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Performance Comparison of a Rhodamine B Concentration Sensor in Distilled Water Using a Fiber Coupler and Fiber Bundle as a Probe without Direct Contact with the Sample

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Abstract

Detection of the concentration of rhodamine B in distilled water using a fiber coupler and fiber bundle as probes with a static position on the sample surface and not in direct contact with the sample was successfully carried out. The working mechanism of the sensor uses the principle of sample absorption of the light that passes through it. The concave mirror functions as a reflector and a sample container, allowing an undirect contact probe sensor with the sample. Both types of sensors show similar performance. The best detection is shown by sensors that use fiber bundles as probes. The resulting sensitivity and resolution are 2.1 mV/ppm and 0.29 ppm, respectively.

Keywords: Fiber coupler, fiber bundle, concave mirror, absorption, rhodamine B.

1. Introduction

Detection of the concentration of substances in liquids or the refractive index of liquids has been carried out using fiber optics with various methods. The fiber interferometer has been able to be used to detect the refractive index of liquids [1], [2]. Fiber optic coating with surface plasmon resonance-based materials can also detect uric acid [3] and manganese ions [4]. A more straightforward technique has also been developed using a fiber coupler or fiber bundle. The technique works based on changes in light intensity after passing through the sample to detect changes in the concentration or refractive index of the sample. The fiber coupler or fiber bundle functions probe is both a transmitter and receiver of light after passing through the sample. Mounting a mirror (flat or concave) on the sample container is done so that light can be reflected and enter the probe sensor after passing through the sample. With this technique, the concentrations of rhodamine B [5], magnesium ion [6], and glucose [7] can be detected using a fiber coupler. In addition, the concentrations of calcium [8] and sodium chloride [9] can be detected using fiber bundles.

Detection of the substance concentration using a fiber coupler and a bundle, as mentioned above, is based on a displacement sensor, where the probe shifts away from or closer to the sample. The shifting probe will produce an optical detector output voltage (a representation of the intensity or optical power of light) as a function of the position probe to the mirror with the sample between the two. The sample concentration is read through the peak voltage value (maximum voltage value) for each detected concentration. The disadvantage of this method is direct contact between the probe and the sample because the probe is immersed in the sample. That requires cleaning the probe when the sensor is to be reused. Detecting rhodamine B concentrations has been published using a fiber coupler [10] and fiber bundle [11] based on a displacement sensor without direct contact between the probe and the sample to overcome that problem. It can be done because the sample volume is tiny and placed on a small concave mirror. Using the absorption principle (the sample absorbs the wavelength of light used), even though the sample volume is small, detecting rhodamine B concentrations can be done quite well.

Detection of the concentration of rhodamine B that has been published [10], [11], the detection mechanism is carried out by scanning the intensity of the reflected light from the sample container. The scan aims to determine the maximum light intensity that enters the probe sensor. This method takes more time. Therefore, in this research, the results of detecting the concentration of rhodamine B in

distilled water will be presented using a fiber coupler and fiber bundle in contact without a probe with the sample. In contrast to previous studies [10], [11], the detection procedure was performed without a scanning procedure. The performance of the two types of sensors used will be compared. The no-scan procedure is performed by placing the probe statically at the position where the peak voltage is obtained.

The proposed rhodamine B concentration detection method can be utilized for the textile industry that uses rhodamine B as a fabric or clothing dye. The results of an accurate measurement of the concentration of rhodamine B will determine the accuracy of the desired fabric dyeing. If further developed, the proposed detection method is expected to be able to detect the presence of rhodamine B in food and beverage or textile industry waste which pollutes the environment. As is known, rhodamine B is often misused for food and beverage coloring because the colors produced are very bright. On the other hand, Rhodamine B is a carcinogen that can cause cancer and damage liver function. Therefore, rhodamine B is prohibited from being used for food and beverage coloring under the Regulation of the Minister of Health of the Republic of Indonesia Number 239/Men.Kes/Per/V/85, 1985 concerning dangerous dyes.

