IDENTIFYING UNIFORM CORROSION OF CARBON STEEL USING ELECTROCHEMICAL NOISE MEASUREMENT

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ABSTRACT

In this study, the electrochemical noise (ECN) measurement technique was utilized to identify the uniform corrosion of carbon steels in the solutions of hydrochloric (HCl), sulphuric (H_2SO_4), sodium chloride (NaCl), sodium hydroxide (NaOH), potassium hydroxide (KOH) and calcium hydroxide ($Ca(OH)_2$). ECN is the fluctuations of current and potential of a corroding system. The potential of electrochemical noise was measured between a working electrode and a reference electrode whereas the current of electrochemical noise was measured between two working electrodes in an electrochemical cell. The data from the measurements were statistically analyzed using time and frequency domains. The time domain analysis reveals the characteristics of a particular corrosion type. The frequency domain analysis estimates the power spectra at various frequencies and the statistical analysis calculates electrochemical noise parameters such as the mean, standard deviation, noise resistance (R_N), coefficient of variation (CoV), characteristic charge (q) and corrosion current (I_{corr}). The results of the time domain analysis show that uniform corrosion only occurred in acidic solutions of HCl and H_2SO_4. The frequency domain analysis was found to be an unsuitable method to identify uniform corrosion in the corrosion system used. The statistical analysis shows that the corrosion rate was greater when using the solutions of HCl and H_2SO_4 compared to NaCl, NaOH, KOH and Ca $(OH)_2$.

Keywords: ECN, uniform corrosion, current, potential

ABSTRAK

Kaedah pengukuran hingar elektrokimia digunakan untuk menentukan hakisan seragam keluli karbon dalam larutan asid hidroklorik (HCl), asid sulfurik (H_2SO_4), natrium klorida (NaCl), natrium hidroksida (NaOH), kalium hidroksida (KOH) dan kalsium hidroksida ($Ca(OH)_2$). Hingar elektrokimia adalah turun naik arus dan beza keupayaan dalam sistem yang sedang terhakis. Hingar elektrokimia beza keupayaan diukur antara satu elektrod sampel dan elektrod rujukan manakala hingar elektrokimia arus diukur antara dua elektrod sampel di dalam sel elektrokimia. Data yang diperolehi daripada pengukuruan dianalisis dengan merujuk kepada masa, frekuensi dan secara statistik. Penganalisisan masa menunjukkan ciri-ciri jenis hakisan. Penganalisisan frekuensi menganggarkan spektrum kuasa pada frekuensi berbeza dan penganalisisan statistik melibatkan pengiraan parameter hingar elektrokimia seperti min, sisihan piawai, rintangan hingar (R_N), pemalar variasi (CoV), cas elektrik (q) dan arus hakisan (I_{corr}). Keputusan penganalisisan masa menunjukkan hakisan seragam hanya berlaku dalam larutan asid HCl dan H_2SO_4 sahaja. Penganalisisan spektum kuasa pada frekuensi berbeza bagi arus dan beza keupayaan pula didapati bukan kaedah yang sesuai untuk menentukan samada terdapat sebarang hakisan seragam dalam enam sistem hakisan tersebut. Keputusan penganalisisan statistik menunjukkan bahawa kadar hakisan adalah tinggi dalam larutan HCl dan H_2SO_4 berbanding dalam larutan NaCl, NaOH, KOH and $Ca(OH)_2$.

Kata kunci: Hingar elektrokimia, hakisan seragam, arus, beza keupayaan

1. Introduction

Corrosion is the deterioration or degradation of material properties due to chemical and electrochemical reactions between the material surfaces with their environments. The corrosion process takes place when unstable metals are in ordinary aqueous environments. Consequently, metals combine chemically with elements to form components and return to their lower energy levels. Generally, there are two conditions for corrosion to occur which are the chemical reaction between the metal and solution and the electrochemical reaction where electrons are transferred between the metal and the solution when they have different potentials. Both of these conditions occur at the same time (Fontana, 1986).

The formation of corrosion is influenced by factors such as temperature, pH value of the solution, type of solution and surface area (Izzuan, 2007). However, in this study, only the type of solution is considered. The solutions used were hydrochloric (HCl), sulphuric (H_2SO_4), sodium chloride (NaCl), sodium hydroxide (NaOH), potassium hydroxide (KOH) and calcium hydroxide $Ca(OH)_2$.

