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Aluminum Corrosion Analysis for Environmental Acid Chloride Solution

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ABSTRACT

Aluminum is the most commonly used metal. Aluminum is present on the bipolar plate which is a key part in PEMFC (Proton Exchange Membrane Fuel Cell). In the air, aluminum is easily oxidized, forming a thin layer (Al2O3). Therefore it's necessary to do an experiment to find out the extent of corrosion on aluminum. In this experiment, corrosion rate analysis on aluminum is arrived at by using hydrochloric acid (HCl) using weight loss and electrochemical methods. And corrosion rate results of aluminum metal with a concentration of 0.1M ; 0.2M; 0.3M; 0.4M and 0.5M with a concentration of 0.5M with a value 0.04250 grams and the smallest corrosion rate of 0.00030 gram with concentration of 0,1M. The largest value of corrosion rate at 0.58610 (mpy) and 0.91589 Ampere using electrochemical method. Morphology on aluminum is seen using SEM (Scanning Electron Microscope is pitting corrosion).

Keywords: *Aluminum, Hydrochloric Acid, Weight Loss Methods, Electrochemical Methods, Corrosion.*

1. INTRODUCTION

Aluminum metal is the most commonly used metal in everyday life (Gouta, et al 2016). Aluminum has two advantages over other metals. First, it has a low density, about one-third of iron and copper. Second, it can react with oxygen in water, forming a thin oxide layer, and is resistant to oxidation (Josefa, 2012).PEMFC has several parts such as anodes, cathodes, catalysts and bipolar plates, of which one bipolar plate material itself is aluminum. Bipolar plates are included in one of the main components of PEMFC (Protton membrane cell membrane cells) and serve to collect and transfer electrons from anode to cathode (Zaidi, 2009).The weakness is easy to experience corrosion due to electrolytes in the membrane PEMFC Swider, et al 2015). Corrosion is a process of destruction of metals by chemical reactions or electrochemicals resulting from the interaction between the metal and its environment. Aluminum surfaces are highly reactive and will act spontaneously by air or water to form Al2O3 aluminum oxide (Mackay & Louis, 1949).Corrosion can occur in dry and wet. In wet medium, corrosion can occur uniformly or locally. Examples of uniform corrosion in the wet medium are when the metal is in a hydrochloric acid solution (HCl), since hydrochloric acid can attract Fe elements to state the aluminum metal.

The concentration of hydrochloric acid (HCl) in PEMFC is 0.1M to 5M (Skinlo, 2005).The corrosion rate occurred in aluminum metal can use weight loss methods as well as electrochemical methods (Tianyuan et al., 2017). Weight-loss methods are often used on an industrial scale and laboratory as the equipment is easy and the results are quite accurate. The principle of this method is to calculate the total weight of the material lost or lost according to ASTM G 31-72 standard with regard to the mass of the metal (Wibowo, 2009). The purpose of this study is to determine the degree of corrosion in aluminum by using hydrochloric acid (HCl) solvents.

2. LITERATURE REVIEW

PEMFC (Proton Exchange Membrane Fuel Cells) has many advantages over other types of fuel cells, such as PEMFC having smaller operating, operating, and low operating and operating temperatures. PEMFC uses solid polymer as electrolyte and porous carbon containing platinum catalysts as electrodes (Wu, 2012).The way PEMFC operates only requires hydrogen, oxygen from free air. Due to the short and mild weather warming. The process that occurs when PEMFC operates (Eniya, et al, 2008) is as follows:

1) Hydrogen gas as fuel is discharged to the anode, while the oxygen gas from the free air flows to the cathode.
2) In the anode, platinum catalysts cause hydrogen to break into positive hydrogen ions (H +) and negative electrons (e).
3) The membrane on PEMFC only passes H + ions towards the cathode, while the electrons will pass through the external circuit into the cathode and generate electrical current.
4) In the cathode, electrons and H + ions join the oxygen gas from the air form the water that will come out of the fuel cell.

2.1 Aluminum

In 1884 aluminum was still a very rare and valuable item, then a 6-pound bulk semi aluminum was placed at the top of the Washington Monument in America and still survived. At present all aluminum alloys are still being studied by many industries in the world by mixing other elements such as copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), and so on to form new alloys that have the properties and Different features. Aluminum is a widely used chemical element worldwide for various products, This element has atomic numbers 13 and is identified with Al symbols. Aluminum is a good, light and strong electrical conductor and a good conductor is also hot and can be used as a sheet (Packard, 2017).Metallic aluminum processing method is by way of dissolved alumina electrolysis in Cryolite. This method was created by Hall in the United States in 1886 and at the same time by Heroult in France. Aluminum is the second easiest metal in terms of formation, and sixth in ductility.

