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Analysis of the Effect of NaCl Solution Concentration on the Properties of Impedance Solutions and Different Phases with a Gold Electrode Impedance Measurement System

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Abstract— *Electrolyte solution is a solution that can conduct electric current. Research on the impedance value of biological materials using dielectric materials has been carried out, whereas impedance studies using electrolyte materials/solutions are still not widely used. The concentration of the solution states the amount of solute in each unit of solution or solvent. The purpose of this study is to determine the relationship between the concentration of the solution and the value of the solution impedance, and the relationship between the frequency and the value of the solution impedance. In this measurement, the researcher used the electrochemical impedance spectroscopy (SIE) method. This method was done by injecting an electric stimulus (input) in the form of an electric current and observing the output (output) in the form of a signal (voltage). This study using four gold electrodes with frequencies used in the range of 1 Hz - 1 MHz. The solution used is a NaCl solution with a concentration range of 0.00017 M - 0.00085 M. From the results of the study found the highest electrical impedance value is at the lowest solution concentration at the concentration of 0.00017 M, while the lowest impedance value is at the highest solution concentration, namely at concentration 0.00085 M. In the frequency range of 1 Hz - 1 kHz the effect of frequency on the electrical impedance value in a solution is difficult to distinguish in the frequency range of 1 kHz - 100 kHz the effect of frequency on impedance can be distinguished well. In the frequency range above 100 kHz, the effect of frequency on the impedance value of the measurement is difficult to distinguish; this is because the tool is increasingly insensitive to changes in frequency.*

Keywords—*Electrical impedance, Electrochemical Impedance Spectroscopy Method, Electrolyte Solution, Electrolyte Solution Concentration.*

I. INTRODUCTION

There is a lot of research done on biological materials with dielectric materials such as impedance measurements in tilapia, impedance measurements to test the milk impedance by adding water and so on. From the study, the biological material measured was a dielectric material. While research using electrolyte materials/solutions is still not widely done. Electrical impedance spectroscopy (EIS) is a method for analyzing the electrical properties of materials by inducing electrical signals at different frequencies into them and measuring signals that respond [1].

There are three frequency domains to measure the electrochemical impedance spectroscopy techniques. The first is in the high-frequency range associated with the transfer of charging on the counter electrode. The second is in the intermediate frequency region associated with electron transfer in the sample. Then, the latter in areas with low frequencies usually reflect surface effects due to electrolyte particle dynamics [2]. Measurement of the electrical impedance of a solution can be done by many methods, such as direct current injection method (two probes and four probes), AC bridge method, the optical method, and the other [3]. A solution contains one solute or more than one solvent. Soluble substances are small components, whereas solvents are components that are present in large quantities. Salt is an ionic compound consisting of positive ions (cations) and negative ions (anions), thus forming a neutral compound (without charge). The salt solution in water (for example sodium chloride in water) is an electrolyte solution, which is a solution that can conduct an electric current.

A solution is a homogeneous mixture of two or more components in one phase. 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 affects 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 [4]. Electrolytes are compounds in solutions that dissociate into positive or negative charged (ion) particles. The electrolyte is a solution that can conduct an electric current.

The electrical conductivity of 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 [4].

In a previous study measuring the impedance value of NaCl solution with a frequency of 1 Hz -1 MHz, the solution

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concentration was 0.0017 M - 0.513 M using electrochemical impedance spectroscopy method with 4 gold probes. In this study using a NaCl solution with the same frequency but the concentration value was reduced to 0.00017 M – 0.00085 M and using the same method. Lowering the solution concentration value aims to determine whether the impedance value can still be distinguished well in all frequency ranges used.

II. Research Method

The principle of impedance measurement with four electrodes is applied to the sample NaCl solution as shown in Figure 1. In general, the injection of electric current from the V to I converter is 100 μA into a sample of NaCl solution through two electrodes (A1 and A2), and electrical impedance measurements with using two needle electrodes B1 and B2. PICOSCOPE 5000 series with type 5422B supports impedance measurement by recording input potential (V in) and output potential (V out), and as a signal controller. The input voltage (V in) is 1 Volt [5].

