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The Effect of NaCl Concentration on the Ionic NaCl Solutions Electrical Impedance Value using Electrochemical Impedance Spectroscopy Methods

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Abstract. NaCl solution is a strong electrolyte that can produce Na^+ and Cl^- ions. Measurements of impedance values of dielectric materials have been widely applied, but for materials containing many ions such as electrolyte solutions still carried out today. This paper analyzes the relationship between concentrations and the electrical impedance value of NaCl solutions. Electrochemical impedance spectroscopy (EIS) method is applied by injecting an electrochemical stimulus in the form of an electric current of one milli-ampere into NaCl solutions. Response output voltage was recorded using PicoScope S-5000. The impedance measurement uses two needle electrodes made of gold in the frequency range 1 Hz to 1 MHz. The sample of NaCl solutions used in NaCl and water ratio is 0.01-3.00%. The electrical impedance of the NaCl solutions decreases with the increase in concentration of NaCl solutions.

Keywords: electrical impedance, electrochemical impedance spectroscopy, NaCl solution.

INTRODUCTION

The electrical impedance of solutions has been widely studied.[1] Observations about the presence of ions in a solution have been made to study the molecular dynamics. Experiments are done by measuring the electrical impedance of a solution, in general, by using Electrical Impedance Spectroscopy (EIS) technique.

A NaCl solution is an electrolyte solution that produces Na^+ and Cl^- ions. The Na^+ ion is the primary cation in blood and extracellular fluids in the body, and up to 95% of all the cations in the body. Electrolyte solution in the human body affect metabolism. Abnormal concentration of electrolyte solutions will cause metabolic disorders in the body. The NaCl solution plays an essential role in the regulation of body fluids, blood pressure, and acid-base balance. NaCl solutions have electrical conductivity because the NaCl solutions is a strong electrolyte in which the constituent ions dissociate entirely so that in NaCl solutions there are free-moving ions.

The electrical conductivity of a material illustrates the ability of the material to conduct electricity. It also relates to the electrical impedance properties of a material where the impedance is the electrical, physical quantity that states how much a material can inhibit the electric current. So it can be said that if a material has high electrical conductivity, then the impedance of the material is low.[2] Electrochemical Impedance Spectroscopy (SIE) is an analytical method to determine the electrical properties of a material. The SIE method is performed by injecting the electron stimulus or input, either in the form of potential or electrical current, in a system and then measuring its response in the way of output in the form of a signal (potential or current strength).[1] Therefore, NaCl solution is an

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electrolyte solution, wherein this research NaCl solution is used that varied in various concentrations. In this research, an SIE device was developed. This device is a continuation of a previously created system.[3,4]

Measurement of electrical impedance properties of a solution can be analogous to an electrical circuit consisting of resistors and capacitors,[5] e.g., in the Randles Circuit, as in Fig. 1.

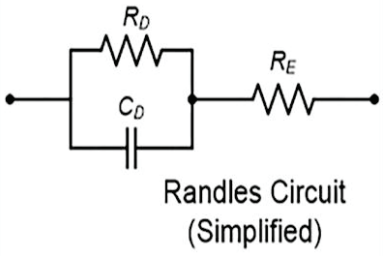

FIGURE 1. The series of Randles models used in this study.

MATERIALS AND METHODS

Measurements system of Electrochemical Impedance Spectroscopy, as shown in Fig. 2. The system consists of five major parts, namely: [3,4]

- V to I converter serves to provide a current injection to the impedance reactor. In this study a current of 1 m was used.
- Signal Conditioning plays an important role as modifiers or controlling sensor outputs to other elements of process control.
- An impedance chamber with two electrodes, a sample solution container equipped with two needle-shaped gold electrodes.
- PicoScope S-5000, the system that controls the input signal and simultaneously can record input and output signals.
- The computer serves as a signal monitor as well as a storage place of data recordings.