Corrosion has a big influence on humans from economic, health and safety aspects. Some countries have spent billions of dollars a year in order to change or repair the materials that have been attacked by corrosion. As an example, a survey conducted in Britain and America showed that the overall direct and indirect cost caused by corrosion amounted to approximately 4.5% of Gross National Product (El-Meligi, 2010). As for health, metals implanted into the human body can corrode and might bring new health problems. In addition, metals used in automobile industries, gas pipelines and aircraft manufacturing have the potential to corrode and this might cause injuries or even loss of life if they corrode and fail. Nevertheless, the loss due to corrosion can be decreased by early prevention such as through undertaking studies on how to control corrosion and prevent the phenomenon of corrosion.

The corrosion process can be detected using a few methods such as Open Circuit Potential Measurement, Electrochemical Impedance Spectroscopy (EIS) or Electrochemical Noise (ECN) (Pierre, 1999). ECN was used in this research in order to observe the formation of uniform corrosion on carbon steel which was immersed in acidic, salt and alkaline solutions. Electrochemical noise refers to the electrochemical potential and current fluctuations in random electrochemical processes and these were measured in this research. The data was then analyzed using Batch ENAnalyse, ENAnalyse and Microsoft Excel. This research also investigated whether the analysis technique could be used to differentiate the corrosion systems.

2. Literature Review

2.1. *Corrosion*

The electrochemical corrosion mechanism is illustrated through an electrochemical cell. A typical electrochemical cell consists of the plate metal (anode and cathode), a metallic conductor and electrolyte. An electrical current would flow through the metallic conductor and the electrolyte. The anode would corrode chemically. This is an oxidation reaction. Simultaneously, a nondestructive chemical reaction (reduction) occurs at cathode, depends on electrode and electrolyte. If the metallic conductor were replaced with a voltmeter, a difference of potential could be measured between the electrodes (Peter & Julio, 2002).

An electrolyte is a solution containing ions, which are the particles bearing an electric charge. Ions are present in solutions of acids, alkalis and salts. For iron corroding in water, the electrochemical reactions are as follows:

(i) $\quad 4Fe \rightarrow 4Fe^{2+} + 8e^-$

$\quad 4Fe + 3O_2 + H_2O \rightarrow 2Fe_2O_3 \cdot H_2O$ (hydrated red iron rust)

(ii) $\quad 4Fe + 2O_2 + 4H_2O \rightarrow 4Fe(OH)_2$

$\quad 4Fe(OH)_2 + O_2 \rightarrow 2Fe_2O_3 \cdot H_2O$ (hydrated red iron rust) $+ 2H_2O$

The most stable form of iron is Fe_2O_3. However, at higher temperatures of 900ºF to 1300ºF, Fe_2O_3 reverts to Fe_3O_4. The formation of Fe_3O_4 can occur either by heating the rusted steel to high temperatures or by oxidizing (reducing) operations. The metal at anode is attacked at a rapid rate while at the cathode, hydrogen is being evolved continuously, forming a hydrogen gas upon recommendation, even in the absence of oxygen and in an acidic environment (Shreir et al., 2000).

Corrosion affects the metal in many ways depending on its nature and the precise environmental condition. There are several types of metal corrosions that have been identified namely uniform corrosion, pitting corrosion, crevice corrosion, galvanic corrosion, stress corrosion and erosions corrosion as well as cracking, cavitations, fretting, intergranular and dealloying. The effects of uniform corrosion on carbon steel immersed in six different solutions were studied in this research. Uniform corrosion or general corrosion refers to the relatively uniform reduction of thickness over the surface of a corroding material. The rate of uniform corrosion is equal over the entire surface. Uniform corrosion is not fixed in location but distributed over a metal surface where anodic and cathodic reactions take place. Examples of this type of corrosion includes the rusting of steel bridges, tarnishing of silver and patina formation on copper roofs and bronze statues. The life of components attacked by uniform corrosion can be estimated based on the results of a simple immersion test.

2.2. *Electrolytes*

An electrolyte is a substance that can conduct electricity when dissolved in water. The ability of a solution to conduct electricity depends on the number of ions it contains. In chemistry, an acid is traditionally considered as chemical compound that when dissolved in water, gives a solution with hydrogen ion activity greater than in pure water (pH less than 7.0). An acid is a compound which donates a hydrogen ion (H^+) to another compound (called a base). Salt is a neutral compound which has a pH equivalent to 7.0. An alkali is a basic, ionic salt of an alkali metal or alkaline earth metal element. Alkali is a base that dissolves in water with a pH of greater than 7.0 (Peter & Julio, 2002). The corrosion effect (if any) can be monitored at the bottom surface of carbon steel electrodes which are immersed in the electrolyte.