2.2 Corrosion Aluminum

Corrosion is an electrochemical process. In aluminum corrosion, the metal part is located as the anode, where aluminum oxidizes:

$$AlCl_3 + H_2O + Al(OH)_3 + Al_2O_3 + H_2$$

Corrosion can not be prevented or stopped at all, but corrosion can be controlled, thus slowing the destruction process (Fontana, 1987). Aluminum is the elementary chemical element IIIA in the periodic system of elements. In aluminum, it is easily oxidized to form a thin layer of Al2O3 in which layers are formed spontaneously on the metal surface (Linder, 2012). Aluminum can protect erosion at pH between 4 and 9 outside of the corrosive aluminum range, both in acidic and alkaline environments. Erosion takes place in acidic solutions, where the reduction in response (Nugraheni, 2014) is:

$$2Al(s) + 6HCl + 2AlCl_3(aq) + 3H_2(g)$$

Erosion of ordinary metal aluminum is the corrosion of wells (Jones, 1992). The greatness of the well forms a hole. According to (Fontana, 1987) in his book "Corrosion Engineering" on page 14, corrosion rates can be defined in various ways, such as mass loss percentage, milligrams per square centimeter and gram per square inch per hour and also using mil per year state the rate of corrosion penetration. In calculating the rate of corrosion there are two ways corrosion.

2.3 Corrosion Type

Types of corrosion according to the type of damage produced, the corrosion or the type of corrosion, corrosion is divided into several types:

1) corrosion Uniform

Uniformness is the corrosion that occurs on the metal surface due to chemical reaction due to low water pH and humid air, so the longer the metal becomes thinner.

2) Galvanic Corrosion

Corrosion Galvanic is a kind of corrosion that occurs when two different metals come to the direct touch with the destructive media.

3) Corrosion Pressure

Due to metal defects due to metals subject to special treatment (such as strain, bending and other) so that the grain becomes tense and the granules are very easy to react with the environment.

4) corrosion of creation

Corrosion cells caused by the difference in acid concentration. This corrosion occurs due to the narrow gap filled with electrolytes (low water pH) so there is a corrosion cell with a cathode outer surface of the base gap with acidic water more than part of the acidic gap to the anodic.

5) corrosion from wells

This type of carat has its own shape like a well, so it is called a corrosion well. The corrosion progressive direction is not spread to the metal surface but instead thickens into metal thickness and produces construction leakage, especially in non-oxidizing and non-oxidizing environments.

6) Erosion

Erosion that occurs due to wear and cause sharp and coarse parts, this part is easy to erosion and also due to the extremely heavy liquid and may scrape protective film on metal.

2.4 Corrosion Factors

Among environmental factors that may affect corrosion processes (Jiang, et al, 2015), among others:

1) The temperature in the form of temperature rise will cause an increase in the speed of corrosion reaction. This is due to the higher the temperature of the kinetic energy of the particles that reacts will increase beyond the magnitude of the activation energy price and consequently the rate of reaction (corrosion) will also accelerate, and vice versa.
2) Solid material dissolved in water.
3) The pH concentration or acidity and alkalinity of this solution affects the rate of reaction, generally pH and increased alkalinity, the rate of corrosion will increase. Corrosion events under acidic conditions, ie, at pH <7, are greater, due to the additional reduction reaction occurring in the cathode.
4) Higher temperatures, temperatures, faster chemical reactions occur and the increase in water temperature generally increases corrosion rate.

3. RESEARCH METHODOLOGY

3.1 Weight Loss Method

Weight loss method is weight loss is one of the methods used to determine corrosion rates. The basic principle of this test is to calculate the weight (mass) that occurs in the sample weighed and immersed. This method has advantages as this calculation can be used for all types of corrosion conditions for both metal and alloy metal. The disadvantages of this method can not measure the actual factors that occur in the field for large specimens. Calculation of corrosion rate on weight loss during test is in accordance with ASTM G1 standards as shown below:(Fontana, 1910).

$$(CR) = K\frac{W}{AxTxD}\text{ mpy} \qquad (1)$$

Where,

CR = Corrosion rate (mpy)
K = Corrosion constant =534
W = The lost mass (g)
D = Specimens density = 2.7 gr/cm^3
A = Surface Area (In inches)
T = Time of Absorption (Hours)

This method is a way of knowing the value of corrosion rate (mpy) in the test sample.

