VOL. 10, NO. 21, NOVEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

THE EFFECT OF A CIRCULAR NICKEL WIRE AS ELECTRODES OF A PH-SENSOR FOR ACIDITY MEASUREMENT

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ABSTRACT

The aim of this research is to measure acidity using circular nickel wire as electrodes of a pH-sensor. Nickel has been chosen as material due to its benefit of being easy to find in the market with relatively cheap price. The variations of nickel wire diameter used during the measurement were 0.8 mm, 0.9 mm, 1.0 mm, 1.2 mm and 1.4 mm, whereas the variations of distance between electrodes were 0.50 cm, 1.00 cm and 1.50 cm. To ensure the distance, resin has been used to fix the bond between electrodes. A liquid pH-buffer has been used during the acidity measurement. The electrodes of the pH-sensor have been immersed during one minute in the liquid buffer. The results show that the best sensitivity has been obtained for acidity measurement along the pH-range of 1-7 using the combination of 1.0 cm of distance between electrodes and -1.1 volt corresponding with pH-level increment of 1.

Keywords: pH sensor, nickel, wire.

INTRODUCTION

Sensor is a type of transducer which is used to change the quantities of mechanical, magnetic, heat, light, and chemical characteristics into voltage and current quantities. Sensors are often used for detection in instrumentation, measurement or control systems. Some examples among various available types of sensor include heat sensor, sound sensor, gas sensor, light sensor, pH sensor and motion sensor.

A pH-sensor is a device to measure the pH level in a liquid. The electrodes of the pH-sensor are immersed into the liquid to indicate the voltage value corresponding to the pH level values [1], [2]. Recently, the need for a pH measurement tool to determine the degree of acidity or alkalinity of a solution has increased significantly. It is used in various sectors, including industry, food, health and environment. Due to its significant importance, there are still needed continuous researches on pH-sensors with more accurate performance and lower price [3], [4].

The pH-sensor gets the name from its main working principle. The pH means the power of Hydrogen, as the concentration level of hydrogen ion $[H^+]$ is to be known from the pH-scale. It is defined as the negative logarithmic of $[H^+]$ ion concentration in an acid liquid, and varies from 0 till 14. The value of pH=7 indicates the neutral condition, pH<7 acid, whereas pH>7 is alkaline. For example, orange juice and battery are categorized as acid and each has a pH-value between 0 and 7, whereas pure water is neutral or has a pH-value of 7.

$$pH = -\log[H^+] \quad (1)$$

where $[H^+]$ represents the hydrogen ion concentration, in mol/L.

The pH-value represents the level of $[H^+]$ and $[OH^-]$ ions concentration. If $[H^+]$ concentration is more than $[OH^-]$ concentration, then it is called acid, otherwise it is alkaline.

In general, many types of pH-sensor are made of glass which has a relatively large size and resistance (in the order of Mega-ohm), and is easily broken if being dropped or bumped, besides it is of high cost. In this paper, the use of circular nickel wire as electrodes in a pH-sensor is presented. The circular nickel-alloy has been used to measure acidity with good sensitivity and linear characteristic [5], [6], [7].

RESEARCH METHOD

The circular nickel wire has been used as electrodes in the pH-sensor to detect the acidity of liquid. The sequence to undertake during this research on the effect of a circular nickel wire as electrodes of a pH-sensor for acidity measurement is shown in Figure-1, being started from design, construction, implementation and testing including sensitivity measurement, and characteristics analysis before ended by drawing some conclusions.

