

## Development of Fiber Optic Chemical Sensor for Monitoring Acid Rain Level

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**Abstract.** Acid rain event is very dangerous for human activity especially in five cities of Indonesia. Here, acid rain has consistently attacked over five cities in Indonesia such as Jakarta, Manado, Pontianak, Bogor, and Surabaya with average pH level 4.22 to 6.34 in July 2010. Thus, in this study aim to develop Fiber Optic Chemical Sensor (FOCS) for monitoring acid rain level over five cities in Indonesia. The development of FOCS is used evanescent wave type and photodiode FDS10X10 to monitor acid rain quality. In this study, the Optical Power Meter (OPM) is used as a validator equipment to capture FOCS capability. The result shows absorption loss was successfully detected using OPM and photodiode FDS10X10 in FOCS evanescent wave type. Here, the maximum value ammonia mass over acid rain level has successfully detected with value range 7.12 dBm to 8.34 dBm and 7.51 dBm to 7.71 dBm using photodiode FDS10X10 and OPM, respectively. The good result over validation process shows FOCS has successful working with strong correlation 0.78 to monitor acid rain level.

### 1. Introduction

Fiber Optic Chemical Sensor (FOCS) is categorized as a chemical sensor based on fiber optic to monitor acid rain level over aerosol and environmental. In this study, the FOCS evanescent field type was used to assess chemical condition in acid rain level. Here, FOCS evanescent field type measured chemical material involved hydrocarbon oxides, ammonia, and nitrogen ( $\text{NO}_x$ ) over acid rain level [1]. In current study of acid rain measurement level using chemical material sensor, the  $\text{NO}_x$  gases sensor was used to calculate precipitation index and chemical emission index [2]. However, calculation result doesn't good due to lack of precipitation index during measurement and processing data. To improve precipitation index of calculation acid rain level, Cai *et al* propose to develop a new sensor using stabilized zirconia and  $\text{MoO}_3\text{-In}_2\text{O}_3$  Nano composites [3]. The highly sensitive using stabilized zirconia and  $\text{MoO}_3\text{-In}_2\text{O}_3$  were given improvement over  $\text{NO}_x$  gases sensor and calculation result. However, the stabilized zirconia and  $\text{MoO}_3\text{-In}_2\text{O}_3$  sensor does not safety due to have chemical reaction over electrochemically material. Thus, Mulyati *et al* has successful to develop Micro-ring resonator to monitor ammonia substance over acid rain event [4, 5]. Here, the Micro-ring resonator is a dielectric ring sensor with smallest refractive

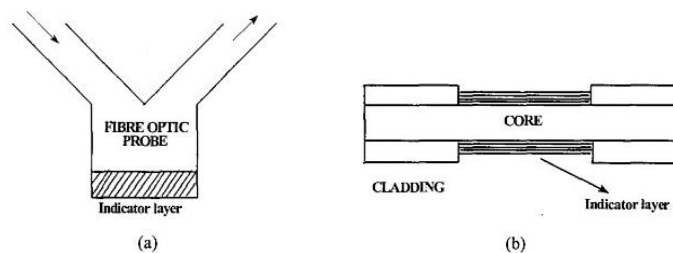


index based on optical principal was developed to measure chemical reaction over electrochemically material [6, 7]. In addition, the Micro-ring resonators have a capability to change ammonia substance from acid rain to optical wavelength 5000 nm to 10000 nm (as a chemical transducer based optical sensor) [8, 9]. However, the developing cost of Micro-ring resonator it's very expensive if the farmer and fish breeder used this sensor to measure acid rain level. Thus, in this study we develop FOCS and prototype ammonia detector to assess ammonia substance during acid rain level based on fiber optic. The optical field from FOCS has highly capability to transmit ammonia substance over acid rain level. Finally, we successful to develop FOCS and ammonia detector over acid rain level and calculate the FOCS performance using statistical and correlation analysis.