2. Method

2.1. Sensor Work Mechanism

The design of the rhodamine B concentration sensor in distilled water using a fiber coupler and fiber bundle is shown in Figure 1. The sample container is a concave mirror with sample volumes (meniscus in nature) measuring almost twice the volume of a concave mirror. The sensing port fiber coupler (Figure 1a) and fiber bundle probe (Figure 1b) are in a fixed position (static), i.e., a distance *d* from the sample surface. This is the distance at which the intensity of light enters the sensing port or probe bundle maximum value.

The working mechanism of the sensor using the fiber coupler to detect the concentration of rhodamine B in distilled water (Figure 1a) is as follows. The laser beam that enters the input port of the fiber coupler (P_{in}), half of its intensity, is transmitted by the sensing port through the sample. After being reflected by the concave mirror surface, the reflected light beam penetrates the sample again and some of it re-enters the sensing port. The beam of light is returned to the sensing port and half of its intensity is transmitted to the optical detector through the detection port. The optical detector reads the intensity or optical power of the light in terms of the detector's output voltage. Suppose the wavelength of the laser used is absorbed by the rhodamine B solution. In that case, changes in the concentration of rhodamine B will change the intensity of the light entering the sensing port. As a result, the output voltage of the detector also changes [11], [12]. A similar mechanism of action occurs if the sensor uses fiber bundles as a pair in Figure 1b. The difference is the reflected light beam from the concave mirror that passes through the sample. Part of it enters the fiber, directly forwarded to the optical detector. At the same time, the light beam to the sample is emitted through fibers. Thus, the optical detector output voltage will read the detection of rhodamine B concentration in distilled water using a fiber coupler or fiber bundle [12].

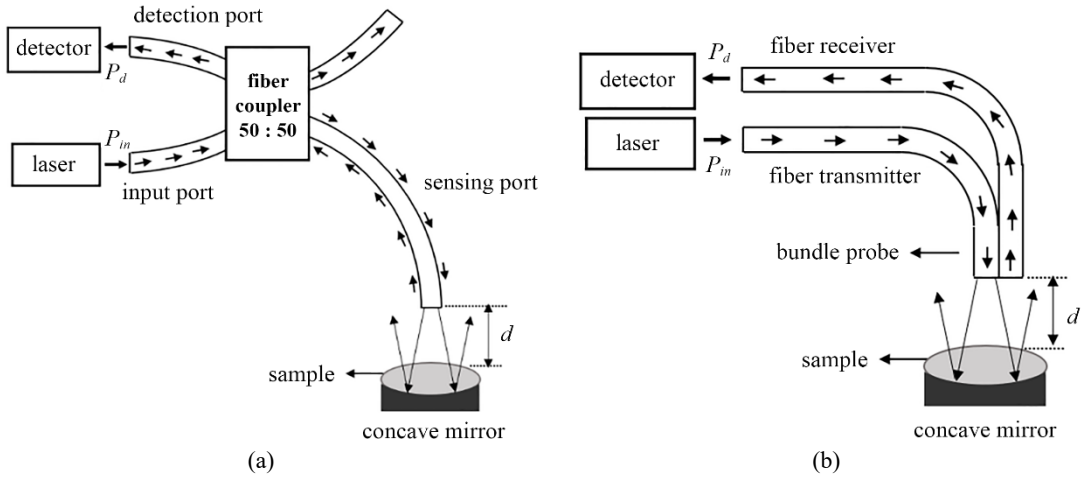

Figure 1. Design of a rhodamine B concentration sensor using (a) fiber coupler and (b) fiber bundle.