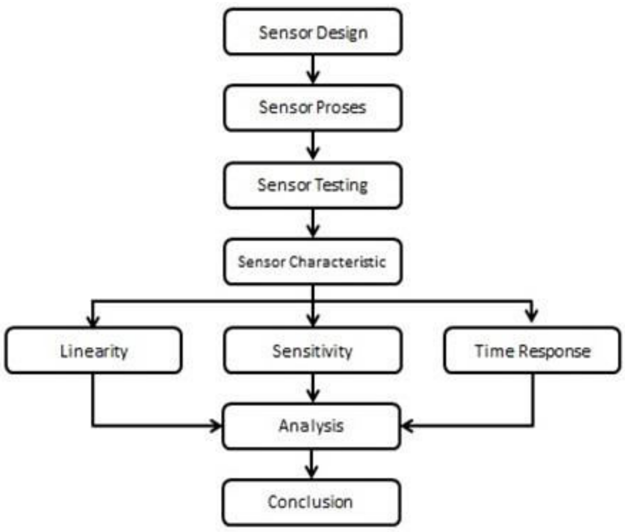

Figure-1. Research method.

Experiments have been performed using three different values of distance between electrodes, i.e. 0.5 cm, 1.0 cm and 1.5 cm. Five variations of wire diameter have been considered, i.e. 0.8 mm, 0.9 mm, 1.0 mm, 1.2 mm, and 1.4 mm [8]. To ensure the distance between the two nickel wires, resin liquid has been used to fix the bond between electrodes, as shown in Figure-2.

Liquid buffer with pH values of 1-14 has been used during the acidity-sensor measurement. The electrodes of pH-sensor are immersed into the buffer liquid during one minute, while at the same time the electrodes outputs are connected to a Wheatstone-bridge (Figure-3) to obtain the output quantity in volts. It is used to amplify the electrodes output before being amplified furthermore using an instrumentation amplifier (Figure-5).

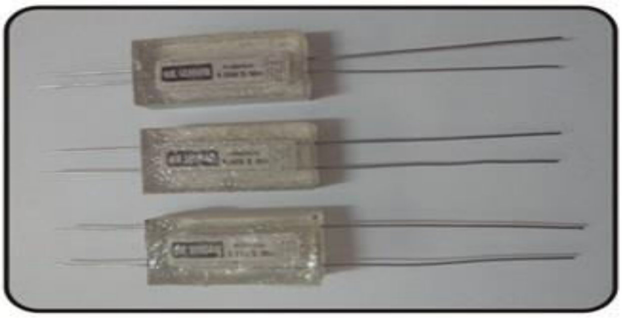

Figure-2. The bond between electrodes.

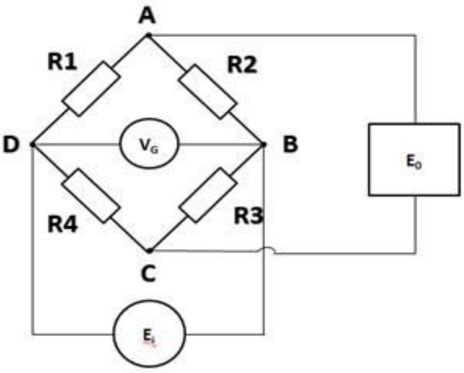

Figure-3. The Wheatstone-bridge circuit used in the experiment.

The bridge has been fed with 10-V power supply and a volt-meter has been used to measure the results [9], [10], [11]. It is used to measure the output of sensor electrodes with better precision [12], [13].

The block diagram of the laboratory experiments done is shown in Figure-4.

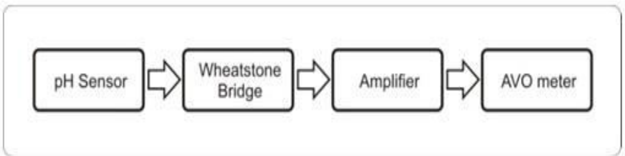

Figure-4. The laboratory experiment block diagram.