## 2. Methodology

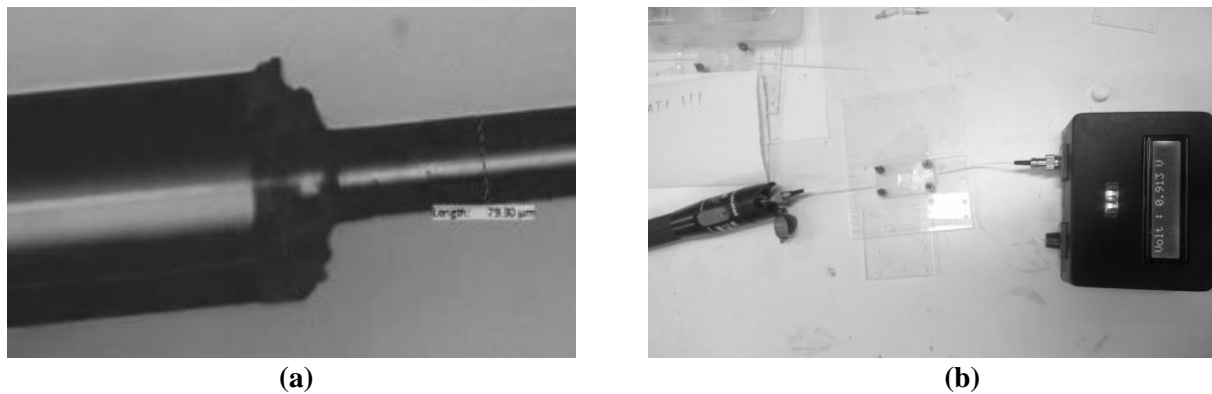
### 2.1. Fiber Optic Chemical Sensor (FOCS)

Today, fiber optic function expanded as a Fiber Optic Chemical Sensor (FOCS) to monitor acid rain level. The two designs of FOCS are suggested to obtain ammonia mass over acid rain level monitoring. Here, the fiber optic was modified into two type such as distal type probe and Evanescent wave type to monitor acid rain level (see Figure 1).