3.2 Electrochemical Method

The electrochemical method is the method of measuring the rate of corrosion by measuring the potential difference of objects to obtain the corrosion rate that occurs, this method measures the corrosion rate estimating

4. PURPOSE OF OUTCOMES AND DISCUSSION

4.1 Weight Loss Method

To see the rate of aluminum metal rust was immersed using a hydrochloric acid solution (HCl) with a concentration of 0.1M; 0.2M; 0.3m; 0.4M and 0.5M for 1 day, 3 day and 5 day. Weight reduction of aluminum metal could be seen in table 1 seen in weight loss tables.

Table 1. Loss of data (grams) of aluminum metal in hydrochloric acid (HCl).

	Concentration on HCl				
Period	0.1	0.2	0.3	0.4	0.5
1	0,00030	0,00052	0,00068	0,00102	0,01104
3	0,00062	0,00078	0,00086	0,00116	0,02562
5	0,00064	0,00086	0,00140	0,00492	0,04250

Larger concentrations of hydrochloric acid and longer immersion times the greater the weight was due to the destruction of passive layers in a particular local area in front of the electrolyte. For detailed information on weight loss graphs from time to time could be seen from the graph of Fig. .1. This was in line with the research conducted by (Guddi, et al, 2013) which stated that the increased concentration of HCl solutions and test times affected the weight loss , From the results of the calculation of the average value when the combined graph would show the difference in weight loss as in Graphic 4.1 below:

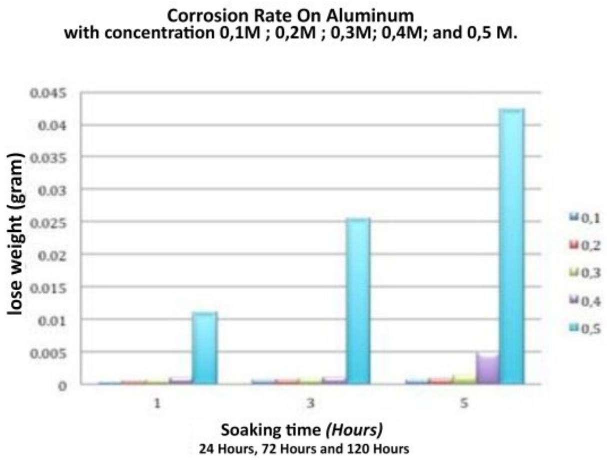

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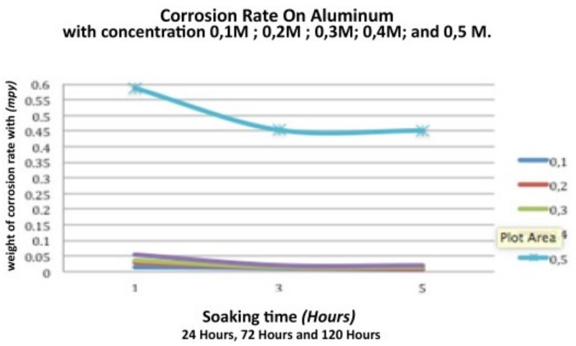
Figure.1 *Weight Loss*

Analysis of corrosion rate (CR) from investigation of aluminum immersion process with 1x1cm depth using formula.

Corrosion Rate: Table 2. Corrosion rate data on aluminum metal in Chloride Acid with a concentration of 0.1 M; 0.2M; 0.3m; 0.4M and 0.5M with immersion times 1, 3 and 5 days.

Corrosion Rate (CR) MPY					
Period	0.1	0.2	0.3	0.4	0.5
1	0,01592	0,02761	0,03610	0,05415	0,58610
3	0,01097	0,0138	0,01522	0,02053	0,45345
5	0,00679	0,00913	0,01486	0,02017	0,45132

For further details it was presented in the figure in Figure.2 for corrosion rate results.



Based on the largest corrosion rate diagram was 0.58610mpy with 0.5M concentration. For the lowest corrosion rate 0.00679mpy 0.1M with 5 days immersion time. It was clear that the higher the concentration of erosion rates was increasing, this was similar to the research (Kumari, 2013).

4.2 Testing With Electrical Methods

Metal aluminum (Al) test use of hydrochloric environment with 0.1M concentration; 0.2M; 0.3m; 0.4M and 0.5M during the 60-second test obtained the corrosion rate seen in table 3 below.

Table 4.3 Data on aluminum metal using in hydrochloric acid solution (HCl) with concentration of 0.1M; 0.2M; 0.3M; 0.4M and 0.5M.

For more details, see the timeline diagram in Figure 3 and time to potential in Figure 4.5 below. Cm^2.