Samples of NaCl solution were placed in a sample container made of acrylic, with dimensions of tube length 2.3 cm and tube diameter 2.7 cm. At the end of the container, there are two gold plate electrodes (A1 and A2) in the form of a circle with a diameter of 0.8 cm with a distance between the plates is 2 cm. In the middle between the two A1 and A2 plates, there are two gold needle electrodes (B1 and B2) with a distance between the needles of 0.6 cm. Electrical impedance is measured up to 1 MHz. The voltage used to measure the impedance value is the *peak-to-peak* voltage of the output voltage (Vout) divided by two. The electrical impedance value is obtained by calculating the potential divided by the injected current.

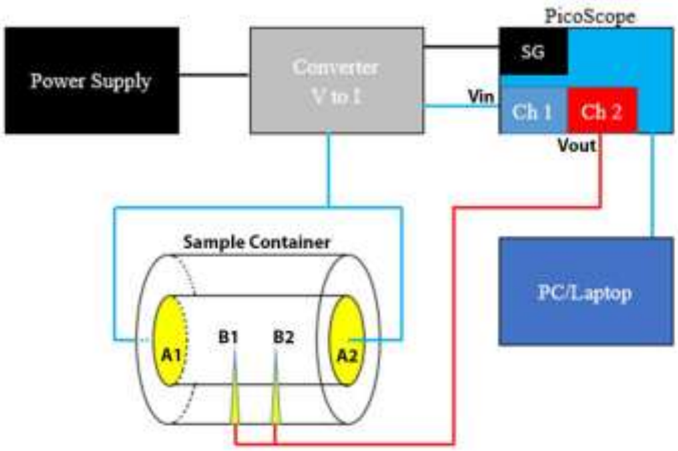

Fig. 1. The electrical impedance measurement system using four electrodes.

In this study, the sample used was NaCl crystals. To determine the concentration of each sample, the NaCl crystals are weighed first with an Ohaus balance. Then after getting the desired mass with seven variations, the next step is to dissolve the crystals with distilled water with a volume of 100 ml distilled water and stirred using a magnetic stirrer until the solution became homogeneous. Then the measurement of a sample is ready.

In the impedance measurement, the sample is inserted into the chamber using a syringe or syringe so that no air bubble used is 100 μA which is set in the V to I converter. Measurements were done on each solution sample with seven different variations of concentration with three repetitions. After finishing the first solution then it continued on the next solution in the same way.

The measurement results from the research on the Analysis of the Effect of Electrolyte Solution Concentration on the Properties of Solution Impedance with the Gold 4 Electrode Impedance Measurement System with the application of electrochemical impedance spectroscopic models in the form of voltage in sinusoidal waveforms. The wave value taken as data is half of the value of the *peak-to-peak* voltage measured in picoscope, which is with the following equation:

$$V = \frac{Vpp}{2} \tag{1}$$

The measured impedance value of the sample is in the acquisition circuit system data obtained from the equation

$$Z = \frac{V}{I} \tag{2}$$

III. Results and Discussion

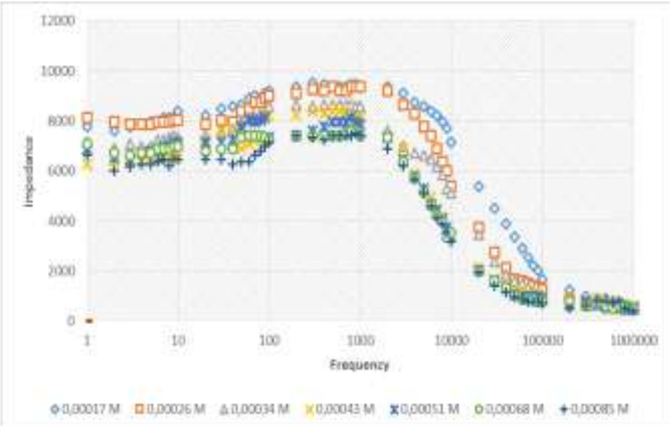

Fig. 2. Graph of Electrical Impedance to Frequency at seven Variations in NaCl Solution Concentration.

