CORROSION STUDY OF AISI 304 ON KOH, NaOH, AND NaCL SOLUTION AS AN ELECTRODE ON ELECTROLYSIS PROCESS

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Abstract

AISI 304 is a kind of austenitic stainless steel that can be applied for various technologies. Since AISI 304 consists of chromium, nickel, and other materials, understanding the performance of this material is different from its parent material (i.e., iron oxide). Here, the purpose of this study was to investigate the characteristics of AISI 304 on various electrolyte solutions (i.e., KOH, NaOH, and NaCl). The electrolyte solution selection is an important parameter for getting high efficiency in the electrolysis process. To precisely investigate the effect of the electrolyte solution on the performance of AISI 304, several analyses were conducted: weight loss method measurement and scanning electron microscope (SEM) equipped with energy dispersive x-ray spectroscopy (EDS). The result showed that the AISI 304 had low corrosion rate in all electrolyte solution variations. The low corrosion rate of AISI 304 can be obtained due to the existence of chromium oxide which can be identified by EDS. During the immersion of AISI 304 into electrolyte solution, pitting corrosion in the microstructure level was formed, detected by the SEM analysis. This study confirmed that although there is some corrosion phenomenon, AISI 304 can be classified as a good candidate material to be applied in the process conducted in the either acid or basic conduction.

Keywords: Corrosion rate, Weight loss method, AISI 304, SEM, EDS.

1. Introduction

Water electrolysis has been well-known as an excellent process to produce pure hydrogen and oxygen gas by carrying out the electrical discharge through two

electrodes. To be reliable in the various conditions of electrolysis, the selection of electrode is important, in which the electrode must have good corrosion resistance specifically against corrosive environments. Therefore, studies on corrosion profile of electrode have brought tremendously attention for researchers in the past decade.

Corrosion is one of the most destructive parameters. In short, the corrosion occurs via interaction between the metallic materials and their corrosive agent. Depending on the type of environment and a number of prevailing conditions, corrosion can be classified as chemical and electrochemical types. The electrochemical-typed corrosion occurs by the existence of the flow of electrons. Chemical-typed corrosion is a type of corrosion from purely basic laws of chemical kinetics [1].

One of the best electrodes is austenitic stainless steel. Austenitic stainless steel has superior corrosion resistance, excellent mechanical properties, and good welding ability [2]. Austenitic stainless steel is divided into two subgroups, i.e., 200- and 300-series. 300-series austenitic stainless steels achieve austenitic structure primarily by the additional nickel element, whereas 200-series austenitic stainless steels needs manganese and nitrogen (in addition to small nickel content) for getting austenitic structure. Among the groups, AISI 304 is the most common austenitic stainless steel. This type is extensively used in such items as, cookware, cutlery, and kitchen equipment.

Corrosion resistance of the austenitic stainless steel is due to the existence of chromium oxide thin layer on the material surface. Interestingly, the film can be categorized as a self-healing layer that can quickly improve and healed in the presence of oxygen after being damaged. Although stainless steel has self-healed chromium oxide layer to against corrosion, the specific chemical can destroy, lowering the performance of AISI304.

Based on our previous reports that informs the effectiveness of stainless steel for being used as an electrode in the electrolysis process [3], the purpose of study was to investigate the characteristics of AISI 304 in various electrolyte solutions. Although some researchers have suggested the additional nanostructured layer (i.e., TiO_2 layer [4], Cu and Sn layer [5], etc.) for improving the performance of AISI 304 against corrosion, their reports did not inform in detail what phenomena happened in the AISI 304. Other researchers have proposed to change the electrolysis process condition [6]. However, the change in the process condition is somewhat impractical for industrial uses. The change in the process possibly creates different product yield and properties.

To the best of our knowledge, there is no report on the investigation onto corrosion resistance of AISI 304 electrode on various electrolyte solutions. In fact, this study is important for getting information about corrosion characteristics of AISI 304 during the water electrolysis process that can change the electrolyte condition. As models of electrolytes, this study used solutions with KOH, NaOH, and NaCl. These three types of electrolyte solutions can be decomposed into positive and negative ions. KOH and NaOH are selected as a model of basic solution, whereas NaCl is an acid solution.