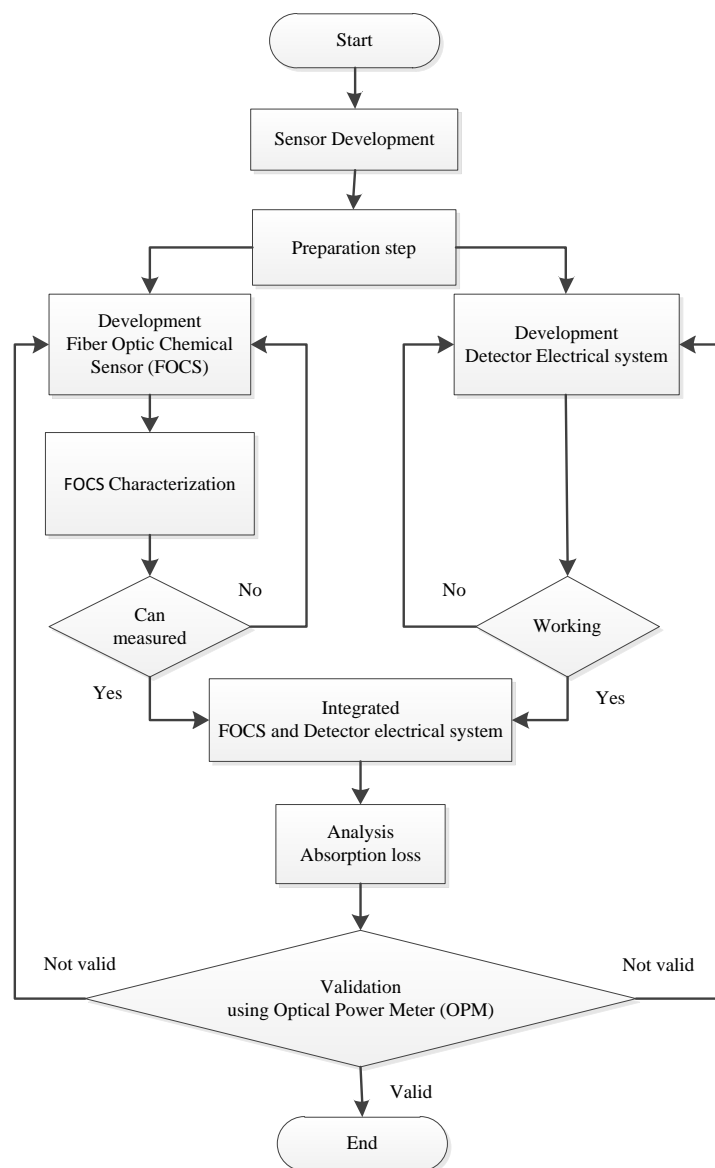


**Figure 1.** The common FOCS design (a) Distal type probe and (b) Evanescent wave type.

As can be seen in Figure 1, the distal type probe and evanescent wave type had different design to assess acid rain level. Here, the differences design of distal type probe FOCS and evanescent wave type FOCS located on indicator layer (sectional area). In order to monitor acid rain level, the evanescent field type was selected due to have large sectional area compared Distal type probe FOCS. During development process, we assess five sample of ammonia mass to obtain bias index ( $n$ ) over experimental method using evanescent wave type FOCS. Here, the absorption loss ( $\alpha$ ) from ammonia bias index obtained using prototype ammonia detector. In addition, we develop this system in two steps design such as Fiber Optic Chemical Sensor (FOCS) and prototype ammonia detector using FDS10X10 (photodiode sensor) to obtain  $\alpha$  value. In the first step, we choose 10 cm single mode fiber and etched using hydrogen fluoride (HF) 40% over 30 minutes (etching rate 1.52  $\mu\text{m}/\text{minute}$ ). During 30 minutes etching process the temperature, pressure, and RF power setting are reached 40°C, 60 mTorr, and 300 Watt, respectively. After that, we obtain the FOCS diameter  $\pm 79.30 \mu\text{m}$  in 30 minutes etching process. In second steps, the developing prototype ammonia detector system using FDS10X10 (photodiode sensor) was applied in this study. Here, the photodiode FDS10X10 integrated with FOCS and microcontroller Atmega328 system to obtain  $\alpha$  value. In addition, the Optical Light Source (OLS) with 1310 nm is use as a light source over input FOCS while photodiode FDS10X10 was used as a detector output FOCS (see Figure 2).



**Figure 2.** The system development FOCS in (a) first and (b) second steps to monitor acid rain level.



**Figure 3.** Flowchart testing process of FOCS with prototype ammonia detector and OPM.

As can be seen in Figure 2, the OLS light source displaced into ammonia bias index from acid rain.

Here, FOCS sensitive layer (in indicator layer) captured the differences bias index over acid rain level. The absorption of OLS light source by ammonia bias index detected FDS10X10 (photodiode sensor). In addition, the prototype ammonia detector has equipped one backlight negative LCD 16X2 to monitor  $\alpha$  value in real time measurement to assess variation ammonia over acid rain level. After the system has successful developed, the Optical Power Meter (OPM) was used to validate capability FOCS and prototype ammonia detector during testing process. The comparison results between OPM and ammonia detector prototype was analyzed to obtain Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and Percent True (PT). Here, we have three steps during tested process to obtain  $\alpha$  value between OPM and ammonia detector prototype such as developing process, integrated process, and validation (see Figure 3). In order to obtain minimum  $\alpha$  value over FOCS, the material tested has placed between substrate and sensitive material. Here, we use variation of ammonia mass (1 ~ 5%) to test capability FOCS capture minimum  $\alpha$  value.

## 2.2. Acid rain level

Acid rains are containing Ammonia ( $\text{NH}_3$ ), Sulphur Dioxide ( $\text{SO}_2$ ) and Nitrogen Oxides ( $\text{NO}_x$ ) in low atmosphere. Here, acid rain will be contaminated rainwater and brings chemical pollutant trapped in the low atmosphere back to earth when the changing chemical composition of the surface soil and water [10]. The contaminated rainwater with acid was going down over lake, river, and water resources especially in five big cities, Indonesia. The pollution index was increased due to car and motor cycle with fossil fuel increasing 9.8% per-years over five big cities in Indonesia. Thus, the pH level of water resources was increased with average range 4.22 to 6.34 over five big cities in Indonesia (Jakarta, Manado, Pontianak, Bogor, and Surabaya). This condition means water resources over five cities in Indonesia are contaminated ammonia substance (acidic) with average range 4.22 to 6.34. Table 1 shows pH quality over July 2010 over Jakarta, Manado, Pontianak, Bogor, and Surabaya during acid rain event.