From previous research shows that in the low-frequency range from 1 Hz to 50 Hz, the electric impedance value decreased with increasing frequency. 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. 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). 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

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resistive nature of the NaCl solution is dominant at high frequencies, whereas its capacitive properties appear only at low frequencies. [4].

From the graph of the electrolyte solution above we can see the effect of concentration on changes in the value of the electrical impedance in the solution. The solution shows that the highest electrical impedance value is at the lowest solution concentration, which is at the concentration of 0.00017 M, while the lowest impedance value is at the highest solution concentration, which is at 0.00085 M.

In metal bonds, there are free valence electrons. The free valence electron movement is determining the heat alkali conductive and electricity. The easier the electron valence moves, the greater the electrical conductivity and heat. Conversely, the harder the electrons move, the smaller the conductivity of electricity and heat.

The maximum impedance value is in the frequency range of 100 Hz-1000 Hz. Resistive and capacitive properties of the material affect the impedance value at a frequency of 1 Hz - 100 Hz. However, in figure 2 the more visible value is the resistive nature of the material. The resistive value does not depend on frequency; we can see that the impedance value is not constant. Besides, the effect of the double layer also results in the inhibition of ion migration in the solution and its electrodes, so that the current flowing is very small which results in a large impedance value. In the frequency range of 100 Hz - 1 kHz it tends to be constant even if there is not a drastic decrease or increases this is because in the frequency range the effect of capacitance on the circuit is very small so that the measured impedance value is more due to the effect of solution resistance. At a frequency of 1 kHz - 100 kHz there is a significant decrease in impedance value because at that frequency the solution is capacitive with a large capacitive resistance value. That is why the electric current that flows very little causes the impedance value to be even greater. The influenced of Capacitive reactance is frequency, the higher the frequency, the smaller the impedance. In the frequency range above 100 kHz the effect of frequency on the impedance value that is difficult to distinguish; this is because the tool is increasingly insensitive to changes in frequency.

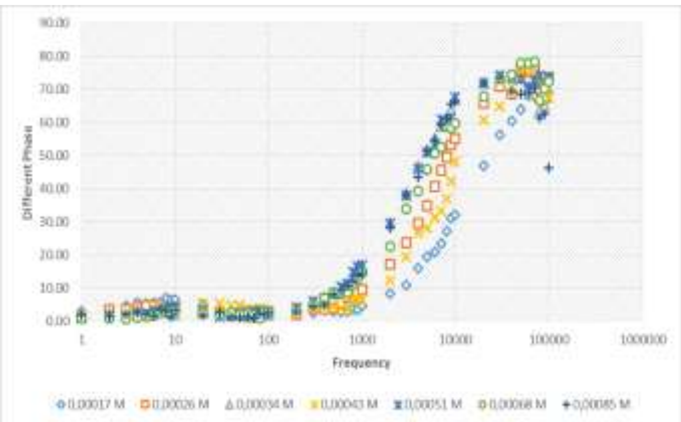

Fig. 3. Differential Phase Graphs to Frequency at seven Variations in NaCl Solution Concentration.

The resistance value shows the real part, while the reactance value (inductive and capacitive) shows the imaginary part. At a frequency of 1 Hz-1 kHz, the measured phase difference values tend to be stable. Because the frequency is only affected by the resistivity of the material. At frequencies above 1 kHz, different phase values increase with increasing frequency. This is due to the double layer effect between the material and the electrode surface where reduction and oxidation reactions occur. So that the capacitance value appears in the circuit.

IV. Conclusion

The amount of the solution concentration influenced the electrical impedance value of the solution in the six tested solutions. The greater the concentration of the solution, the smaller the impedance, the smaller the concentration of the solution, the greater the impedance. The type of electrolyte solution from each material affects the value of the electrical impedance in the solution.

Besides the measurement of the impedance value in the range of 1 Hz - 1 kHz it is difficult to distinguish the effect of the frequency on the measured impedance value of the solution. This is due to the influence of the polarization of the electrodes. Generally, the frequency range of 1 kHz - 100 kHz is the effect of frequency on solution impedance values whereas it can be distinguished well. That is, the lower the frequency, the greater the impedance value, on the contrary, the higher the frequency, the smaller the electrical impedance value of the solution.

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