2. Experimental Method

Several chemicals were used in this study: potassium hydroxide (KOH; technical grade; PT. Bratachem, Indonesia), sodium hydroxide (NaOH; technical grade; PT.

Bratachem, Indonesia), and sodium chloride (NaCl; technical grade; PT. Bratachem, Indonesia). All chemicals were used without further purification. AISI 304 was used as the main electrode material. AISI 304 was sliced into a thin plate shape with dimensions of 20, 10, and 1.50 mm for length, width, and thickness, respectively. Plate shape is preferably used to the cylindrical shape because it gives good performance as an electrode in the electrolysis apparatus. To get the information about the characteristics of corrosion resistance of AISI 304, concentration of NaOH, KOH, and NaCl solutions has been varied.

To investigate the corrosion performance of AISI 304, mass loss method was used. The parameters for mass loss method are taken based on the results of our previous studies [3]. Detailed information for the parameters used in corrosion testing is shown in Table 1. Microstructure and corrosion type of AISI 316 before and after the corrosion were characterized using a scanning electron microscope (SEM; FE-SEM SU5000, Hitachi Co. Ltd., Japan) equipped with an energy dispersive X-ray spectroscope (EDS).

Table 1. Parameters used in the testing of AISI 304 corrosion resistance in KOH, NaOH, and NaCl solution.

Condition	Value
Electrolyte concentration	0.27 - 0.53 M
Temperature	25°C
Exposure time	336 - 1344 h
Air pressure	960 mbar
Relative humidity	72%

3. Results and Discussion

Different from other types of steels, stainless steel consists of 10.5% of chromium. This chromium produces a thin layer of oxide on the surface of the steel, which is known as the "passive layer". This oxide layer prevents any further corrosions of the surface of steel. Thus, in the normal atmospheric or water based environments, stainless steel such as AISI 304 will not corrode. Thus, this material is used in domestic sink units, cutlery, saucepans, and work-surfaces [7].

Although stainless steel is much more corrosion resistant compared to ordinary steels, in some circumstances, corrosion can still occur. Specifically, stainless steel will be corroded when contact with some chemicals, notably acids, basic, and chloride ions. The passive layer may be attacked uniformly depending on the temperature and the concentration of corrosion agent. During the corrosion, the metal loss is distributed over the entire surface of the steel. Therefore, this study investigates the corrosion resistances of AISI 304 stainless steels in KOH, NaOH, and NaCl solutions with a view to select the most stable of them as probable material of construction for the electrode of water electrolyzer.

The corrosion profile of AISI 304 stainless steel after immersion with various concentrations in the KOH, NaOH, and NaCl electrolyte solution is presented in Figs. 1, 2, and 3, respectively. The corrosion rate profile of all samples is parabolic curve, and most of the samples corroded since the beginning of the immersion. The results showed that the change of the type and the concentration of electrolyte

allowed different mechanisms in the corrosion phenomenon. Indeed, this creates different corrosion rates.

Calculating the average corrosion rate, AISI 304 can be classified as the material with good corrosion resistance. This is because the average value of corrosion rate is about 0.0051530 mpy, which is below than 1 mpy [8].

Figures 1, 2, and 3 showed that the corrosion profile in all types and concentrations of electrolytes have the same tendency. Initial time resulted in the increases in the corrosion rate. After reaching the maximum rate, the rate decreased spontaneously.