The sensor output, E_o, can be obtained using:

$$E_0 = E_{BD} = E_{AD} - E_{DC} \quad (2)$$

$$E_{DC} = \frac{R_4}{R_3 + R_4} E_i \quad (3)$$

$$E_{AD} = \frac{R_1}{R_1 + R_2} E_i \quad (4)$$

$$E_0 = \frac{R_1 R_3 - R_2 R_4}{(R_1 + R_2)(R_3 + R_4)} E_i \quad (5)$$

$$R_1 R_3 = R_2 R_4 \quad (6)$$

$E_o = 0$

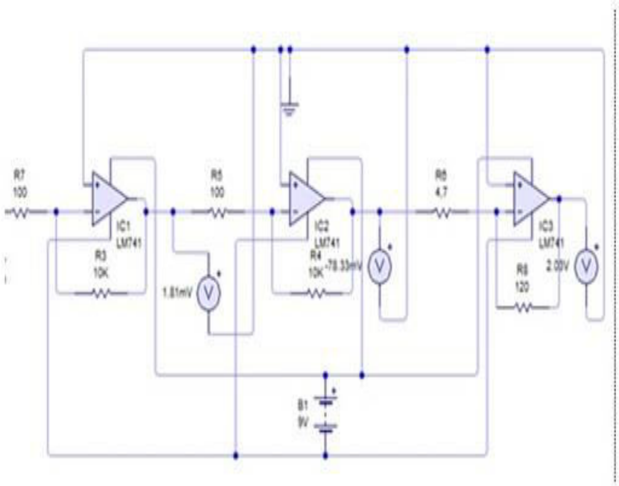

Figure-5. The instrumentation amplifier.

RESULTS AND ANALYSIS

Five variations of wire diameter have been considered: 0.8 mm, 0.9 mm, 1.0 mm, 1.2 mm, and 1.4 mm. For each considered diameter, the experiment has been done using three variations of distance between electrodes, i.e. 0.5 cm, 1.0 cm, and 1.5 cm. Sensor I, II, and III represent the distance of 0.5 cm, 1.0 cm, and 1.5 cm subsequently. Each measurement has been taken by immersing the electrodes into the buffer liquid of pH values 1 to 14 during one or two minutes. Each measurement has been repeated three times, and its average value has been considered [14].

Results of sensor test with 0.8 mm wire diameter

Figure-6 indicates the measurement results of sensor with 0.8 mm wire diameter and three variations of distance between electrodes (0.5 cm, 1.0 cm, and 1.5 cm). For each experiment, the pH-sensor has been tested during 10 seconds.

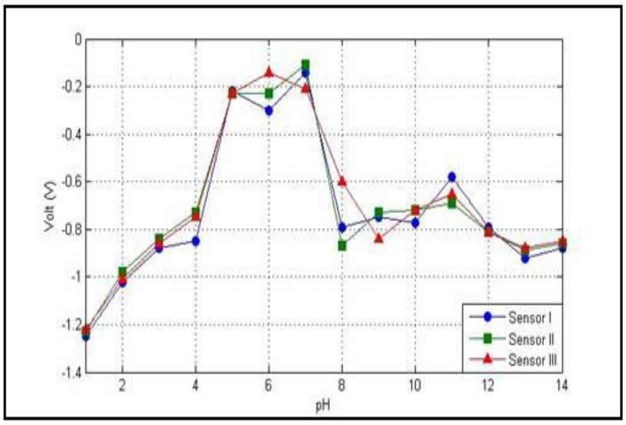

Figure-6. Measurement results of sensor with 0.8 mm wire diameter and three variations of distance between electrodes (0.5 cm, 1.0 cm, and 1.5 cm).

Figure-6 shows that the voltage output changes linearly with the change in pH values from 1 to 7, but it is not the case for the pH values above 7. The quadratic approximation of the relationship between the sensor output voltage and the pH values for sensor with 0.8 mm wire diameter and the distance between electrodes of 0.5 cm is shown in Figure-7.

