Application of plastic optical fiber material as pH measurement sensor using loop configuration

A Arifin*, Hardianti, M Yunus and S Dewang

Physics Department, FMIPA, University of Hasanuddin, Makassar, 90245 Indonesia

*arifinpide@gmail.com

Abstract. Plastic optical fiber testing as a sensor can be applied in pH measurement using loop configuration. It was made of a plastic optical fiber material with two types of peel, namely with cladding and without cladding. Sensor testing was done by dipping the sensor into buffer solutions with varying pH values. The light intensity from the LED will experience power losses due to the effect of adding the solution refractive index around the sensor, so the phototransistor will receive smaller the light intensity. Changes of light intensity in the optical fiber causes the output voltage read on the microcontroller and the computer decreases. The best measurement was obtained at sensor type of without cladding 4 loops with sensitivity 0.035 V/pH and resolution 0.029 pH.

1. Introduction
The acidity or base level of a solution is expressed with pH. The pH value shows the relative concentration of hydrogen ions in a solution. The pH scale consists of 0 to 14, with a normal pH is 7. Acidic solution indicated when the pH value is less than 7, while base solution indicated when the pH value is more than 7 [1]. Measurement of pH is one of the most important procedures in biochemistry. Almost all biological processes depend on pH, if there is a small change in pH value, it can cause metabolic complications. For example in the medical field it is necessary to measure the pH of the patient's blood. This is to determine the pH value of blood that is still within the normal range of 7.3 to 7.5 [2]. In addition, pH measurements are also needed in the fields of chemical, pharmaceutical, food and beverage industries.

Science and technology development in the instrumentation field allows the measurement of pH by using a optical fiber as sensor. It is waveguide that transmits light [3]. Optical fiber generally consist of glass optical fiber (GOF) made from silica materials and plastic optical fiber (POF) made from polymeric materials [4]. POF has a flexible nature so it is widely applied as a sensor system for measuring pressure, strain, vibration, solution concentration, and measurement of the pH solution [5].

Research on pH sensors by using optical fiber has been done by several researchers including regarding pH sensors by using Tipped Fiber Bragg Grating (TFBG) coated with multilayer film as a sensing layer with a pH range that can be measured between 4.66 to 6.02 [6]. Then pH measurement based on Thin-Core Fiber Capital Interferometer (TCFMI) optical fiber with coating layer uses Sodium Alginate (SA) and Polythelyenimine (PEI) with a pH range that can be measured from 2 to 11 with a sensitivity of 1.51 nm/pH [7]. In addition, the utilization of POF as a pH sensor uses a gel
solvent sensing matrix layer. Its characteristics have a measurable pH range of 5 to 8 with a sensitivity of 0.5 a.u/pH [8].

In previous studies, it was still using a complicated sensor system, namely optical fiber coated with sol gel as sensing elements and having a small measurement range [8]. In this study, pH sensor will be made using POF with cladding and without cladding types. They use loop configurations are expected to increase the sensor characteristics, namely the range of power loss, sensitivity and resolution will get better. Optical fiber sensor for pH measurement have advantages such as low cost, easy fabrication, wide measurement range, high sensitivity, easy to operate, as well as it able connected to the computer and microcontroller.

2. Method
Design and manufacture of pH sensor based on POF uses a voltage source from the power supply and a light source an IF-E91A type infrared LED with 950 nm wavelength. An IF-D92 type phototransistor are receiver output light from POF which is connected with differential amplifier, Arduino Uno microcontroller and computer. The POF used was made from multimode type polymethyl metacrylate (PMMA) with a core diameter of 980 μm and a cladding diameter of 1 mm. PMMA has a numerical aperture 0.5, while core and cladding in PMMA have refractive indexes are \( n_{\text{core}} = 1.492 \) and \( n_{\text{cladding}} = 1.402 \). Sensors are made using by loop configuration with variable number of 1, 2, 3, and 4 loops. The pH test solution uses buffers solution with range of pH values from 1 to 11. The scheme of pH sensor is shown as in Figure 1.

![Figure 1. The scheme of pH sensor based on POF.](image)

Sensor of pH sensor based on POF has a working principle that the light from LED propagates along POF sensor. When the sensor is dipped in a pH buffer solution, the POF will experience power loss due to changes in the medium refractive index by changes in pH around the POF sensor. Phototransistor will receive the smaller light intensity, so it causes the output voltage decreases. Electrical signal in the form of voltage from the phototransistor will be enlarged by the differential amplifier. Furthermore, the analog signal produced by the differential amplifier will be converted into a digital signal by the microcontroller and the output voltage result will be displayed on the computer.

3. Result and Discussion
In this study, pH sensor based on POF by using loop configurations with two types of sensors, namely sensor type of with cladding and sensor type of without cladding. Sensor testing uses variations of variable number consists of 1, 2, 3, and 4 loops with constant loop diameter of 2 cm. The length of the POF used is 40 cm and the length of POF peel is 30 cm respectively for both of types of sensors. The test results of pH sensor based on POF by using loop configuration for the sensor type of with cladding shown in the following Figure 2.
Figure 2. Graph of output voltage changes to the pH value for the type of with cladding sensor.

Based on Figure 2 is show about level of pH values increasing cause output voltage decrease. The values of output voltage will be smaller if pH values will be greater. The result of pH sensor test using by loop configuration for the sensor type of without cladding shown in the Figure 3.