**Table 1.** pH quality over July 2010 over five big cities in Indonesia during acid rain event.

No.	pH quantity	Indonesia Province
1.	4.52	Jakarta
2.	4.22	Manado
3.	4.29	Pontianak
4.	4.40	Bogor
5.	6.34	Surabaya

As can be seen in Table 1, the pH quality over acid rain level is very harmful for environmental and human life. Here, the increasing acid rain level over five big cities in Indonesia are indicated environmental status is unhealthy for human life. The unhealthy environmental effect was disturbed physical condition human during life activity. Thus, in this study we use fiber optic technology to assess ammonia substance using FOCS with prototype ammonia detector

## 3. Results and discussion

In order to achieve the objective, we obtain a minimum Fiber Optic Chemical Sensor (FOCS)  $\alpha$  value using substrate and sensitive material. Here, the variation ammonia mass (1 ~ 5%) are added over sensitive material to obtain minimum FOCS  $\alpha$  value. During laboratory experiment, we collect seven sample measurements to see FOCS responses. By using variation ammonia mass (1 ~ 5%), we assess FOCS responses using Optical Power Meter (OPM) and prototype ammonia detector system using FDS10X10 (photodiode sensor) with light source 1310 nm (see table 2 and 3).

**Table 2.** Performance FOCS to capture ammonia mass using OPM.

Ammonia mass (%)	Absorption loss using OSA with light source 1310 nm						
	I (dBm)	II (dBm)	III (dBm)	IV (dBm)	V (dBm)	VI (dBm)	VII (dBm)
1	7.510	7.510	7.510	7.440	7.510	7.710	7.510
2	7.510	7.550	7.990	7.550	7.860	7.550	7.550
3	7.550	7.550	7.760	7.550	7.550	7.830	7.550
4	7.570	7.620	7.570	7.570	7.550	7.570	7.660
5	8.000	7.710	7.710	7.710	7.710	7.710	7.710

**Table 3.** Performance FOCS to capture prototype ammonia detector system using FDS10X10 (photodiode sensor).

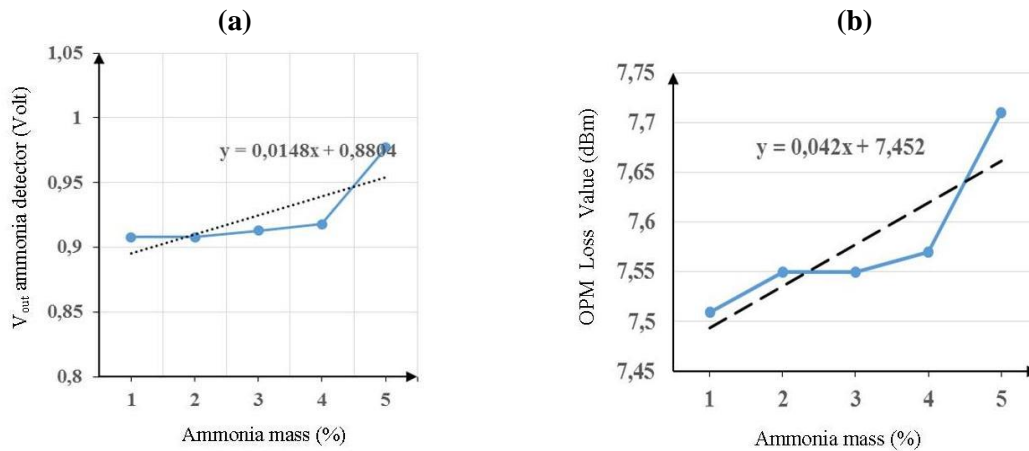
Ammonia mass (%)	Absorption loss using FDS10X10 (photodiode sensor) with light source 1310 nm						
	I (Volt)	II (Volt)	III (Volt)	IV (Volt)	V (Volt)	VI (Volt)	VII (Volt)
1	0.908	0.908	0.908	0.910	0.908	0.908	0.908
2	0.997	0.908	0.908	0.908	0.908	0.952	0.915
3	0.913	0.913	0.913	0.940	0.900	0.932	0.900
4	0.918	0.913	0.990	0.918	0.918	0.918	0.918
5	0.977	0.990	0.977	0.977	0.980	0.977	0.977