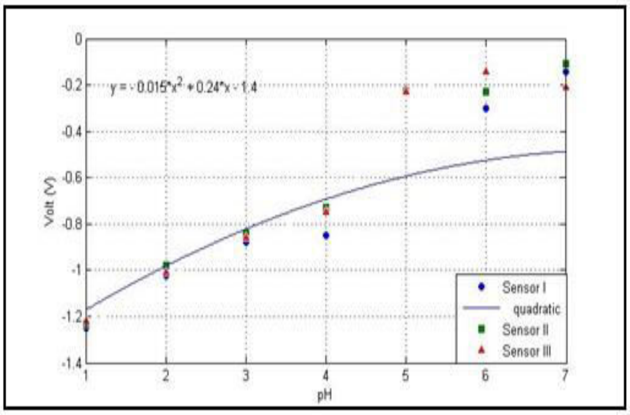

Figure-7. Quadratic approximation of the relationship between the sensor output voltage and the pH values for sensor with 0.8 mm wire diameter and the distance between electrodes of 0.5 cm.

The resulted quadratic equations for the all three distance variations are as follows:

Sensor I: $y = -0.015x^2 + 0.24x - 1.4$
Sensor II: $y = -0.015x^2 + 0.22x - 1.3$
Sensor III: $y = -0.016x^2 + 0.24x - 1.4$

Results of sensor test with 0.9 mm wire diameter

Figure-8 indicates the measurement results of sensor with 0.9 mm wire diameter and three variations of distance between electrodes (0.5 cm, 1.0 cm, and 1.5 cm).

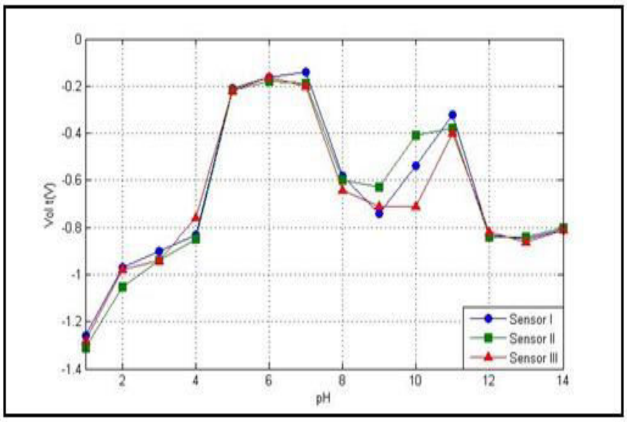

Figure-8. Measurement results of sensor with 0.9 mm wire diameter and three variations of distance between electrodes (0.5 cm, 1.0 cm, and 1.5 cm).

Figure-8 shows that the voltage output changes linearly with the change in pH values from 1 to 7, but it is not the case for the pH values above 7. The quadratic approximation of the relationship between the sensor output voltage and the pH values for sensor with 0.9 mm wire diameter and the distance between electrodes of 0.5 cm is shown in Figure-9.

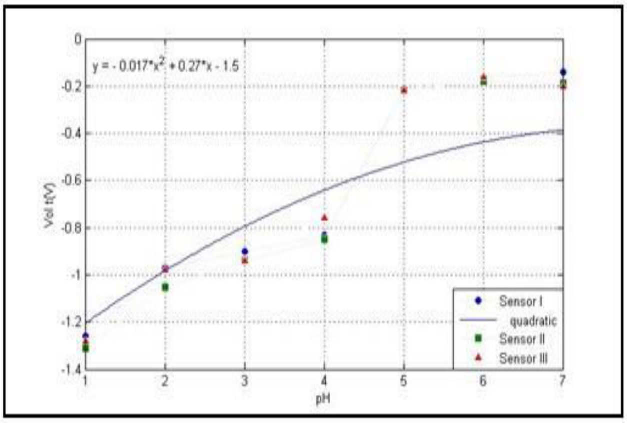

Figure-9. Quadratic approximation of the relationship between the sensor output voltage and the pH values for sensor with 0.9 mm wire diameter and the distance between electrodes of 0.5 cm.