2.3. *Electrochemical noise*

In electrochemical noise, 'electrochemical' refers to the transfer of electrons between the surfaces of materials with the aqueous environment (electrolyte) whereas the term 'noise' refers to the unwanted sound. Unwanted sound does not mean that it does not contain any useful information. The noise can be interpreted into useful information by using certain skills. As an example, the noise of an engine can be interpreted to identify various fault conditions (Cottis & Turgoose, 1999). According to Iverson studies on ECN as cited by Hanna (2003), ECN was generated by a variety of materials using relatively simple apparatus in the sixties and it was concluded that the voltage fluctuations contributed to the detection and study of the corrosion process and corrosion inhibitors. The development of the theoretical basis of ECN measurement by Cottis and Turgoose (1999) comes with the suggestion of ECN resulting from the statistically independent pulses of charge that can be analyzed by a simple shot noise model. The current noise power is proportional to the corrosion rate whereas the potential noise power is inversely proportional to the corrosion rate. The estimation of charge, *q* involved in the reaction can be

made by assuming that the noise resistance is equivalent to the polarization resistance at the low frequency limit. A large value of q indicates localized corrosion (Cottis and Turgoose, 1999). The ECN parameters which are derived from basic statistical parameters determined in this research consist of noise resistance (R_N), coefficient of variation (CoV), characteristic charge (q) and corrosion current (I_{corr}).

2.4. *Statistical shot noise parameters*

The electrochemical noise resistance, R_N is the standard deviation of potential, σ_V divided by the standard deviation of current, σ_I. The noise resistance tends to be the best-established parameter to interpret the electrochemical noise especially in giving useful information for the uniform corrosion processes (Cottis & Turgoose, 1999).

$$R_N = \frac{\sigma_V}{\sigma_I} \tag{1}$$

The coefficient of variation, CoV is the standard deviation of current, σ_I divided by the mean current, $\bar{I}$ and is a measure of the signal noisiness compared with its mean current. The coefficient of variation has been used as an indicator of localized corrosion. The mean current is expected to be small whereas the coefficient of variation is expected to be large.

$$CoV = \frac{\sigma_I}{\bar{I}} \tag{2}$$

Characteristic charge, q is the average charge of the individual transients that make up the electrochemical noise. The charge is normally the electron charge in electrical circuit but in electrochemical situations the charge may be greater than this. The calculation of characteristic charge is as below.

$$q = \frac{\sigma_V \times \sigma_I}{bB} \tag{3}$$

where b is the bandwidth (0.5 Hz) and B is the Stern-Geary coefficient (0.026 V).

Corrosion current, I_{corr} is produced by the pulse of charge in every second in a shot noise process. Corrosion current can be analyzed by using the resistance noise. As the resistance noise influences the corrosion rate, so does the corrosion current. Equation (4) shows the relation of corrosion current with the noise resistance.

$$I_{corr} = \frac{B}{R_N} \tag{4}$$

2.5. *Analysis software*

The ECN data was analyzed using Microsoft Excel, ENAnalyse and Batch ENAnalyse. Microsoft Excel is used to plot the graph of the time recorded and power spectral density, PSD. Both the ENAnalyse and Batch ENAnalyse software have a similar function which is to analyze the electrochemical noise data. ENAnalyse requires a 32-bit version of Windows (Windows 95/98 or NT) and can only handle a single time record of current version although it can upload random columns from the input data file (Cottis & Turgoose, 1999). Therefore, the ECN current and potential were analyzed separately. In this research, each experiment comprised 8192 points. The graph of time record, FFT power spectrum and MEM power spectrum can be plotted using this software. The statistics of the analysis from ENAnalyse was divided into two parts which are those with no trend removal and with trend removal. The difference between ENAnalyse and Batch ENAnalyse is that Batch ENAnalyse can perform calculations in batches. This can be done by adjusting the numbers of input points.

