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Low-cost Fiber Optic Chemical Sensor Development for Fishpond Application

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Abstract

In this study, aimed to develop low-cost sensor based on fiber optic to assess ammonia index for fishpond application. Here, the simple design was proposed by using Evanescent wave type to assess ammonia index during acid rain event. The experiment result showed maximum absorption loss with variation ammonia mass 1~5% with wavelength 1310 nm from Optical Light Source (OLS) is 27.56 dBm while Optical Spectrum Analyzer (OSA) reached 25.86 dBm. We had calculated RMSE, MAE, and Percent Error (PE) value both of the device (Low-cost fiber optic chemical sensor and OSA) are 1.692%, 0.916%, and 98.833% respectively. A good result from low cost fiber optic chemical sensor has successful developed with lowest production less than 1,455 USD per-year.

Keywords: *acid rain, ammonia (NH_3), fiber optic, fishpond, low-cost sensor*

1. Introduction

Nowadays, the acid rain phenomenon is categorized as an environmental hazard especially in Indonesia. Here, acid rain was composed by hydrocarbon oxides, Ammonia (NH_3) and nitrogen (NO_x). The three types of acid rain particles are very harmful for environment and human health [1]. During acid rain event, the pH level of water quality index is decreased to 4.7~5.6 (moderate) due to NH_3 particle increased [2-4]. The conventional acid rain measurement using pH meter probe is very expensive for Indonesian fish breeders. Many users of pH meter probe to detect NH_3 substance in Indonesia was decreased until 20~30% over July 2010 due to lack of budget [5]. Thus, this study aimed to develop low-cost sensor to assess NH_3 over Indonesian fishpond based Fiber Optic Chemical Sensor (FOCS).

The current study of NH_3 sensor development to assess contaminated water was successful obtained by using arrays sensor based on conductive polypyrrole film (called electrochemically). The deposited electrochemically on glassy carbon surface and internal solid layer (between sensing membrane and solid electrode surface) has occurred NH_3 over polluted area [6]-[8]. Due to lack of data in real time measurement, the wireless sensor was used as a low-cost sensor to assess NH_3 [9]. Wireless sensor has a fast response with measurement range 1-5 slope of 56.3 mV [10]. However, this sensor does not safety due to located in the fishpound area. The new revolution of non-chemical material NH_3 detector has successful developed using Un-Ionized Ammonia (UIA) [11, 12]. The four parameters such as pH, temperature, dissolved oxygen, and ammonium are captured using UIA sensor in freshwater. The UIA sensor had 95% confident level to measure four parameters. However, the UIA sensor cannot assess NH_3 due to limitation of hardware instrument based on gas-sensing electrode. To improve the performance UIA sensor, the Micro-ring resonator was proposed to detect NH_3 percent value during acid rain event [13]. Micro-ring resonator is a dielectric ring sensor with smallest refractive index based on optical principal. The Micro-ring resonators have a capability to change and assess NH_3 index from contaminated water to optical wavelength 5000 nm to 10000. The result shows the Micro-ring resonator has a fast response to assess NH_3 value

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index from contaminated water. However, the developing cost of Micro-ring resonator it's very expensive to applied in fish breeder.

In this study, we had developed low-cost Fiber Optic Chemical Sensor (FOCS) to assess NH_3 value index from contaminated water based on fiber optic. The advantages of low-cost FOCS have highest capability and safety due to the device using light source. In near future, low-cost FOCS sensor was applied as a National Standard of Indonesia to assess NH_3 parameter over fishpond contaminated water.

2. Literature Review

2.1. Ammonia

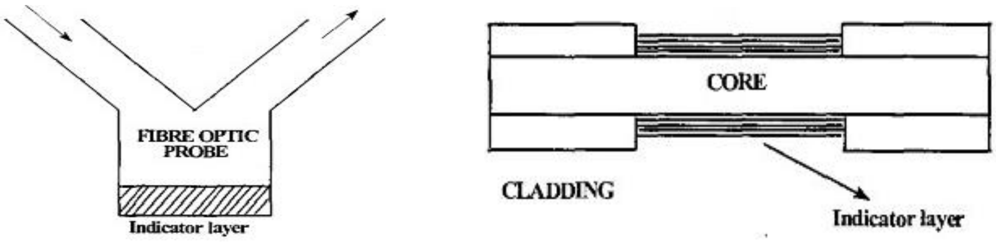
Ammonia (NH_3) is composed by three hydrogen atoms and one nitrogen atom. The physical characteristic of ammonia is colorless, gases, odorless, and alkaline with soluble in water. The water decomposition in troposphere is affected by two surface meteorological parameters such as pH and temperature. In aqueous solution, equilibrium exists between Un-Ionized Ammonia (UIA), NH_3, and ionized ammonia NH_4^+. Ammonia forms in the water called UIA [11, 13] while ammonium ion in water called NH_4^+. The method to average UIA and ammonium concentration called total ammonia-nitrogen (TAN) due to different slightly relative molecular masses, expressed in (1) [10] [14]:

$$NH_4^+ + H_2O \Leftrightarrow NH_3 + H_3O^+ \quad (1)$$

where, H_2O and H_3O^+ are pure water and hydronium ion

2.2. Fiber Optic Chemical Sensor (FOCS)

Since 1960, fiber optic was used to improve quality communication service and internet bandwidth. However, in this study the fiber optic function has been changed as a Fiber Optic Chemical Sensor (FOCS) to assess NH_3 index [15, 16]. Here, the common FOCS design such as Distal type probe and Evanescent wave type are used to monitor water quality as shown in Figure 1.



(a) (b)

Figure 1. The common FOCS design (a) distal type probe and (b) evanescent wavetype

As we can see in Figure 1, the distal type probe and evanescent wave type had different design to monitor water quality. The differences design of two FOCS located on indicator layer to assess water quality [17]. In order to assess water quality over fishpond, the evanescent field type is selected in this study due to cheapest and easy to assess water quality over Indonesian fishpond. The few parts of fiber optics such as core, cladding, and primary buffer was peeled to obtain ammonia bias index over contaminated water is showed in Table 1.

As we can see in Table 1, ammonia bias index over contaminated water have correlation with ammonia mass. In order to obtain ammonia bias index in contaminated water, the fiber optic was peeled over middle area. Here, Optical Light Tester (OLT) has given light source to peeled area to assess ammonia bias index in contaminated water in middle fiber optic. The OLT have specifications1310 nm wave length with visible light to give light source into peeled area. Furthermore, we use photodiode sensor type FDS10X10 as an ammonia bias index detector. Hence to validate the output ammonia bias index from photodiode FDS10X10, the Optical Spectrum Analyzer (OSA) and Optical Power Meter (OPM) was proposed as a validator device in this study.

Table 1. Ammonia Bias Index Over Contaminated Water

Mass (%)	m/mol Kg^{-1}	c/mol L^{-1}	Bias index (*n*)
0.5	0.295	0.292	1.3332
1	0.593	0.584	1.3335
2	1.198	1.162	1.3339
3	1.816	1.736	1.3344
4	2.447	2.304	1.3349
5	3.090	2.868	1.3354
6	3.748	3.428	1.3359
7	4.420	3.983	1.3365
8	5.106	4.533	1.3370
9	5.807	5.080	1.3376
10	6.524	5.622	1.3381
12	8.007	6.695	1.3393
14	9.558	7.753	1.3404
16	11.184	8.794	1.3416
18	12.889	9.823	1.3428
20	14.679	10.837	1.3440
22	16.561	11.838	1.3453
24	18.542	12.826	1.3465
26	20.630	13.801	1.3477
28	22.834	14.764	1.3490
30	25.164	15.713	1.3502

2.3. Acid Rain

Ammonia (NH_3) was selected as a waste product during metabolic process from fish on normal condition. In small amounts of ammonia were provoke fish condition e.g. stress and grill damage over fishpond environmental [18], [19]. During acid rain event, the ammonia level was increased due to chemical pollutant over rainwater. Here, the pollutant substance from industry (SO_2 and NO_x) will be contaminate rainwater and brings chemical pollutant trapped in the atmosphere back to earth when the changing chemical composition of the surface soil and water [20]-[22] as shown in Figure 2.