The resulted quadratic equations for the all three distance variations are as follows:

Sensor I: $y = -0.017x^2 + 0.27x - 1.5$
Sensor II: $y = -0.018x^2 + 0.3x - 1.6$
Sensor III: $y = -0.016x^2 + 0.26x - 1.4$

Results of sensor test with 1.1 mm wire diameter

Figure-10 indicates the measurement results of sensor with 1.1 mm wire diameter and three variations of distance between electrodes (0.5 cm, 1.0 cm, and 1.5 cm). It shows that the voltage output changes linearly with the change in pH values from 1 to 7, but it is not the case for

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the pH values above 7. The quadratic approximation of the relationship between the sensor output voltage and the pH values for sensor with 1.1 mm wire diameter and the distance between electrodes of 0.5 cm is shown in Figure-11.

The resulted quadratic equations for the three distance variations are as follows:

Sensor I: $y = -0.017x^2 + 0.29x - 1.5$
Sensor II: $y = -0.016x^2 + 0.28x - 1.5$
Sensor III: $y = -0.019x^2 + 0.32x - 1.6$

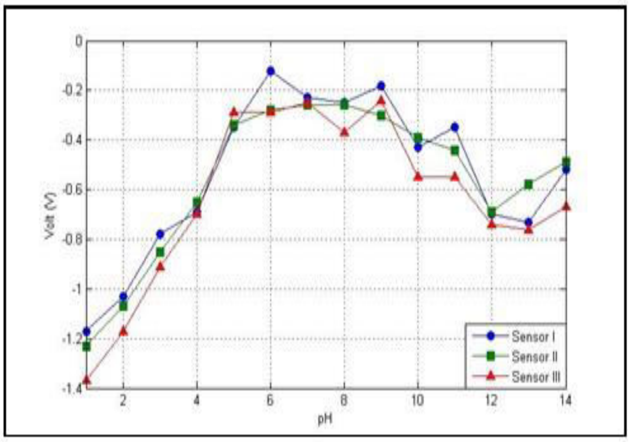

Figure-10. Measurement results of sensor with 1. 1 mm wire diameter and three variations of distance between electrodes (0.5 cm, 1.0 cm, and 1.5 cm).

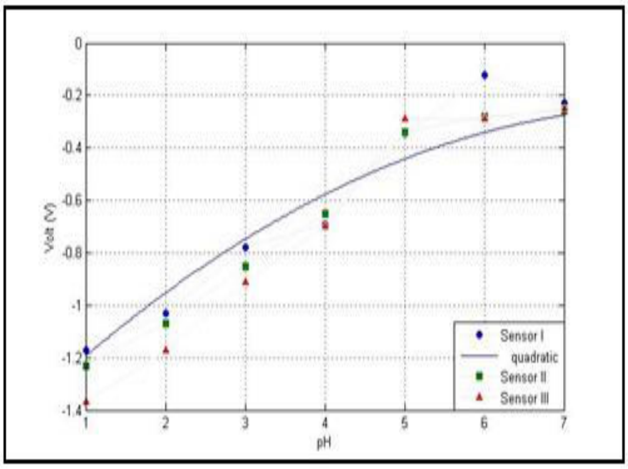

Figure-11. Quadratic approximation of the relationship between the sensor output voltage and the pH values for sensor with 1.1 mm wire diameter and the distance between electrodes of 0.5 cm.

Results of sensor test with 1.2 mm wire diameter

Figure-12 indicates the measurement results of sensor with 1.2 mm wire diameter and three variations of distance between electrodes (0.5 cm, 1.0 cm, and 1.5 cm).

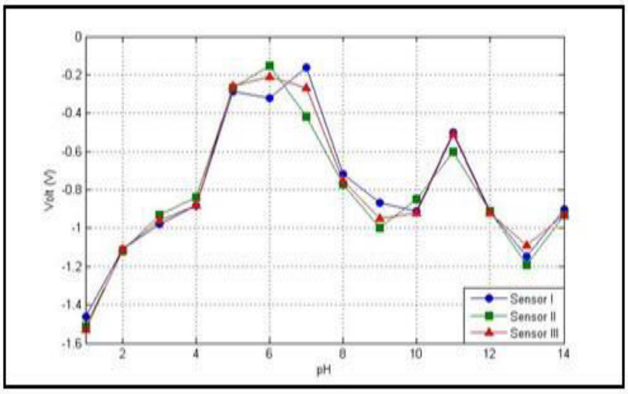

Figure-12. Measurement results of sensor with 1.2 mm wire diameter and three variations of distance between electrodes (0.5 cm, 1.0 cm, and 1.5 cm).