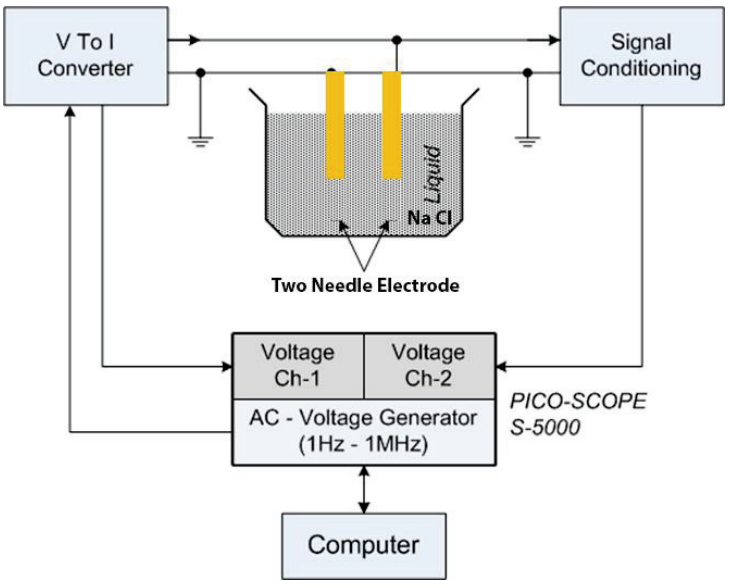

FIGURE 2. The data acquisition system of electric impedance spectroscopy uses two electrodes.

The impedance chamber made of an acrylic tube with an inner dimension (solution container): tube diameter 8 mm and length of 20 mm. In the middle position, there are two needle electrodes, 6 mm apart from each other. An

injected current of 1 mA connected to both electrode needles. PicoScope S-500 is set to control frequencies from 1 Hz to 1 MHz, with a voltage of 1 V.

The NaCl solution sample obtained by dissolving the mass of NaCl with 100 mL Aquades, then stirring for 2 minutes using a magnetic stirrer. The ratio of NaCl and Aquades is 0.01%, 0.05%, 0.10%, 0.20%, 0.30%, 0.50%, 0.80%, 1.00%, 1.50%, 2.00%, 2.50%, 3.00%. It means, the concentrations of NaCl solution are between 1.7 to 514 mM. Samples are prepared shortly before the impedance measurement. Measurement of the conductivity of the NaCl solution sample by using a conductivity meter with an accuracy of up to 0.001 mS/m.

The impedance measurement, by inserting the sample into the measurement chamber using a syringe, where the chamber is connected to the impedance measurement system. Measurement of sample impedance within 30 minutes to avoid oxidation. Measurements of electrical impedance made by taking 64 frequency points in the range 1 Hz to 1 MHz that is set through the Picoscope software on the computer, at room temperature. The measured input or output voltage recorded by the Picoscope, is in the form of peak-to-peak voltage (Vpp) values.

RESULTS AND DISCUSSION

Measurements of the impedance of NaCl solution carried out at room temperature, as shown in Fig. 3. Each part is connected to each other by using a coaxial cable, following the diagram in Fig. 1.

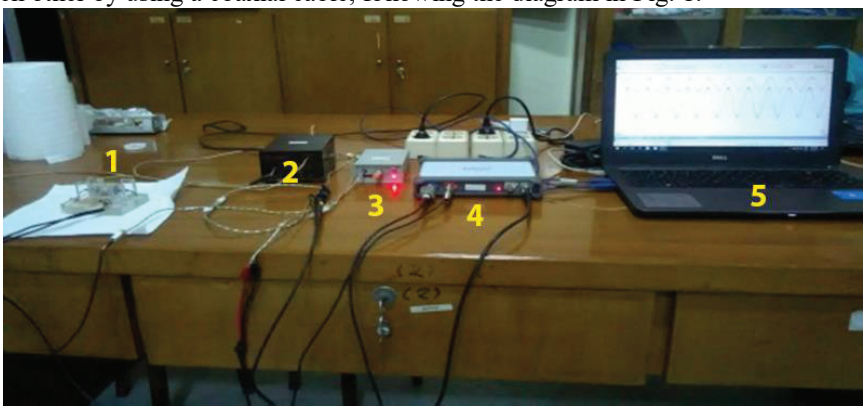

FIGURE 3. The electrical impedance measurement system of NaCl solution: 1: Reactor system two electrodes, 2: V to I system, 3: Signal Conditioning system, 4: PicoScope S-500, 5: Computer.