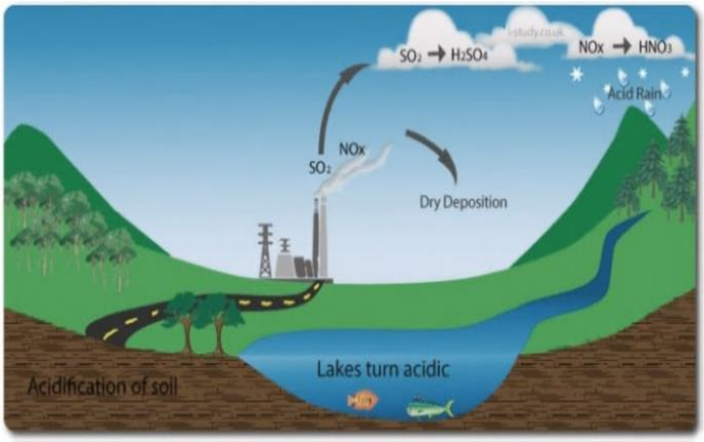


Figure 2. Acid rain scheme

As we can see in Figure 2, the contaminated rainwater is going down over fishpond water with high acidic level. Here, the pH level of fishpond water decreased until 6.34 on July 2010 especially in Indonesia. The five big cities in Indonesia such as Jakarta, Manado, Pontianak, Bogor, and Surabaya have acidic pH level with average range 4.22 to 6.34 as shown in Table 2. [23, 24].

Table 2. pH Quality over July 2010 in Five Big Cities 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

This condition it's very harmful for Indonesian fishpond ecosystem specially to increase the fish commodity over five big cities in Indonesia country during the acid rain event.

3. Methodology

In order to develop low-cost ammonia bias index in this study, the experimental method was proposed to design and analyze the capability a new FOCS. Here, the ammonia variation level over contaminated water are assessed using a new low-cost FOCS. The variation level is detected from absorption loss (α) over middle (peeled) fiber optics area. In order to develop the highest capability low-cost ammonia sensor, we choose single mode fiber optic and etched with length 79.30 μm using 40% hydrogen fluoride (HF) in 30 minutes. Here, we obtain the best etching rate $\pm$ 1.52 μm/minute over Etching process as shown in Figure 3.

Figure 3. Etching process of fiber optic using HF 40% over 30 minutes

In order to obtain a minimum α value in FOCS development, the characterization study of FOCS was applied to assess ammonia level index. The new FOCS has been tested to obtain ammonia level index during characterization study. The ammonia mass variation (1~5%) was used to obtain highest capability and response during testing process. If the FOCS have low response to detect ammonia level over ammonia mass variation, the FOCS will be re-etching until obtained a good response to detect ammonia mass variation. The developing electronics detector system using photodiode type FDS10X10 was applied in this study. Here, the photodiode FDS10X10 are integrated with microcontroller Atmega328 system to capture α value, the mechanism of FOCS system to capture α value is showed in Figure 4.

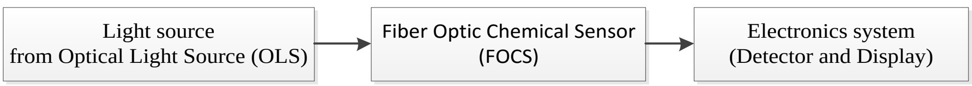


Figure 4. Mechanism FOCS to capture α value

Figure 4 shows the electronics system has two parts such as detector and display system to assess ammonia level index from α value. The electronics system was designed to replace Optical Spectrum Analyzer (OSA) function with low-cost concept due to OSA is expensive for fish breeder. However, in this study OSA was used as a validator device from development low-cost ammonia detector. In addition, the statistical method is performed in this study to analyze α value from OSA and low-cost ammonia detector, respectively.

In order to obtain the minimum α value, FOCS has placed between substrate and analyze sensitive material. Here, the variation of ammonia mass (1~5%) is added over analyze sensitive material to obtain the minimum α value. Figure 5 shows the Optical Light Source (OLS) with 1310 nm is used as a light source over input FOCS while photodiode FDS10X10 and OSA was used as a detector output FOCS, respectively.

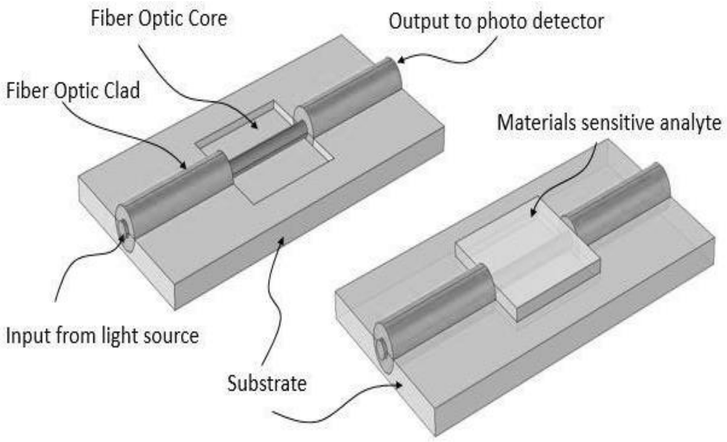


Figure 5. FOCS position during validation process

The light source from OLS was displaced by ammonia's refractive index variation in analyze sensitive material. Here, ammonia's refractive index absorbed light source until the light detected by photodiode FDS10X10 and OSA. Afterwards, the comparison of measurement result from photodiode FDS10X10 and OSA will be assessed.