Figure-12 shows that the voltage output changes linearly with the change in pH values from 1 to 7, but it is not the case for the pH values above 7. The quadratic approximation of the relationship between the sensor output voltage and the pH values for sensor with 1.2 mm wire diameter and the distance between electrodes of 0.5 cm is shown in Figure-13.

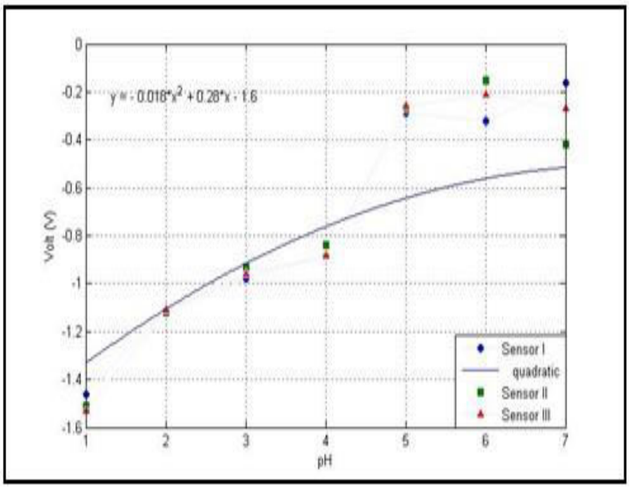

Figure-13. Quadratic approximation of the relationship between the sensor output voltage and the pH values for sensor with 1.2 mm wire diameter and the distance between electrodes of 0.5 cm.

The resulted quadratic equations for the three distance variations are as follows:

Sensor I: $y = -0.018x^2 + 0.28x - 1.6$
Sensor II: $y = -0.018x^2 + 0.27x - 1.6$
Sensor III: $y = -0.018x^2 + 0.28x - 1$

Results of sensor test with 1.4 mm wire diameter

Figure-14 indicates the measurement results of sensor with 1.4 mm wire diameter and three variations of distance between electrodes (0.5 cm, 1.0 cm, and 1.5 cm).

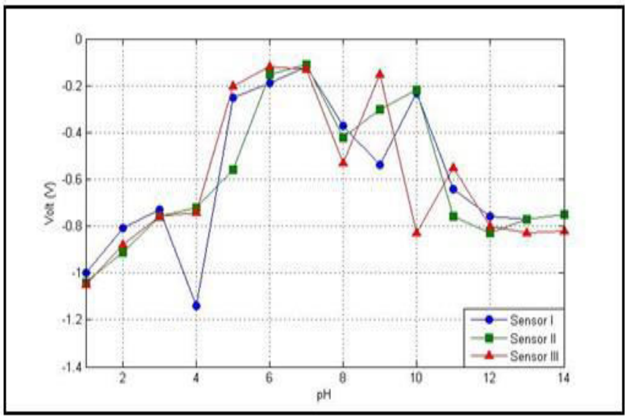

Figure-14. Measurement results of sensor with 1.4 mm wire diameter and three variations of distance between electrodes (0.5 cm, 1.0 cm, and 1.5 cm).

Figure-14 shows that the voltage output changes linearly with the change in pH values from 1 to 7, but it is not the case for the pH values above 7. The quadratic approximation of the relationship between the sensor output voltage and the pH values for sensor with 1.4 mm wire diameter and the distance between electrodes of 0.5 cm is shown in Figure-15.

