilitate the hydrogen filling process by knowing the pressure conditions in storage. Modification results can be seen in Figure 2.
2.1 Treatment and Static Analysis
In this research, there are two types of research variables that will be used: fixed variable and non-fixed variable. Fixed variables as research objects are the adsorbent type, adsorbent mass, and hydrogen volume, while the fixed variable in the form of variations in gas pressure entered in the storage set, among others, 0.5; 1.0; 1.5; 2.0; and 2.5 bars. Based on variations in the conditions of hydrogen gas entering storage, a variation in the amount of hydrogen gas stored in storage will be obtained which can then be used as literature for hydrogen storage methods in storage. In addition, the ratio of mixing zeolite X-carbon as an adsorbent to storage capacity can also be varied.

2.2 Adsorbent Preparation
The process of adsorbent preparation is done by preparing the initial stages of coal and zeolite by performing several stages, namely grinding, crushing, and sieving. The second stage is activating the adsorbent with the NaOH solution. In the third stage, the process of mixing and forming adsorbents into pellets with a size of 3 cm. The adhesive used in pellet formation is starch with a ratio of 1% by weight. In zeolite X-carbon adsorbent, the zeolite mixing ratio is used: activated carbon including 1:1, 1:4, 2:3, 3:2, and 4:1. Pellets are printed with the same size, which is 3 cm long. The determination of the size of the pellet is based on the diameter of the adsorbent inlet. The adsorbent entrance and exit can be seen in Figure 2 number 7.

2.3 Procedure of Hydrogen Enter the Storage
The process of determining the amount of hydrogen energy in storage is done by the gravimetric method. First, weigh the empty tank. Furthermore, weighing 150 grams of adsorbent. Insert the adsorbent into storage through the top. Adjust the pressure of hydrogen in storage. Weighing the mass of hydrogen + storage. Record the time and temperature of hydrogen in storage. Calculate hydrogen gas absorbed in the adsorbent.

3. Results And Discussion
This research has been done by using the Aluminum Corrosion and Electrolysis (ACE) devices, it is known that this instrument has an ACE reactor which functions as the place for the electrolysis process to separate the KOH and aluminum become hydrogen and oxygen.

The decomposition process occurs due to the supply of electric current in the ACE reactor in the form of an electrode consisting of the cathode and anode poles. Electrolyte and aluminum solutions as the main raw material will enter the ACE. The gas produced will be separated from the others as a barrier or insulation between the cathode and anode. Each gas will come out through the existing pipe without mixing the gas. The hydrogen produced will flow into bubbler 1 and 2 to determine the flow rate, while the oxygen produced will be purified in the bubbler 3 using oxygen scavenger. Known hydrogen flowing is then stored in a temporary storage tank then stored in hydrogen storage after compressed by
the compressor. Hydrogen that has been collected is then used for the production of green diesel in the Thermal Cracking reactor.

In the hydrogen storage process, the adsorbent will first be put into storage. This adsorbent is very helpful in the absorption process due to the adsorption method which is currently a physics adsorption method. In the process, there will be an interesting pull between the adsorbent and the adsorbate caused by Van Der Waals's force. A relatively weak attractive force between the surface of the adsorbate and the adsorbate causes it not to be used effectively. Physical adsorption processes occur without energy flow. In this process will form a multilayer layer on the surface of the adsorbent. The bonds formed in physics adsorption can be decided easily. Distribution data on hydrogen storage with the aim as a storage medium with physics adsorption method. In the activated carbon adsorbent and zeolite, the fixed variable called in storage varies from 0.5-2.5 bar. X-carbon Zeolite is a mixture of zeolite porous material and activated carbon. This mixing is used to adjust with zeolite and activated carbon. Zeolites are porous materials that have the advantage of regular structure, large pore volume, and high porosity, but have a relatively small surface area. Whereas carbon has a high surface area, although the pore structure is irregular and porosity is relatively lower. In this study, the variable that remains in X-carbon zeolite is the ratio of mixing zeolite with activated carbon. This variable is the aim to determine its effect on hydrogen gas storage.

3.1 Description of Pressure on Mole Hydrogen

Based on the words of an ideal gas that explains that it is directly proportional to the gas needed in a fixed volume container, it can increase the pressure in the container. This is because the size of the gas particles moves to pound the storage wall. The collision of gas particles with the storage of the wall will produce pressure. This event corresponds to the kinetic theory of gases which explains the macroscopic properties of gases, such as temperature, or volume, taking into account the composition of molecular gases and their movements. In essence, this theory states that logic is used by molecules, as Isaac Newton used, which also exists between collisions between groups that move at different speeds. This can be seen in Figure 3.

![Figure 3. Effect of Pressure and Hydrogen Mass on Mole Hydrogen Gases](image)

From Figure 3, it can be seen that the greater the hydrogen gas pressure, the greater the mole of hydrogen gas. Absorption using zeolite is greater than using activated carbon. Where the highest mole of hydrogen gas is found in the zeolite at a pressure of 2.5 bar with a value of 19.09 gr while using activated carbon is 6.84 gr and without using an adsorbent is 2.52 gr. Zeolites have the advantage of regular structure, large pore volume, and high porosity compared to activated carbon.

3.2 Effect of Pressure on Hydrogen Energy

Mole gas hydrogen also has a relationship to hydrogen energy stored in the storage. The greater the mole of hydrogen gas, the greater the hydrogen energy stored in the storage. This statement corresponds to the equation \( dQ = n \times CP \times t \) which explains that the amount of energy produced is
directly proportional to the number of moles of gas meaning that a mole of a gas is added in a fixed volume container, can increase gas energy in the container. For more details, see Figure 4.