4. Results and Discussion

In order to obtain the minimum absorption loss (α) from FOCS, the statistical method is performed in this study to analyze the result. Here, seven measurements were collected from FOCS response to capture ammonia mass variation using OSA with light source 1310 nm as shown in Table 3.

Table 3. Performance FOCS to Capture Ammonia Mass Using OSA

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	25.78	24.22	25.78	25.78	24.22	25.78	25.02
2	26.02	26.54	26.54	25.54	26.02	26.02	25.54
3	23.62	26.47	26.47	26.47	26.47	25.78	26.47
4	27.29	26.47	27.56	27.56	27.29	27.29	27.56
5	27.56	23.79	27.56	27.56	27.56	27.56	27.29

As can be seen in Table 3, the minimum and maximum range of α values in seven measurements started between 23.62 dBm to 27.56 dBm, respectively. By using modus from statistical method, we obtain five α values from seven measurements such as 25.78 dBm, 26.02

dBm, 26.47 dBm, 27.29 dBm, 27.56 dBm for ammonia mass variation 1%, 2%, 3%, 4%, and 5%, respectively. Furthermore, the low-cost sensor using photodiode FDS10X10 was used as a comparator to analyze performance of FOCS using ammonia mass variation 1%, 2%, 3%, 4%, and 5% with light source 1310 nm as shown in Table 4.

Table 4. Performance FOCS to Capture Ammonia Mass Using Low-cost Sensor

Ammonia mass (%)	Absorption loss using low-cost sensor with light source 1310 nm						
	I (dBm)	II (dBm)	III (dBm)	IV (dBm)	V (dBm)	VI (dBm)	VII (dBm)
1	24.02	24.01	24.01	24.07	24.02	24.02	24.02
2	26.37	24.01	24.01	24.02	24.02	25.18	24.20
3	24.15	24.15	24.15	24.86	23.81	24.65	23.81
4	24.28	24.15	26.45	24.28	24.28	24.28	24.28
5	25.84	26.45	25.84	25.84	25.92	25.84	25.84

Table 4 shows the minimum and maximum range of α value in seven measurements started from 24.01 dBm to 26.45 dBm using low-cost sensor (photodiode FDS10X10). Here, the different result (α value) from OSA and low-cost sensor photodiode FDS10X10 it's very closed between 0~1.11 dBm. Thus, by using modus from statistical method, we obtain five α value from seven measurements such as 24.02 dBm, 24.02 dBm, 24.15 dBm, 24.28 dBm, 24.85 dBm for ammonia mass variation 1%, 2%, 3%, 4%, and 5%, respectively. In order to see the performance between OSA and low-cost FOCS using photodiode FDS10X10 detecto, the Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and Percent True (PT) was performed in this study as shown in Table 5.

Table 5. Statistical Comparison between OSA and Low-cost FOCS Sensor

Parameters	OSA	Low-cost FOCS sensor (photodiode FDS10X10)
RMSE (%)	1.832	1.692
MAE (%)	1.293	0.961
PT (%)	98.108	98.883

Table 5 shows the comparison performances between OSA and low-cost FOCS (photodiode FDS10X10) over ammonia mass variation have a good result. The result shows RMSE and MAE for OSA and Low-cost FOCS (photodiode FDS10X10) have a good result more than 90% and less than 3%, respectively. Here, PT was calculated to obtain the accuracy of OSA and Low-cost sensor (photodiode FDS10X10) to capture α value. In addition, we obtain the high accuracy of Low-cost FOCS (photodiode FDS10X10) more than 95% to capture α value. The increasing value for all parameter caused by detection source electromagnetic and light wave (OSA and Low-cost FOCS). Furthermore, the budget comparison to development FOCS and Low-cost sensor (photodiode FDS10X10) was performed in this study. During development process of FOCS and Low-cost sensor (photodiode FDS10X10), the budget to develop this prototype is entailed $\pm$ 211 USD as shown in Table 6.