The conductivity of NaCl Solution

The Arrhenius theory states that the ionic conductivity of an electrolyte solution determined by its electrolyte ions. The conductivity of a medium illustrates the ability of the medium to carry electricity. In a liquid consisting of many ions, it will easily transfer the electricity. If there are more Na^+ and Cl^- then more electricity is carried or moved and this means a higher conductivity of the liquid. Water is regarded as an environmentally inactive medium.[6]

The results of conductivity measurement of NaCl solution at various percentages, indicating that there is a linear relationship between conductivity values and NaCl percentage. The higher the concentration, the greater the conductivity value, as shown in Fig. 4.

The result of measurements obtained according to theory, that the higher concentration of NaCl solution, the greater the value of the conductivity of the solution. The high NaCl concentration will accelerate ion migration in NaCl solution. Therefore, the conductivity value of the solution will increase as the concentration of the solution increases.

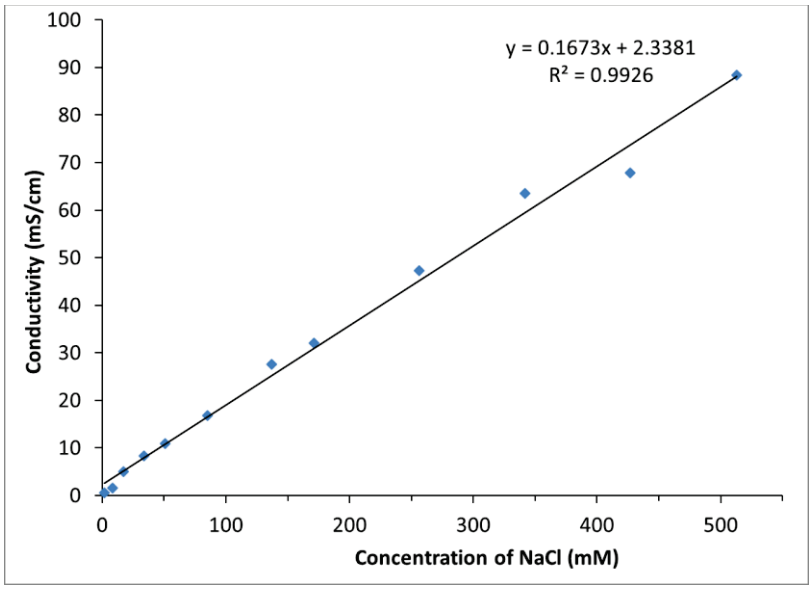

FIGURE 4. The plot of the Conductivity of NaCl aqueous at various percentage NaCl mass.

Relation of Frequency to Impedance of NaCl Solution

Measurement of the impedance of ionic NaCl solution at frequency range 1 Hz to 1 MHz, in that range of signal or output potential, it tends to be stable. The stability is due to the V to I converter. The results showed that in the low-frequency range from 1 Hz to 50 Hz, the electric impedance value decreased with increasing frequency, as shown in Fig. 5. At low frequencies, the electrical impedance value is affected by the double layer effect that is an interface effect between ionic in solution and electricity at the electrode. The value of electrical impedance is also affected by the use of a probe that is two electrode needles made of gold.

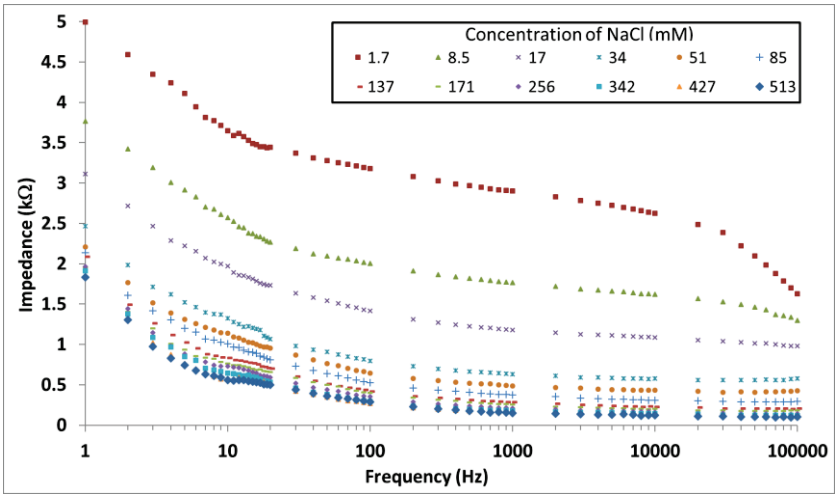

FIGURE 5. The characteristic properties of the electrical impedance of various NaCl concentrations at frequencies of 1 Hz to 1 MHz.