Figure 4. Effect of Pressure and Hydrogen Energy on Hydrogen Produce

From Figure 4, shows that the greater the mole of hydrogen gas, the greater the hydrogen energy stored in storage. The highest hydrogen energy is found in hydrogen storage using a 2.5 bar pressure zeolite adsorbent, with a value of 176.30 Joule/L. At the same pressure, hydrogen energy is stored by using activated carbon adsorbent of 56.32 Joule /L, and without using adsorbent for 10.63 Joule/L. According to Hwang and Varma [11], the best adsorbent material used as a hydrogen storage material is a material that has a high surface area and high porosity. According to Broom [12], zeolite porosity is higher than activated carbon. From the data above, the highest energy is found in hydrogen storage using zeolite adsorbent of 176.30 Joule/L.

3.3 Effect of X-carbon Zeolite Ratio on Hydrogen Storage

Based on the data and calculations that have been carried out, the data from the storage research before going through the adsorbent obtained 1.86 grmol of hydrogen gas mole, resulting in stored energy in storage of 7.84 Joule/L, while the data on the results of storage research after adsorbent using ratio variation a comparison of the weight of zeolite mixture and activated carbon (1:1) obtained mole of 3.54 gmol of hydrogen gas, resulting in stored energy in storage of 17.03 Joule/L, while the data on the variation of the ratio of the weight ratio of zeolite and activated carbon (1:4) obtained mole of hydrogen gas 2.07 gmol, produced storage energy in storage of 14.98 Joule/L, while data on variations in the ratio of weight ratio of zeolite mixture and activated carbon (2:3) obtained mole of hydrogen gas 4.30 gmol The resulting energy stored in storage is 41.42 Joule/L, while the data on the variation of the ratio of weight ratio of zeolite and activated carbon (3:2) is obtained by mole of gas hydrogen 3.35 gmol, 18.84 Joule/L of stored energy stored in storage, while the data on the variation of the weight ratio of the zeolite mixture and activated carbon (4:1) obtained 2.81 gmol of gas mole, generated energy stored in storage of 20.85 Joules/liter.

Figure 5. Effect of Zeolite and Active Carbon Ratios on Hydrogen Energy Stored in Storage
From Figure 5, shows that the ratio of the weight ratio of the zeolite mixture and the active carbon that produces hydrogen energy is highest in the variation of the ratio of the weight ratio of zeolite and activated carbon (2:3) which is 41.42 Joule/L and the lowest in the ratio of the mixture weight zeolite and activated carbon (1:4) which is equal to 14.98 Joule/L. At the ratio (2:3) can produce the highest hydrogen energy caused by the ratio (2:3) is the optimum mixture because at the ratio (2:3) has a hydrogen absorption capacity that is greater than the other ratio of 4.54% weight. In the study Suartika [13], the ratio (2:3) resulted in the highest absorption efficiency with 88.57%.

![Graph showing storage capacity vs. adsorbent ratio](image)

**Figure 6.** Effect of Zeolite and Active Carbon Ratios on Storage Capacity in Storage

From Figure 6, shows the difference in hydrogen storage capacity for each variation of the ratio of the weight ratio of zeolite mixture and activated carbon. It can be seen that the ratio of weight ratio of zeolite mixture and activated carbon produces the highest hydrogen storage capacity in the variation of the ratio of weight ratio of zeolite and activated carbon (2:3) that is 5.46% by weight and the lowest is the ratio of weight ratio of zeolite and activated carbon (1:4) which is 2.17% by weight. The difference between these results is caused by the ratio of the weight ratio of zeolite mixture and activated carbon (2:3) the mixture between activated carbon and zeolite is said to be optimum because both cover each other's weaknesses each zeolite has a relatively small surface area covered with excess activated carbon that has high surface area. Whereas carbon has a relatively lower porosity covered by the advantages of zeolite which has a regular structure, large pore volume, and high porosity, therefore at the ratio of weight ratio of zeolite mixture and active carbon (2:3) the mixture between activated carbon and zeolite is said to be optimum for absorb hydrogen gas.

### 3.4 Hydrogen Storage Capacity

Physical adsorption occurs when the intermolecular force is greater than the intramolecular force. Intermolecular force is the pulling force between the fluid molecules themselves while the intramolecular force is the pulling force between the fluid molecules and the solid surface molecules. Adsorption will decrease when the temperature in the process increases. The force involved in physical adsorption is the Van Der Walls style, which is a relatively weak attractive force between the surface of the adsorbent and the adsorbate. Thus the adsorbate is not strongly bound to the surface of the adsorbent so that the adsorbate can move from one part of the surface to the other surface. If in the state of equilibrium the condition is changed, for example, the pressure is lowered, or the temperature is raised, then some adsorbate will be released and will form a new equilibrium. To find out the effect of pressure in hydrogen storage can be seen in Figure 7.
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Figure 7. Effect of Pressure on Storage Capacity

From Figure 7, shows that the relationship of pressure to storage capacity by adsorbents is obtained that the greater the pressure in the storage, the greater the hydrogen stored in the storage. The pressure of 2.5 bar of storage capacity by zeolite adsorbent was 20.42%, while at the same pressure the storage capacity of the activated carbon adsorbent was 8.42%. Zeolites have a regular structure, large pore volume, and high porosity levels according to Broom’s statement, zeolite porosity is higher than activated carbon.

4. Conclusion

Based on the research that has been done on hydrogen storage, it can be concluded that the relationship of pressure to storage capacity by the adsorbent shows that the greater the pressure in the storage, the greater the hydrogen stored in the storage. Where, at a pressure of 2.5 bar the storage capacity by zeolite adsorbent is 20.42%, while at the same pressure the storage capacity by activated carbon adsorbent is 8.42%. In X-carbon zeolite the maximum storage capacity is 4.54% at the ratio (2:3).

5. References

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