3. Research Methodology

In the measurement of ECN, a signal conditioning circuit and two digital multimeters were connected to a computer via the IEEE 488 bus. An IEEE 488 bus which was connected to a personal computer was used as the data acquisition system. Sometimes the multimeters stopped and the computer lost the readings due to high frequency spikes on the main electricity source. Therefore, the Uninterruptible Power Supply (UPS) filters the unrequired spikes from the main source and supplies electricity to the instrument if the power is cut off. The electrochemical cell and the signal conditioning circuit were placed in a faraday cage which was connected to the ground in order to avoid the external noise and disturbances. The potential electrochemical noise was measured between one working electrode and a reference electrode whereas the current electrochemical noise was measured between the two working electrodes in an electrochemical cell. The signal circuit contained a zero-resistance ammeter (ZRA), voltage amplifier and low-pass active filters. The schematic diagram of ECN set-up is shown in Figure 1 below. The solutions used as electrolytes in this research were 1M of concentration of the acidic solutions (HCl and H_2SO_4), salt (NaCl) and alkaline solutions [NaOH, KOH and Ca(OH)$_2$]. The measured potential and current electrochemical noises were then analyzed using Microsoft Excel, ENAnalyse and Batch ENAnalyse software.
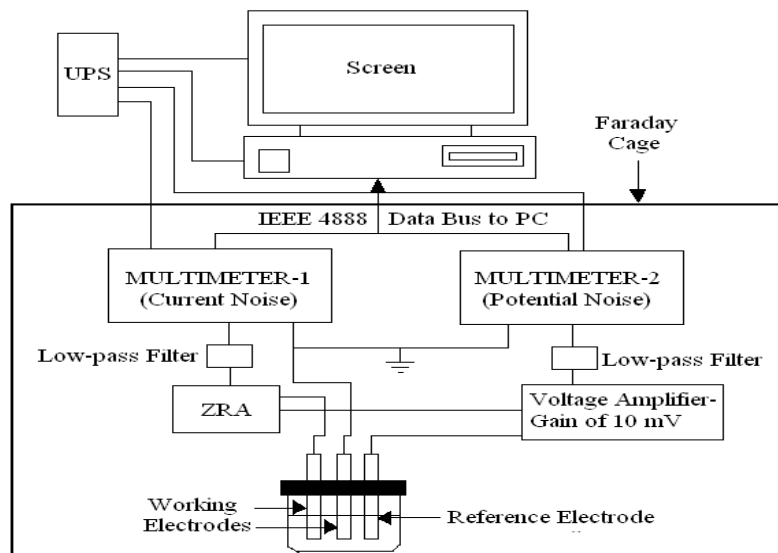

Figure 1: Schematic diagram of ECN set-up

4. Result and Discussion

A set of data was analyzed from each of the six corrosion systems. Each set of data consists of 8192 readings for both current and potential noise. The data was analyzed using time domain, frequency domain and also statistically. Both of the current and potential were compared for all of the corrosion systems.

4.1 *Time Domain*

Time domain in this research is used to see the fluctuation of current and potential as a function of time in order to identify the characteristics of corrosion. A graph of current and potential as a function of time was plotted for each corrosion system as shown in Figure 2 (a - f).

The graph in Figure 2 (a) does not indicate that uniform corrosion occurred in the 1M NaCl solution since there was no significant fluctuation of the electrochemical noise. The NaCl solution does not affect the anode carbon steel electrode which corrosion may produce. The NaCl solution is a neutral solution of salt with the pH value of 7.

Graphs (b) and (c) in Figure 2 show that the high frequency transient and high amplitudes of both currents and potential indicate the characteristics of the uniform corrosion. The frequent and continuous spike of the electrochemical noise shows that a uniform corrosion process occurred at the surface of the carbon steel electrodes in both solutions of HCl and H_2SO_4. This is in accordance with Hanna's (2003) study which states that electrochemical noise fluctuations contribute to the detection of corrosion process. The acidic solutions of HCl and H_2SO_4 are the general corrosive solutions. There were conspicuous changes in the current fluctuations in graph (c) as the time increased from 5000 to 8000 second. This might be due to errors of the instruments while taking the readings.

The signals in graph (d), (e) and (f) do not show that uniform corrosion occurred in the corrosion systems even though they look like the electrochemical noise of uniform corrosion. Generally, alkaline solution produces an oxidation layer at the surface of the material. This oxidation layer protects the material surface from corroding. However, pitting corrosion may occur when the oxidation layer cracks. The signals produced by the corrosion systems of $Ca(OH)_2$, KOH and NaOH may look like the electrochemical noise of uniform corrosion because of the instrument noise.
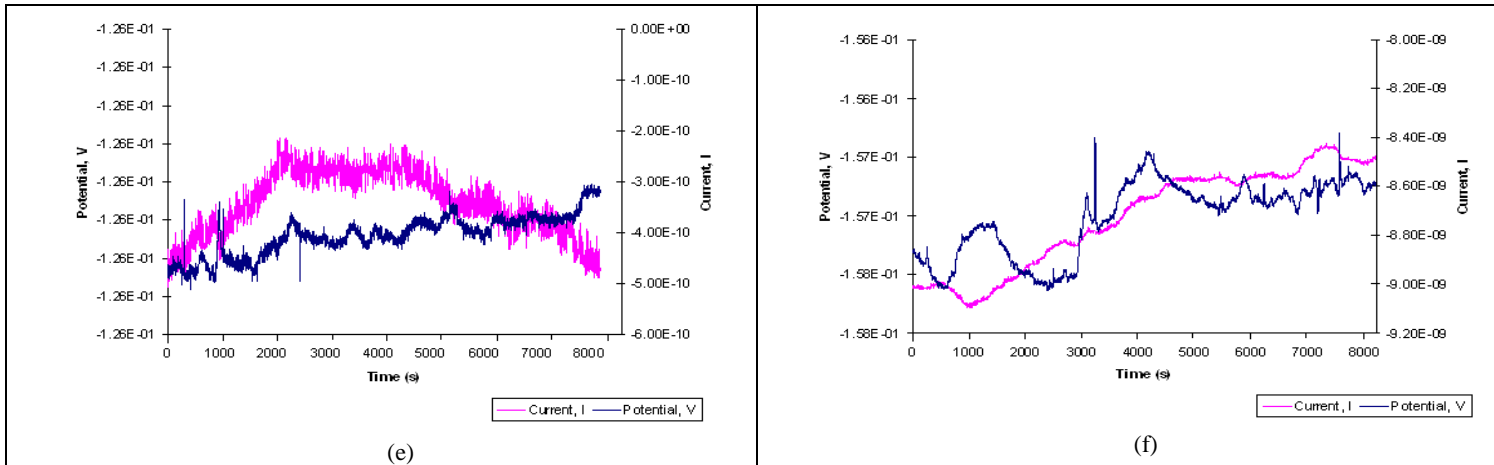