At low frequency a significant decrease in impedance occurs because the NaCl solution at that frequency is capacitive with a very large capacitive resistance value (also due to the double layer effect). The current passing

through the capacitor being very small or negligible, where the current only flows on the resistor. Capacitive reactance is highly dependent on frequency; where the greater the frequency the lower the capacitive reactance.

The reactions in charged particles in NaCl solution, i.e., Na^+ and Cl^- ions, which pass through the surface of two phases of a substance, i.e., the metal phase (electrode) and the solution phase (NaCl solution) lead to an imbalance of electrical charge on the electrode and electrolyte. The presence of a gap between the electrode and the NaCl solution is analogous to the capacitor, whereas the NaCl solution, in particular the ions attached to the electrode surface, are analogous to the resistor, resulting in an equivalent RC circuit, such as the Randles model in Fig. 1.

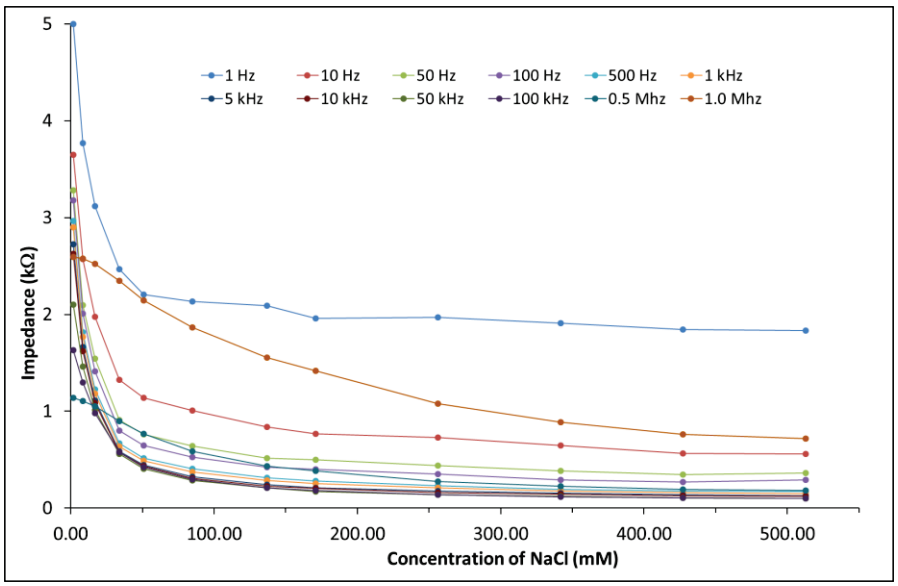

FIGURE 6. Plot of Electrical impedance vs percentage of NaCl solution at various frequencies.

In the frequency range above 50 Hz, the electrical impedance of the NaCl solution tends to be constant; this is because the NaCl solution is an ionic solution having greater conductivity properties. The resistive nature of the NaCl solution is dominant at high frequencies, whereas its capacitive properties appear only at low frequencies. NaCl solution is a solution with an ionic bond. When the current is injected into the NaCl solution, there is an electric field effect in the solution resulting in a shift of ions resulting in ion polarization in the solution.

The dipole formed by this polarization is a non-permanent dipole, so it takes a long time to reach a state of equilibrium when given a unidirectional electric field. When the field is removed, the ion position will return to its original state for a relatively long time. Therefore, in alternating current (AC), polarization fields can occur at low frequencies. As shown in Fig. 6, when the low-frequency impedance value decreases significantly, while at high frequency the value is relatively constant.

CONCLUSION

NaCl concentration has a linear effect on the conductivity value of NaCl solution, the higher the NaCl concentration, the higher the conductivity of the solution. NaCl solution concentration has an effect on electric impedance value of NaCl solution, the electric impedance value of NaCl solution is lower along with increasing concentration of NaCl solution. Measurement of impedance by electrochemical impedance spectroscopy method using two electrodes made of gold and 1 mA injection current can distinguish the concentration of NaCl solution.

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