As can be seen in Table 2 and 3, the FOCS performance assessment using variation ammonia mass (1 ~ 5%) has successful developed. Here, we obtain minimum and maximum FOCS performance assessment ( $\alpha$  values) over seven measurements started between 7.440 until 8.000 dBm using OPM. However, in the second assessment using prototype ammonia detector system we obtain FOCS performance between 0.900 to 0.997 Volts. The differences measurement result between OPM and prototype ammonia detector based on set point unit over both of this device (dBm and Volt). Thus, the statistical method (modus) was performed in this study to see ammonia mass effect over voltage output value between OPM and prototype ammonia detector, respectively (see Table 4).

**Table 4.** The modus method to see variation ammonia mass and voltage value between OPM and prototype ammonia detector.

Ammonia mass (%)	Modus OPM (dBm)	Modus prototype ammonia detector (Volt)
1.	7.51	0.908
2.	7.55	0.908
3.	7.55	0.913
4.	7.57	0.918
5.	7.71	0.977

After all the data obtained, the regression fitting is applied in this study to shows the relation between voltage ( $V_{out}$  from prototype ammonia detector), OPM loss value, and ammonia mass, respectively. Here, the calculation result was performed to see capability prototype ammonia detector and OPM devices to assess ammonia mass during acid rain event (see Figure 4).



**Figure 4.** The regression fitting between (a)  $V_{out}$  from prototype ammonia detector and (b) OPM loss value over ammonia mass during acid rain event.

As can be seen in Figure 4, the regression fitting gives the model status between Figure (4a) and (4b) to obtain correlation for each parameter in conjunction with ammonia mass. Here, we find two models regression for each parameter in Figure (4a) and (4b). However, we cannot find the correlation between prototype ammonia detector and OPM due to different unit (dBm and Volt). Thus, during correlation analyses, we use all the measurement data from OPM and prototype ammonia detector after ammonia detector unit converted into dBm unit in this study. Here, we obtain  $R^2$  value between OPM and prototype ammonia detector we obtain 0.78 (strong correlation) with value range 7.12 dBm to 8.34 dBm and 7.51 dBm to 7.71 dBm using prototype ammonia detector and OPM, respectively. The advantages of prototype ammonia detector are cheapest compared by Micro-ring resonator. However, the Micro-ring resonator is more sensitive to assess acid rain level [4, 5] compared prototype ammonia detector due to the material of both sensors is different [5]. In addition, the principal of both sensor is use optical concept to assess acid rain level [11]. Finally, the development FOCS to assess acid rain was successful developed using prototype ammonia detector.

#### 4. Conclusions

The development Fiber Optic Chemical Sensor (FOCS) with Evanescent wave type to assess acid rain level was successful in this study. The FOCS system is capable to applied over big five cities in Indonesia such as Jakarta, Manado, Pontianak, Bogor, and Surabaya during acid rain event. The development of FOCS is equipped with prototype ammonia detector to monitor  $\alpha$  value. The tested result of FOCS sensor with prototype ammonia detector was successful and validated with Optical Power Meter (OPM). The correlation analysis shows FOCS sensor with prototype ammonia detector and OPM have strong correlation in the 0.78 over 7.12 dBm to 8.34 dBm and 7.51 dBm to 7.71 dBm, respectively. Thus, based on the result we were successful developed FOCS with prototype ammonia detector to assessed acid rain level.

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