(a)

(b)

(c)

(d)
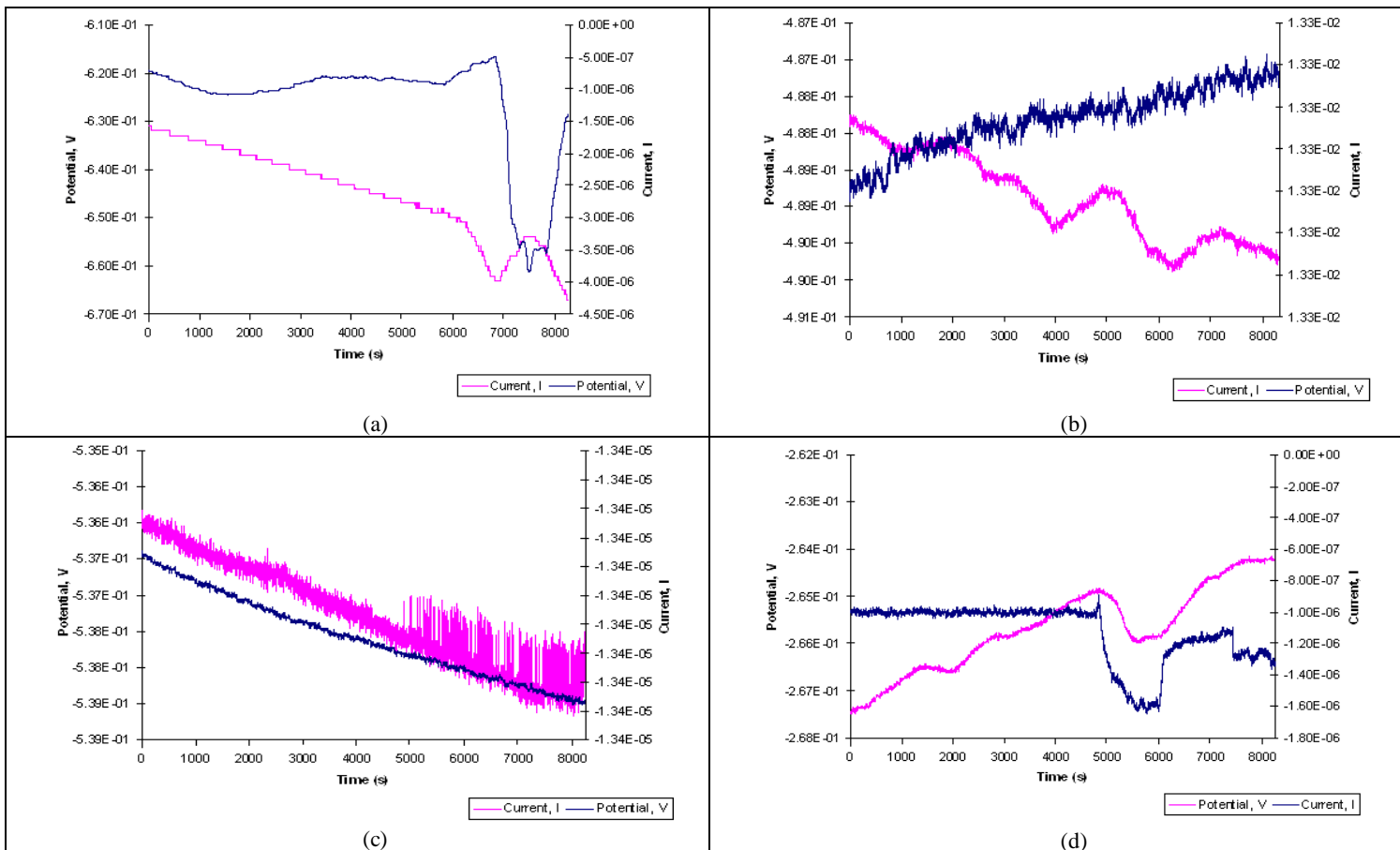
Figure 2: Graph of current and potential versus time for carbon steel electrodes in (a) 1M NaCl, (b) 1M H$_2$SO$_4$, (c) 1M HCl, (d) 1M Ca(OH)$_2$, (e) 1M KOH and (f) 1M NaOH solutions