From the above picture showed that the current increased in Acid Chloride (HCl) to the largest aluminum at 0.5M concentration with 0.91589 Amper at 60 seconds ago for the smallest current at 0.1M concentration at -0.10634. To see the current-time relationship as shown in Figure .3 at a concentration of 0.1M HCl for 60 seconds potential value increased from -0.10634 Amper to -0.11549

Fitting Data	Concentrations of HCl				
	0.1	0.2	0.3	0.4	0.5
lo(A/Cm^2)	0.18348	-8313	-0.0056798	-0.040951	0.071985
Eo(V)	-0.39929	0.39931	-0.39931	-0.3993	0.3993
Corrosion Rate (MPV)	23606	-27858	-7307.7	-52687	92617

Amper might be within a certain local passive layer which was damaged as a research (Pancal et al., 2011) Then to see the current potential was also shown the current graph to the potential in Figure 4.

In Figure 4 showed a potentiometric test with a solution of hydrochloric acid (HCl) with 0.1M concentration yielding 0.097176 Amper current at potential -0.3993 Volt. The current continues to increase as the concentration of test solutions increased but the potential for potentiometric testing had not changed as a test (Hamer, et al 1939.

4.3 SEM Results (Electric Scanning Microscopy)

To see the surface morphology of the test material on aluminum metal before immersing and after soaking 120 hours (5 days), the immersion test material as shown in Figure 4.5

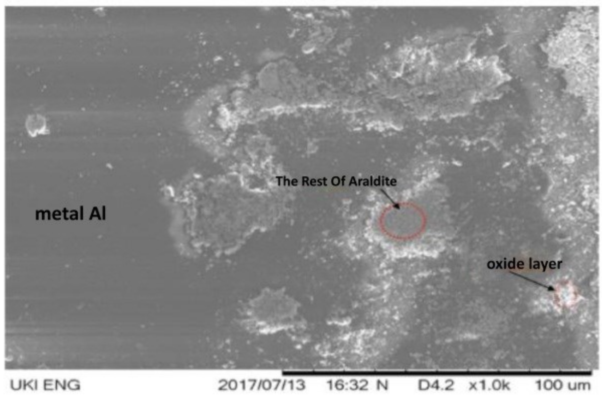


Figure 5. SEM results before immersion.

From the results of SEM (Scanning Electron Microscope) above could be explained because the nature of aluminum itself was easily oxidized, aluminum samples that had not been soaked in the oxidation caused by air factor, the reaction was Al (s) + O2 (g) → Al2O3 (s)

It was een that the oxide layer formed was Al2O3 on arrows which refers to the white surface, as well as the whole thick-formed araldite formed on aluminum metal before making soaking processes forming patterns such as the island.

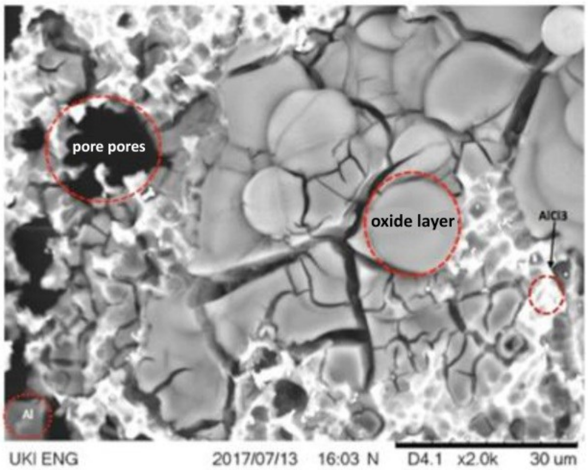


Figure 6. shows the SEM decision using a 0.5M HCl settlement in a 5-day bath

Al_2O_3 thin film removal on aluminum metal shell surfaces maked it easy for aluminum metals to react with HCl solutions as in the following reaction equations:

$$2Al_{(s)} + 6HCl \rightarrow 2AlCl_{3(l)} + 3H_{2(g)}$$

5. CONCLUSION

After testing and analysis of test results it could be concluded that:

1) Using the weight loss method and the corrosion rate (mpy) was concluded after being immersed using hydrochloric acid (HCl) with a concentration of 0.1M; 0.2M; 0.3m; 0.4M and 0.5M during soaking time 1, 3 and 5 days had the biggest weight loss in 5 day soaking with 0,5M concentration of 0.04250gr and the lowest weight in 0,1M soaking for 1 day 0.0003gr. The highest mpy corrosion rate value occurred at 0.5M 0.58610 and the lowest was 0.00679 at 0.1M.

2) Observation using electrochemical method gets the largest current at 0.5M concentration equal to 0.91589 Ampere.

3) The SEM (Scanning Electron Microscope) output with 1000x magnification shows that the aluminum metal morphology with 0.5m soaked for 5 days, had a passive layer of aluminum oxide in certain premises that form small holes in some places. It showed an oxidation of aluminum that forms an Al3 + ion.

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