Evanescent fiber optic sensors using single mode fiber optics to measure acidity

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Abstract. This research aims to develop fiber optic sensors that can be used to measure acid rain levels. This fiber optic sensor uses the evanescent wave type method. SFP (Small Form-factor Pluggable) Transceiver with a wavelength of 1310nm is used as a fiber optic transmitter and receiver, while the Optical Power Meter (OPM) is used as a validator to test the developed sensor capability. The measurement results indicate the presence of loses successfully detected by OPM and SFP Transceiver. It appears that the maximum value of pH level has been successfully detected with a range of values of 8.72 dBm to 9.75 dBm and 8.7 dBm to 9.74 dBm respectively using SFP Transceiver and OPM. Good results during the validation process show that the fiber optic sensor has successfully worked with a strong correlation of 0.78 to monitor acid rain levels.

1. Introduction
Clean water is the most important requirement for human activities. Quantitative lack of clean water is PH measurement is very important in the medical world, industry, and research. PH measurement, i.e., the measurement of hydrogen ions in a solution. Low pH solutions are called "acid" solutions, while high pH solutions are called "alkaline" solutions [1]. The base scale extends from 0 (strong acid) to 14 (strong base) where 7 is the middle value representing pure water. In its development, a fiber optic can be utilized and functioned as a pH sensor. Sensors that work based on fiber optic have the advantage of sensors that work based on electricity. The sensor will be formed as needed to be able to detect pH values. Some of them are high accuracy, not affected by electric and magnetic fields, do not cause sparks, and send information very quickly [2-6].

In a previous study conducted by Mulyanti et al, the manufacture of fiber optic sensors used diode lasers as a source of light [7]. In that study, aiming to get the value of the light absorption of ammonia solution using fiber optic sensors. Another study was also carried out by Qomaria to detect the pH value using single mode fiber optic sensors. However, this study did not test the validity of using data from a tool that already have a standard, so that the study cannot be declared invalid. Additionally, Mulyanti et al have succeeded in designing micro-ring resonator to monitor ammonia substances in acid rain [8,9]. Here, the micro-ring resonator is a dielectric ring sensor with the smallest refractive index is based on...
optical principles developed to measure the chemical reaction of the electrochemical materials [10,11]. However, the cost of the development of micro-ring resonator it is very expensive if made to simply measure the pH level [7]. Manivanan et al conducted a study to detect ammonia using fiber optic with a single-walled carbon nanotubes (SWCNT) coating. This study successfully detected ammonia well below 50 ppm [12]. Renganathan in his research succeeded in making a fiber optic sensor that can detect ammonia gas [13]. Mishra et.al succeeded in making fiber optic sensors to detect ammonia gas in 1-10ppm concentrations [14-16].

This research aims to make fiber optic sensors that can detect pH levels. In this paper designed an instrument that can measure the level of pH solution within a particular range of values using fiber optic. Limitation of problems in this paper only in the scope of the discussion on the detector pH solution using fiber optic coating with the resin. Resin is used to bind the H and OH. The sample solution is tested using a solution with a pH of 4, 7, and 12. This prototype using SFP (Small Form-factor Pluggable) Transceiver for transmitter and receiver of light source. While fiber optic used for pH sensor is a single mode fiber optic type FD-620-10. The output of this research is a voltage value out of a voltmeter. The results of the voltmeter will be compared with the results of using the Optical Power Meter measurements to validate the measurements made with the prototype made.

2. Method

2.1. Fiber optic sensor

All chemicals were used as received without further purification. In the design of fiber optic-based pH, sensor systems are carried out in stages to facilitate the analysis of the system. The procedure works include manufacturing variations solution pH solution with various concentrations, the manufacture of fiber optic sensors, the fabrication of power supply circuit, the circuit limiter, LED driver circuit, and circuit testing. Before carrying out the design and realization of the equipment, it is necessary to determine the specifications of the equipment to be made. Equipment specifications that will be planned include the SFP Transceiver as transmitter and receiver the light, and the fiber optic cladding peel is used hydrogen fluoride (HF) as a coating. The output of this pH sensor is a voltage value on the comparison voltmeter with the reference pH solution through 10 repeat measurements.

This pH sensor is designed using a single mode plastic fiber optic cable type. Fiber optics have different values of refraction of light between fiber optics in a straight and curved position [7]. Therefore, the sensor was designed with two different designs, namely the distal probe type and the evanescent wave type (see Figure 1).

![Figure 1](image_url)

**Figure 1.** The typical FOCS design (a) Distal type probe and (b) Evanescent wave type.

As shown in Figure 1, remote probes and fast wave types reduce different designs. The difference between the distal type of probe (Figure 1a) and evanescent wave type (Figure 1b) in the layer type indicator (sectional area). But in the present study used evanescent wave type because this type is easier to transmit light with a wider cross-section of the sensor [15]. In the process of making these sensors, we use single mode fiber optic 10cm and uses 40% hydrogen fluoride (HF) for 30 minutes (the etching rate of 1.52 μm / min). For 30 minutes the etching process temperature, pressure, and RF power reach
400°C, 60 mTorr, and 300 Watts. After that, the sensor is ready for use to be combined into a fiber optic chemical sensor system.

2.2. Electrical sensor system

After the sensor is ready for use, it is necessary to design an electrical detector for the optical signal system so that changes in the value of the voltage coming out of the sensor can be read. This system consists of a sinusoidal pulse generator, initial amplifier, led driver, on the transmitter and photodiode driver, power amplifier, and buffer on the receiver (See figure 2).