4.2 *Frequency Domain*

Frequency domain is the process of estimating the power spectral density (PSD) at various frequencies. The PSD as a function of frequency were plotted for selected data taken from each of the corrosion systems. Fourier transforms (FFT) and maximum entropy methods (MEM) are the two commonly used methods for the estimation of PSD in electrochemical noise. The FFT produces noisy spectra whereas MEM produces smoother spectra. Therefore, the MEM was chosen in the spectra analysis in this research.
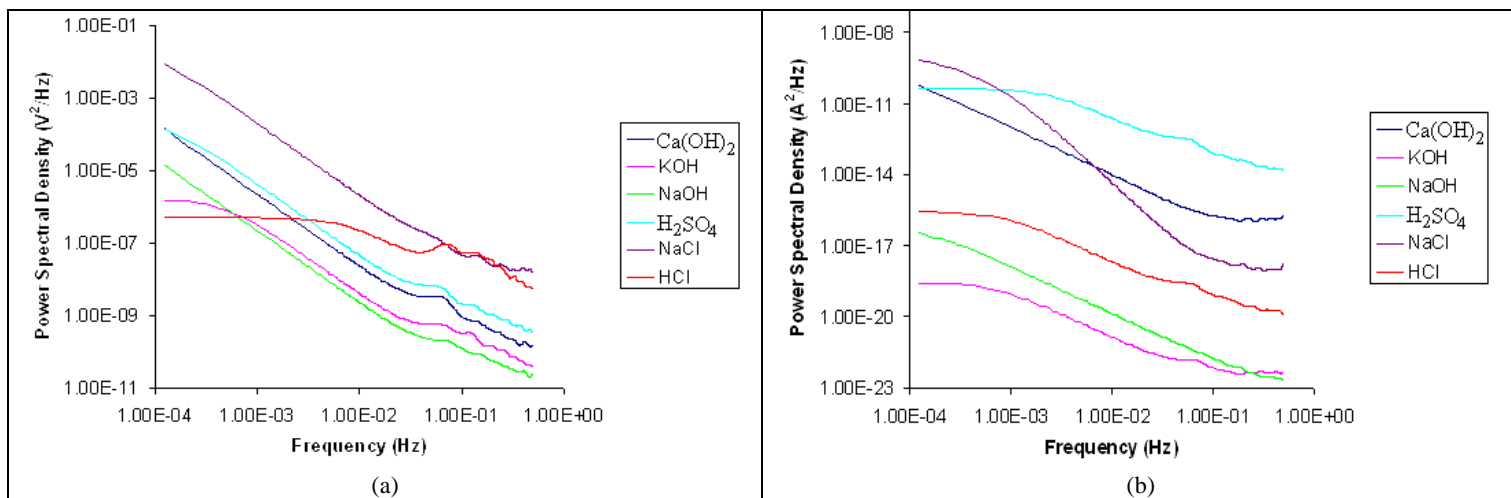

Figure 3: (a). Graph of potential power spectral density versus frequency and (b) Graph of current power spectral density versus frequency for the six corrosion systems

According to the graph in Figure 3(a), it is difficult to determine the low frequency plateau and the knee frequency of most of the corrosion system signals except for the KOH and HCl corrosion systems. The low frequency plateau is the constant value of the power before it starts to decrease as the frequency increases whereas the knee frequency is the frequency when the power starts to decrease. The low frequency plateau for KOH was in the range of 1×10^{-4} to 3.25×10^{-4} Hz and at the power level of 1.495×10^{-5} V^2/Hz whereas for HCl, it was at the range of 1×10^{-4} to 7.75×10^{-4} Hz at the power level of 1.595×10^{-5} V^2/Hz. The knee frequencies for KOH and HCl were 3.25×10^{-4} Hz and 7.75×10^{-4} Hz respectively. The roll of slope of the signals can be observed easily from the graph for all the corrosion systems. The roll of slope is the slope of