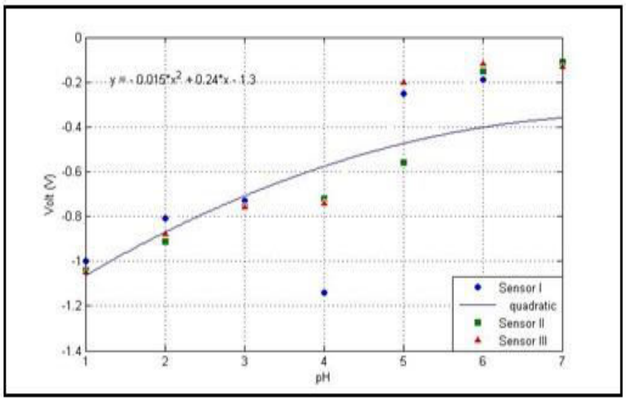

Figure-15. Quadratic approximation of the relationship between the sensor output voltage and the pH values for sensor with 1.41 mm wire diameter and the distance between electrodes of 0.5 cm.

The resulted quadratic equations for the three distance variations are as follows:

Sensor I: $y = -0.015x^2 + 0.24x - 1.3$
Sensor II: $y = -0.017x^2 + 0.28x - 1.6$
Sensor III: $y = -0.018x^2 + 0.30x - 1.5$.

Sensitivity measurements

The sensitivity values during each measurement are as follows:

For sensor with wire diameter of 0.8 mm, the sensitivity values for each case of distance between electrodes of 0.5 cm, 1.0 cm, and 1.5 cm, subsequently are:

$S = -0.137\ ^{V}/_{pH}$; $S = -0.125\ ^{V}/_{pH}$; and $S = -0.150\ ^{V}/_{pH}$.

For sensor with wire diameter of 0.9 mm, the sensitivity values for each case of distance between electrodes of 0.5 cm, 1.0 cm, and 1.5 cm, subsequently are:

$S = -0.170\ ^{V}/_{pH}$; $S = -0.185\ ^{V}/_{pH}$; and $S = -0.160\ ^{V}/_{pH}$.

For sensor with wire diameter of 0.9 mm, the sensitivity values for each case of distance between electrodes of 0.5 cm, 1.0 cm, and 1.5 cm, subsequently are:

$S = -0.185\ ^{V}/_{pH}$; $S = -0.170\ ^{V}/_{pH}$; and $S = -0.195\ ^{V}/_{pH}$.

For sensor with wire diameter of 1.1 mm, the sensitivity values for each case of distance between electrodes of 0.5 cm, 1.0 cm, and 1.5 cm, subsequently are:

$S = -0.162\ ^{V}/_{pH}$; $S = -0.162\ ^{V}/_{pH}$; $S = -0.162\ ^{V}/_{pH}$.

For sensor with wire diameter of 1.2 mm, the sensitivity values for each case of distance between electrodes

$S = -0.150\ ^{V}/_{pH}$; $S = -0.155\ ^{V}/_{pH}$; $S = -0.160\ ^{V}/_{pH}$.

For sensor with wire diameter of 1.41 mm, the sensitivity values for each case of distance between electrodes of 0.5 cm, 1.0 cm, and 1.5 cm, subsequently are:

CONCLUSIONS AND PERSPECTIVES

From the measurement results and analyses, some conclusions to be drawn are as follows.

1) Sensor with circular wire diameter could operate well to measure liquid acidity in the pH-range of 1-7, being indicated with its linear proportionality between the voltage output and the pH values of the liquid.
2) The best measurement sensitivity of $S = -0.125\ ^{V}/_{pH}$ has been obtained using the distance between electrodes of 1 cm and with the proportionality relationship given by the quadratic equation $y = -0.015x^2 + 0.22x - 1.3$.

It is suggested that the use of instrumentation based on microprocessor should be considered in the future research to obtain real time measurement.

ACKNOWLEDGEMENTS

The authors would like to thanks Mr. A. Zainuri, Mr. Rangga, and Mr. Eka Maulana, for their invaluable contribution to the accomplishment of this research.

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