During the initial condition, the additional of electrolyte ions attack the steel. Although there is passive layer, the present passive layer cannot avoid the corrosion. The ions diffuse into the steel and make some corrosion. However, during the corrosion, the existence of oxygen element can make additional passive layer. The reformation of passive layer that is thicker than the initial passive layer can prevent further corrosion [9]. Indeed, for some cases, this can make the corrosion to stop, reaching zero value of corrosion rate.
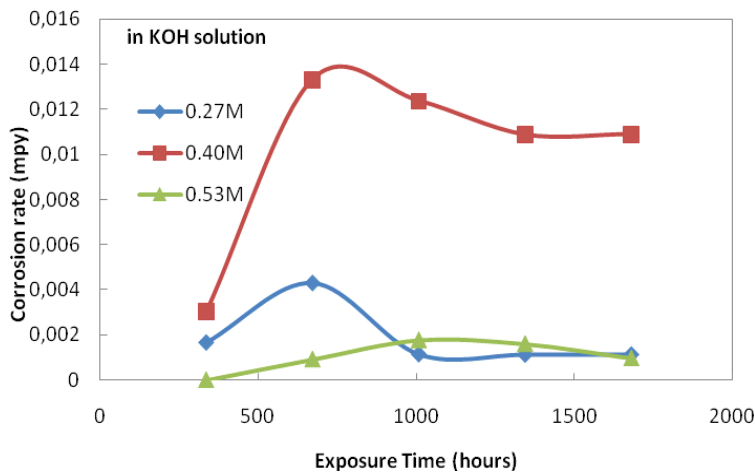

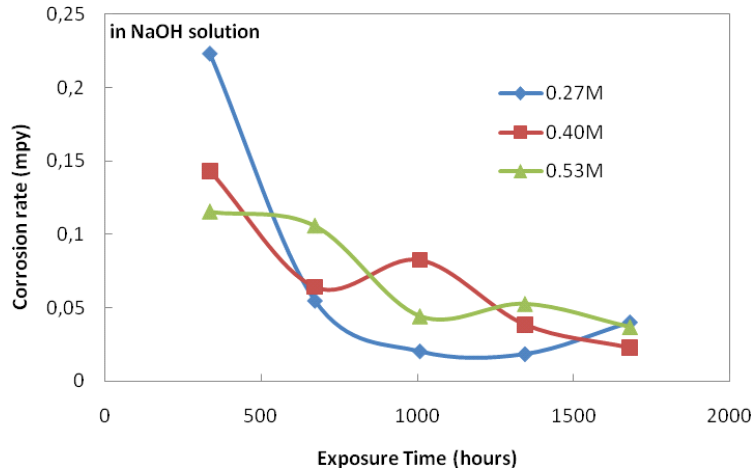**Fig. 1. The corrosion rate of AISI 304 in KOH solution.**

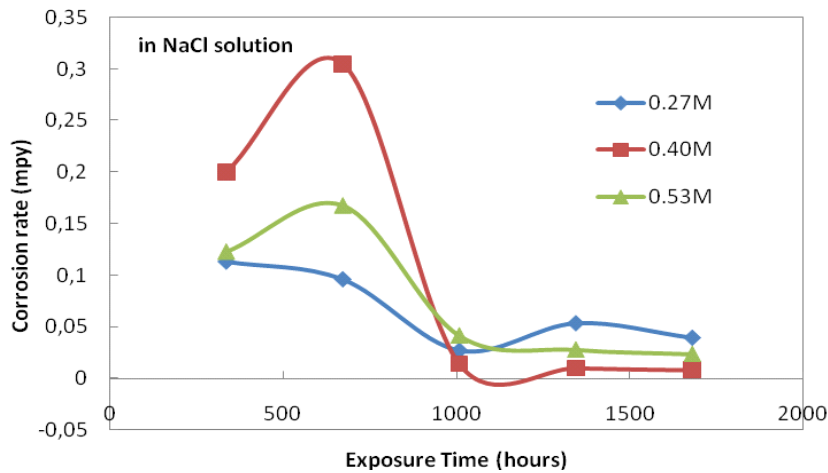**Fig. 2. The corrosion rate of AISI 304 in NaOH solution.**

Fig. 3. The corrosion rate of AISI 304 in NaCl solution.

To support the above hypothesis for the corrosion mechanism during the immersion, EDS analysis of the corroded sample using KOH was conducted (Table 2). The result showed that several elements were obtained, for example carbon (C), oxygen (O), aluminium (Al), silicon (Si), potassium (K), chromium (Cr), iron (Fe), and nickel (Ni). Some elements are then combined with oxygen to form oxides, such as aluminium oxide (Al_2O_3), silica (SiO_2), potassium oxide (K_2O), chromate (Cr_2O_3), iron oxide (FeO), and nickel oxide (NiO).