14

the signal when the power decreases as the frequency increases. By looking at the graph, the roll of slope for the $Ca(OH)_2$, NaCl, NaOH and H_2SO_4 corrosion systems can be estimated into -1.01 x 10^{-3} V^2/Hz^2 whereas for KOH and HCl, these were -1.00 x 10^{-3} V^2/Hz^2 and 7.33 x 10^{-4} V^2/Hz^2 respectively. These three parameters (low frequency plateau, knee frequency and roll of slope) were used to distinguish the effect of different corrosion systems and hence different types of corrosion. As a conclusion, the potential of PSD method is not a suitable method to analyze the potential noise data because it failed to distinguish the low frequency plateau and the knee frequency of the corrosion systems used in this research. By referring to the graph in Figure 3(b), it is easier to distinguish the current signal of PSD than the potential signal of PSD [Figure 3(a)] for all of the corrosion systems utilized. Table 1 shows the values of the parameters in order to analyze the current of PSD.

Table 1: PSD parameters of current

Systems	Low Frequency Plateau	Knee Frequency (Hz)	Roll-off Slope (A^2/Hz^2)
NaCl	Cannot be estimated	Cannot be estimated	-1.4 x 10^{-7}
HCl	x 10^{-4} to 1.0 x 10^{-3} Hz at power level of 5.01 x 10^{-15} A^2/Hz	1.0 x 10^{-3}	-1.39 x 10^{-13}
H_2SO_4	1.0 x 10^{-4} to 1.2 x 10^{-3} Hz at power level of 2.51 x 10^{-9} A^2/Hz	1.2 x 10^{-3}	-1.39 x 10^{-7}
$Ca(OH)_2$	Cannot be estimated	Cannot be estimated	-7.63 x 10^{-10}
KOH	x 10^{-4} to 5.91 x 10^{-4} Hz at power level of 5.01 x 10^{-18} A^2/Hz	5.91 x 10^{-4}	-3.47 x 10^{-16}
NaOH	Cannot be estimated	Cannot be estimated	-7.63 x 10^{-16}

Table 1 shows that the parameters of the PSD current could only be estimated for corrosion systems of HCl, H_2SO_4 and KOH. This implies that this method also failed to distinguish the low frequency plateau and the knee frequency of the six corrosion systems. Therefore, it can be concluded that this method is also not suitable to analyze current noise of the corrosion systems used in this research.

4.3 *Statistical Analysis*

The basic statistical parameters considered in this research were the means and standard deviation of the potential and current. The parameters were analyzed using the Batch ENAnalyse and ENAnalyse software. Table 2 shows the statistical analysis parameters of the data obtained from the six corrosion systems.

Table 2: Mean and standard deviation values of the corrosion systems

Systems	Mean Potential, $\overline{V}$	Mean Current, $\overline{I}$	Standard Deviation of Potential, σ_V	Standard Deviation of Current, σ_I
$Ca(OH)_2$	-2.66 x 10^{-01}	-1.13 x 10^{-08}	3.50 x 10^{-05}	1.68 x 10^{-11}
KOH	-1.26 x 10^{-01}	-4.05 x 10^{-10}	1.16 x 10^{-05}	8.46 x 10^{-12}
NaOH	-1.57 x 10^{-01}	-8.73 x 10^{-09}	1.27 x 10^{-05}	1.72 x 10^{-11}
H_2SO_4	-4.89 x 10^{-01}	1.33 x 10^{-06}	1.09 x 10^{-04}	2.74 x 10^{-07}
NaCl	-6.45 x 10^{-01}	-1.20 x 10^{-06}	3.23 x 10^{-05}	3.52 x 10^{-10}
HCl	-5.37 x 10^{-01}	-1.34 x 10^{-05}	1.27 x 10^{-04}	2.70 x 10^{-08}

The mean values were the average of all values in the recorded time. From the table, the mean potential in the alkaline solutions of $Ca(OH)_2$, KOH and NaOH are greater compared to the acidic solutions of HCl and H_2SO_4 and salt solution of NaCl. The mean current are greater in the solutions of HCl, H_2SO_4 and NaCl compared to the solutions of $Ca(OH)_2$, KOH and NaOH. Table 2 illustrates that the standard deviations of both current and potential are greater in acidic solutions of HCl and H_2SO_4 compared to the other corrosion systems. The standard deviation is

the square root of the variance. The variance increases as the corrosion rate increases. Therefore, the corrosion rate is high in HCl and H_2SO_4 solutions since their standard deviations for both current and potential are high.

4.4 *Electrochemical noise parameters*

The electrochemical noise parameters considered were electrochemical noise resistance (R_N), coefficient of variation (CoV), characteristic charges (q), and corrosion current (I_{corr}). The values of the parameters were determined using the equations as presented in the literature review.