Table 6. Development budget of OSA and Low-cost sensor

Material	Quantity	Amount (USD)
Fiber optic (Single mode)	1 pcs	15
Hydrogen Fluoride (40%)	5 Liter	20
Etching cost	10 pcs	80
Battery 12VDC	2 pcs	5
Photodiode FDS10X10	1 pcs	80
Microcontroller (ATMega328)	1 pcs	11
Total		211
OSA HP70952B (600nm-17000nm)	1 pcs	5,200

As can be seen in Table 6, the differences budget cost between OSA and Low-cost sensor (photodiode FDS10X10) around ± 4,900 USD. Here, we obtain OSA is very expensive than prototype Low-cost sensor (photodiode FDS10X10). In addition, by using this sensor we save the budget almost 4800 USD during development low cost sensor. In order to achieve the objective, we tested low cost sensor and OSA by calculation Nile Tilapia fish (*OreochromisNiloticus*) export commodity [25]. Here, the Nile Tilapia fish is a famous commodity export in Indonesia with 19.7 million USD in 2010 [26]. However, during acid rain event in July 2010, the Nile Tilapia fish has decreased until 31% over five cities in Indonesia [26]. However, in November to December 2010 commodity export was increased 12% until 4 million USD after the acid rain event as shown in Table 7.

Table 7. Comparison between Fish Export Commodity with Low-cost Sensor and OSA Investment during Acid Rain Event over Fishpond Application in Five Cities Indonesia

Month of 2010	Fish Export Commodity (USD)	Low cost sensor (USD)	OSA (USD)
Jan-Feb	4.7 mil.	1,055	26,200
Mar-Apr	4 mil.	N/A	N/A
May-Jun	1	N/A	N/A
Jul-Aug	3	400	1,000
Sep-Oct	3	N/A	N/A
Nov-Dec	4	N/A	N/A
Total	19.7 mil.	1,455	27,200

As can be seen in Table 7, the comparison between Nile Tilapia export commodity with low cost sensor development during one-year investment and maintenance over five cities. Here, the development of low-cost sensor is 1,055 USD while OSA device is 26,200 USD in one year. In addition, the total cost (including development maintenance fees every six months) is 1,455 for low cost sensor and 27,200 for OSA device, respectively. Furthermore, the high maintenance cost of OSA due to rewiring cable connection while low cost sensor is replacement FOCS inside sensitive material over fishpond. The advantages and weakness of both devices presented in Table 8 in fishpond application. Here, the comparison between OSA device and FOCS low cost sensor was assessed based advantages and weakness due to accuration and responsibility both of device.

Table 8. Comparison between OSA and FOCS Low-cost Sensor

Status	OSA	FOCS Low-cost sensor
Expensive	✓	-
Accurate	✓	✓
Portable	✓	✓
Easy Installation	-	✓
Eco-Friendly	✓	✓
Save Energy	-	✓
Cheap	-	✓

As can be seen in Table 8, the three advantages both of the devices such as accurate, portable, and eco-friendly was obtained to monitor ammonia index. However, the FOCS low-cost sensor is cheapest than OSA device due to composed by silica (Si) material. Thus, we spouse to use FOCS low cost sensor to monitor ammonia index during acid rain event in the fishpond application. In addition, FOCS low-cost sensor is recommended for professional fish breeder and as a basic device to monitor acid rain effect over fishpond application in near future.

5. Conclusion

The FOCS with FDS10X10 photodiode to assess ammonia level in acid rain was successful developed in this study. The FOCS low-cost sensor is recommended for professional fish breeder in Indonesia such as Jakarta, Manado, Pontianak, Bogor, and Surabaya during acid rain event. The advantages of FOCS low-cost sensor have highest capability, safety due to the device using light source, and cheap 1,455 USD per-year. In validation result showed FOCS low-cost sensor have a good result (compared by Optical Spectrum Analyzer with light source 1310 nm). Here, FOCS low-cost sensor with photodiode FDS10X10 and Optical Spectrum Analyzerhave highest accuracy more than 98.8% and 98.1%, respectively. Thus, based on the result we were successful develop FOCS low-cost sensor with photodiode FDS10X10 to monitor acid rain effect over fishpond application in near future.

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