As shown in Table 2, compared to the AISI 304 before corrosion process, there is additional element (i.e., potassium (K)) in the chemical composition of samples of AISI 304. K seemed to be an impurity gained from the immersion [1]. Concentration of Cr_2O_3 compound in the immersed AISI 304 is relatively higher, which reach 15.96 wt%. Compared to the composition of Cr_2O_3 compound in the initial AISI 304, the value of Cr_2O_3 compound in the corroded sample is relatively high. The main reason for this increasing composition is due to the additional formation of Cr_2O_3 compound in the material. Since the Cr_2O_3 acts as a passive layer on the metal surface and inhibits further corrosion [10, 11], this condition makes the change in the corrosion rate, in which longer immersion time can result the less corrosion rate.

**Table 2. Chemical composition of AISI 304
after corroded in 0.27 M KOH.**

Elemental analysis			Compound analysis	
Element	(keV)	Mass%	Compound	Mass%
C	0.277	10.23	C	10.23
O		25.16		
Al	1.486	2.14	Al_2O_3	4.03
Si	1.739	4.32	SiO_2	9.25
K	3.312	2.15	K_2O	2.59
Cr	5.411	10.92	Cr_2O_3	15.96
Fe	6.398	40.57	FeO	52.2
Ni	7.471	4.51	NiO	5.74
Total		100.00		100.00

In addition to Cr_2O_3, other oxides (i.e., Al_2O_3, NiO, and FeO) are found on the surface of AISI 304. The existence of FeO and NiO compounds indicates the presence of some pits in AISI 304 after corrosion [12].

To make sure what physical phenomena happen during the immersion, SEM analysis for AISI 304 was conducted (Fig. 4). Figures 4(a) and (b) are the SEM images for samples before and after immersion, respectively.

As shown in Fig. 4(a), the original AISI 304 tends to have a plate surface. There are no any pits in the surface. However, significantly difference in the surface identified by SEM analysis is found after the immersion, Fig. 4(b). The microstructure analysis showed that the presence some pits in AISI 304 after corrosion. The presence of the pits indicates that the samples have been experienced corrosion with the type of pitting corrosion.

Based on the SEM images, although the immersion process can result in the corrosion phenomena, the damage obtained by the corrosion is still acceptable. The corrosion is still on the surface and does not reach the inner position of the metal. This result is in a good agreement with the EDS result in Table 2 as well as the corrosion result in Figs. 1, 2, and 3.
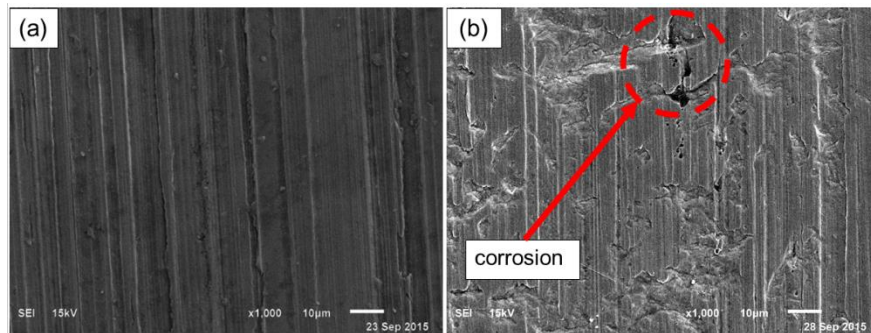

**Fig. 4. SEM images of AISI 304 before (a) and
after (b) the corrosion process using 0.27 M KOH solution.**

4. Conclusion

The corrosion resistance of AISI 304 electrode under various types (i.e., KOH, NaOH, and NaCl) and concentrations of electrolytes (from 0.27 to 0.53 M) had been investigated. AISI 304 has good corrosion resistance in all of electrolyte solution. From all of the samples tested, the average value of corrosion rate is about 0.0051530 mpy. The value of corrosion rate is classified in the category of excellent because its value is below 1 mpy. The most corrosion resistance of AISI 304 occurred in electrolyte solution with lower concentration. Pitting corrosion with low corrosion rate is observed in this condition. Investigation on the long term performance of the corrosion resistance of AISI 304 at variation of solution temperatures is the subject of future studies.

Acknowledgements

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