Table 3: Electrochemical noise parameters

Systems	ECN Resistance, R_N (Ω)	Coefficient of Variation, CoV	Charge, q (C)	Corrosion Current, I_{corr} (A)
Ca(OH)$_2$	2.08 x 10^{05}	1.49 x 10^{-02}	4.52 x 10^{-11}	1.25 x 10^{-08}
KOH	1.37 x 10^{06}	2.09 x 10^{-02}	7.55 x 10^{-11}	1.90 x 10^{-08}
NaOH	7.38 x 10^{05}	1.97 x 10^{-03}	1.68 x 10^{-12}	3.52 x 10^{-08}
H$_2$SO$_4$	1.44 x 10^{02}	2.06 x 10^{-05}	8.30 x 10^{-13}	1.81 x 10^{-04}
NaCl	9.81 x 10^{03}	2.93 x 10^{-02}	8.75 x 10^{-10}	2.83 x 10^{-06}
HCl	4.70 x 10^{03}	2.01 x 10^{-05}	2.64 x 10^{-14}	5.35 x 10^{-06}

Table 3 indicates that the noise resistance values, R_N are low in acidic solutions (HCl and H_2SO_4) compared to those in alkaline (Ca(OH)$_2$, KOH and NaOH) and salt (NaCl) solutions. Since uniform corrosion has a low R_N, the acidic solutions (HCl and H_2SO_4) are then assumed to produce uniform corrosion. The R_N of the salt solution (NaCl) is also low because it also produces uniform corrosion due to its oxygen content.

The coefficient of variation, CoV are also low in acidic solutions (HCl and H_2SO_4) compared to those in alkaline (Ca(OH)$_2$, KOH and NaOH) and salt (NaCl) solutions. The CoV approaches zero in uniform corrosion. Therefore, the acidic solutions (HCl and H_2SO_4) contribute to uniform corrosion process. The characteristic charges, q appear in contrast from one system to another. As stated by Hanna (2003), a high q is referred to pitting corrosion while a low q is referred to uniform corrosion. From the results, the values of the q can be considered low in acidic solutions (HCl and H_2SO_4) compared to the q in alkaline (Ca(OH)$_2$, KOH and NaOH) and salt (NaCl) solutions. Thus, uniform corrosion is assumed to take place in the acidic solutions of HCl and H_2SO_4. According to Cottis & Turgoose (1999), corrosion current, I_{corr} depends on R_N where the values of I_{corr} are inversely proportional with R_N, thus, the R_N is inversely proportional with the corrosion process. From Table 3.0, the I_{corr} values are greater in acidic (HCl and H_2SO_4) and salt (NaCl) solutions compared to the I_{corr} in alkaline solutions [Ca(OH)$_2$, KOH and NaOH]. Alkaline solutions are passivating agents which produce an oxidation layer on material surfaces and these contribute to low I_{corr} and high values of R_N. From the table 3, I_{corr} is also high in NaCl because NaCl may produce uniform corrosion.

5. Conclusions

The data analysis shows that uniform corrosion occurred only in acidic solutions of HCl and H_2SO_4. The fluctuation of electrochemical noise in acidic solutions indicates that there is corrosion and this finding is supported by Hanna (2003) who states that electrochemical noise fluctuations contribute to the detection of corrosion process. The power spectral density (PSD) at various frequencies for both current and potential were found to be not a suitable method in determining whether there was uniform corrosion in the corrosion systems examined. The mean potential in the alkaline solutions [Ca(OH)$_2$, KOH and NaOH] were greater than in the acidic (HCl and H_2SO_4) and salt (NaCl) solutions. The mean currents were greater in solutions of HCl, H_2SO_4 and NaCl compared to in solutions of Ca(OH)$_2$, KOH and NaOH. The electrochemical

noise resistance (R_N) was low in acidic solutions (HCl and H_2SO_4). Corrosion current, I_{corr} was greater in acidic solutions (HCl and H_2SO_4) compared to in alkaline [$Ca(OH)_2$, KOH and NaOH] and salt (NaCl) solutions. The coefficient of variation, *CoV* was high in alkaline solutions [$Ca(OH)_2$, KOH and NaOH] and low in acidic solutions (HCl and H_2SO_4). Characteristic charge, *q* was low in the acidic solutions (HCl and H_2SO_4). These results are in accordance with the description by Cottis and Turgoose (1999) on the occurrences of uniform corrosion where when the noise resistance (R_N) is low, the corrosion current (I_{corr}) is greater. Other than that, uniform corrosion is present when the coefficients of variation, CoV and the characteristic charge, q are low.

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