Figure 3. Graph of output voltage changes to the pH value for the type of without cladding sensor.

The response result in Figure 3 is a changes output voltage of pH sensor based on POF by loop configuration for the type without cladding sensor. It shows that pH solution values inversely proportional to the output voltage. If the pH solution values increase, it causes a decrease values of output voltage of sensor.

The results of measurement are used determine sensor characteristics. Characteristic values of pH sensor based on POF include determining the value of the output voltage range, sensitivity, and resolution. The difference value between the maximum output voltage toward the minimum output voltage, namely range \((\Delta V)\). Sensitivity level of quantity sensor measured, namely sensitivity \((S)\). While, the smallest value of a quantity measured, namely resolution \((R)\). They are calculated by using the equations (1), (2), and (3) below \([5, 9, 10]\):

\[
\Delta V = V_{\text{max}} - V_{\text{min}}
\]

\[
S = \frac{V_{\text{max}} - V_{\text{min}}}{pH_{\text{max}} - pH_{\text{min}}}
\]

\[
R = \frac{V_{\text{max}} - V_{\text{min}}}{pH_{\text{max}} - pH_{\text{min}}}
\]
The pH sensor based on POF is very well used in measuring pH values with high sensitivity. [7, 8]. Another suitability of the research is the higher of refractive index of the solution measured using a POF sensor causes the sensor output power decreases [11]. Measurement of the pH value based on POF as sensor is suitable for use with the advantages such as have a simple measurement process and high sensitivity.

4. Conclusion
Design and manufacture of pH sensor based on POF has been done by using loop configurations in sensor type of with cladding and sensor type of without cladding sensor for number of loop variations. The more number of loops and the greater refractive index value of pH solution cause output voltage decrease and the power losses increase. The best characteristics of pH sensor are obtained at the type of without cladding sensor 4 loops with sensitivity value 0.035 V/pH and resolution value 0.029 pH. The pH sensor based on POF is very well used in measuring pH values because it has a wide measurement range of 1 to 11 with high sensitivity.

Acknowledgements
This research was supported by “PDUPT-UNHAS 2018” Contract No. 1634/UN-4.21/PL.00.00/2018.

References
[1] Mohan C 2006 Calbiochem Buffers (California: Sandiego-EMD)
[2] Voet D, Voet J G and Pratt W C 2008 Fundamental of Biochemistry Third Edition (United Kingdom: Chichester)
[3] Senior J M dan Jamro M Y 2009 Optical Fiber Communication Principles and Practice Third edition (England: Pearson Prentice Hall)
[4] Mitschke F 2009 Fiber Optic, Physic and Technology (Germany: Springer)
[5] Yunus M and Arifin A 2018 Design of Oil Viscosity Sensor Based on Plastic Optical Fiber Journal of Physics: Conference Series 979 1-9

\[ R = \frac{N}{S} \quad (3) \]

Where, \( V_{\text{max}} \) is the maximum output voltage and \( V_{\text{min}} \) is the minimum output voltage. The pH\(_{\text{max}}\) as maximum pH value and pH\(_{\text{min}}\) as the minimum pH value. While, value of 0.001 V is smallest scale value of microcontroller as N. The characteristics of pH sensor based on POF by using loop configurations shown in the Table 1.

Table 1. Characteristics of pH sensor based on POF.

| Characteristics of Sensor | With Cladding | Without Cladding |
|---------------------------|---------------|------------------|
|                           | 1 Loop        | 2 Loop           | 3 Loop | 4 Loop | 1 Loop | 2 Loop | 3 Loop | 4 Loop |
| Range (V)                 | 0.094         | 0.116            | 0.126  | 0.152  | 0.125  | 0.157  | 0.220  | 0.346  |
| Sensitivity (V/pH)        | 0.009         | 0.012            | 0.013  | 0.015  | 0.012  | 0.016  | 0.022  | 0.035  |
| Resolution (pH)           | 0.107         | 0.086            | 0.080  | 0.066  | 0.080  | 0.064  | 0.045  | 0.029  |
[6] Shao L Y, Yin M J, Tam H Y and Albert J 2013 Fiber Optic pH Sensor with Self-Assembled Polymer Multilayer Nanocoatings Sensors 13 1425-1434
[7] Gu B, Yin M, Zhang A P, Qian J and He S 2012 Biocompatible Fiber Optic pH Sensor Based on Modal interferometer Self Assembled with Sodium Alginate/Polythelimine Coating IEEE Sensors Journal 5 1-6
[8] Rovati L, Fabbri P, Ferrari L and Pilati F 2012 Plastic Optical Fiber pH Sensor Using a Sol-Gel Sensing Matrix Fiber Optic Sensor 416-438
[9] Arifin A, Yusran, Miftahuddin, Abdullah B, Tahir D 2017 Comparison of Sensitivity and Resolution Load Sensor at Various Configuration Polymer Optical Fiber The 6th International Conference on Theoretical and Applied Physics (The 6th ICTAP) 1801 1-6
[10] Arifin A, Hatta A M, Sekartedjo, Muntini M S, Rubianto A 2015 Long-Range Displacement Sensor Based on SMS Fiber Structure and OTDR Photonic Sensors 5 166-171
[11] Arifin A, Irwan I, Abdullah B, Tahir D 2012 Design of Sensor Water Turbidity Based on Polymer Optical Fiber IEEE 146-149