![Figure 2](image)

**Figure 2.** Block diagram of the detector electrical system (a) Transmitter (b) Receiver.

As seen from the Figure 2a, the instrumentation system starting from a sinusoidal signal generator, then the signal is forwarded to a preamplifier for strengthened first, the signal is transmitted to the LED driver to convert sinusoidal signals into light signals that are transmitted through fiber optic. As seen from the figure 2.b, photodiode driver will convert the light signals received by a photodiode into an electrical signal sinusoidal. Then, this signal will be amplified in the power amplifier. The buffer circuit is used so that the signal can be read by a voltmeter.

The test solution used consisted of 6 solutions. Three solutions with different pH solutions with different concentrations. The pH test solution varies from pH 4, 7, and 12. This test solution will be dropped on the sensor surface.

Fiber Optic Sensor is integrated with the Sensor Electrical System. After being integrated, a sensor test is carried out by dripping the test solution on the sensor surface. The experiment was carried out several times. After that, the output voltage analysis is performed to determine the effect of the pH level on the output voltage value.

After testing, it uses fiber optic sensors that have been made. Tests are also carried out using Optical Power Meters (OPM) to compare the results with testing using tools that have been made. OPM is also used to validate the capabilities of the fiber optic sensor during the testing process. Comparison of results between OPM and fiber optic sensors were analyzed using Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Percent True (PT) [7].

3. Results and discussion

This experiment was carried out ten times to get more accurate results. This experiment was carried out with a prototype that had been made and also using OPM.
Table 1. PH measurements using OPM.

| pH | I (dBm) | II (dBm) | III (dBm) | IV (dBm) | V (dBm) | VI (dBm) | VII (dBm) | VIII (dBm) | IX (dBm) | X (dBm) |
|----|---------|----------|-----------|----------|---------|----------|-----------|------------|----------|--------|
| 4  | 8.56    | 8.72     | 8.73      | 8.74     | 8.72    | 8.73     | 8.72      | 8.72       | 8.74     | 8.73   |
| 7  | 9.27    | 9.30     | 9.24      | 9.33     | 9.32    | 9.35     | 9.27      | 9.31       | 9.30     | 9.27   |
| 12 | 9.96    | 9.86     | 9.83      | 9.65     | 9.68    | 9.75     | 9.85      | 9.64       | 9.75     | 9.73   |

As seen in Table 1, measuring pH using different values can be done well. Here, we get the minimum and maximum values of 10 experiments in each solution, which is for measuring using OPM in the range 8.56 to 9.96 dBm. In a previous study conducted by Mulyanti et al using single mode fiber optic, the minimum value is 7.510 dBm and the maximum value is 8 dBm [7].

Table 2. PH Measurement using prototype pH detector.

| pH | I (dBm) | II (dBm) | III (dBm) | IV (dBm) | V (dBm) | VI (dBm) | VII (dBm) | VIII (dBm) | IX (dBm) | X (dBm) |
|----|---------|----------|-----------|----------|---------|----------|-----------|------------|----------|--------|
| 4  | 8.52    | 8.70     | 8.70      | 8.79     | 8.97    | 9.06     | 9.16      | 8.88       | 8.70     | 8.97   |
| 7  | 9.16    | 9.25     | 9.25      | 9.16     | 9.25    | 9.35     | 9.25      | 9.35       | 9.25     | 9.16   |
| 12 | 9.64    | 9.54     | 9.44      | 9.74     | 9.84    | 9.95     | 9.74      | 9.64       | 9.54     | 9.74   |

As seen in Table 2, measuring pH using different values can be done well. Here, we get the minimum and maximum values of 10 experiments in each solution, which is for measuring using OPM in the range 8.52 to 9.74 dBm.

Table 3. The modus method to see variation pH and voltage value between OPM and prototype pH detector.

| pH | OPM mode (dBm) | Prototype mode (dBm) |
|----|----------------|----------------------|
| 4  | 8.72           | 8.70                 |
| 7  | 9.27           | 9.25                 |
| 12 | 9.75           | 9.74                 |

From the data obtained from table 4, the statistical method (mode) was conducted in this study to see the correlation of measurements using the two instruments. Here, the results of calculations performed to see the capabilities of a prototype of the OPM in the reading of pH values.
As seen from Figure 4, regression fitting provides the status of the model between figures 4a and 4b to obtain the correlation of each parameter in conjunction with the pH value. Here, we find two of each premature regression model in the picture (4a) and (4b). However, we were unable to find the relationship between pH prototype detector and OPM because it has a different unit (dBm and Volt). Thus, during the correlation analysis, we used all the measurement data from OPM and prototype detector unit pH after the unit converted into dBm in this study. Here we get an R² value of 0.967 at pH measurements using a prototype detector and 0.9691 on the measurement used OPM. Both possess the R² value with the difference that a little bit, so this study demonstrates the validity of the data was tested using the prototype pH detector. Thus, the development of fiber optic as pH sensors have been successfully carried out.

4. Conclusion
Development of Fiber Optic Sensors with Evanescent wave types to assess the level of power of hydrogen was successful in this study. This system has been able to detect pH levels in a chemical solution. The development of fiber optic sensors is equipped with an electronic instrumentation system so that the output voltage level can be known. The results of testing this pH sensor have been successful and validated with an Optical Power Meter (OPM). Thus, based on the results, we have succeeded in developing a prototype fiber optic sensor with a prototype ammonia detector to measure the pH value of a substance.
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