2.2. Experiment

The set-up of experimental equipment for detecting the concentration of rhodamine B in distilled water using a fiber coupler and fiber bundle is shown in Figure 2a and Figure 2b, respectively. The equipment used consisted of (a) a He-Ne laser (543 nm wavelength with a maximum power of 5 mW), (b) a multimode fiber coupler 2 × 2 structure made of plastic (with 1 mm diameter, 1 m length, 50/50 coupling ratio, insertion loss 3.7–5.6 dB, and excess loss 1.6 dB), (c) fiber bundle type a pair made of plastic (2 m long with a diameter fiber of 1mm each transmitting and receiving silicon photodetector with the digital voltmeter to read the detector output voltage), (d) XYZ stage with a shift resolution of 10 µm and a shift range of 25 mm were used to shift probe, (e) a concave mirror as a reflector as well as a sample container with a radius of curvature, (f) a mirror diameter of 9 mm each (the volume of the mirror concavity was 39 µl), and (g) a micropipette (size 10-100 µl) is used to measure the volume and place the sample in the container. Samples were made by dissolving rhodamine B powder in distilled water to produce a solution of rhodamine B with a concentration of 0–20 ppm with a variation of 2 ppm.

The first step of the experiment was to measure the absorption spectrum of the rhodamine B solution using a spectrophotometer and to measure the refractive index value of each concentration of rhodamine B used as a sample using a refractometer Abbe. This step aims to determine whether the sample absorbs the light used as a source in the experiment and whether changes in concentration change the sample's refractive index [13].

The second step is to determine the position probe against the sample surface. This position serves as a reference point in placing the probe statically during the experimental detection of the concentration of rhodamine B solution [13]–[15]. This step is carried out by activating all equipment, then filling the concave mirror with a sample of distilled water (rhodamine B concentration of 0 ppm) as much as 70 µl as Figure 1a for the use of a fiber coupler and Figure 1b for fiber bundle. Next is to place the probe. Using the XYZ stage, the sensor probe is then shifted away from the sample surface. At the same time, the detector output voltage (mV) is recorded each time probe the sensor. The detector output voltage is recorded until the probe is as far as 10 mm from the mirror surface. This second step scans the detector output voltage when the probe shifts to the sample surface. The scanning process will generate detector output voltage data against the probe and then determine the probe which produces a peak voltage (representation of the maximum intensity of the light beam entering the probe sensor).

In the third step, the probe is placed permanently (statically) in a position that produces a peak voltage according to the data generated in the second step. Then the sample with a volume of 70 µl was placed into the sample container using a micropipette and the detector output voltage was recorded for each concentration of rhodamine B tested (0 ppm, 2 ppm, 4 ppm, …, 20 ppm). The experiment was repeated three times to detect the concentration of rhodamine B in distilled water using a fiber coupler and fiber bundle.

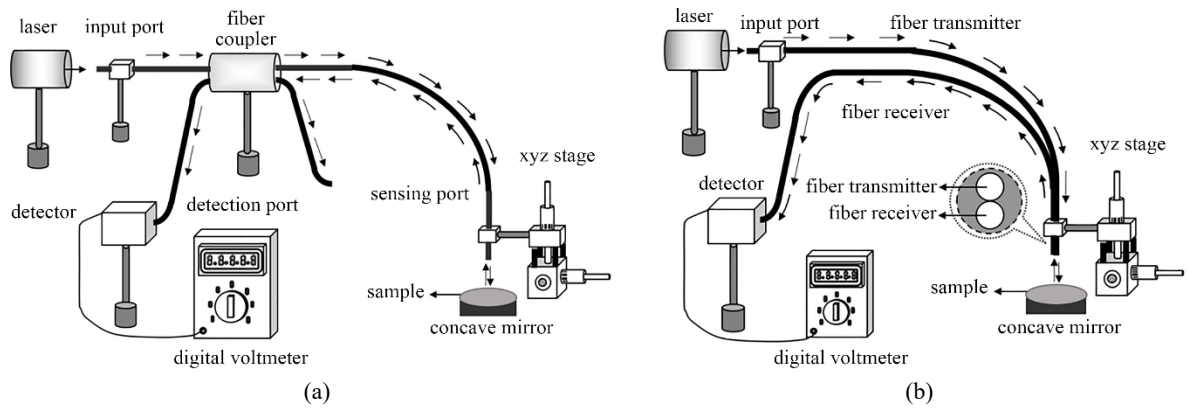

Figure 2. The set-up of equipment for detecting the concentration of rhodamine B solution in distilled water using (a) a fiber coupler and (b) a fiber bundle.

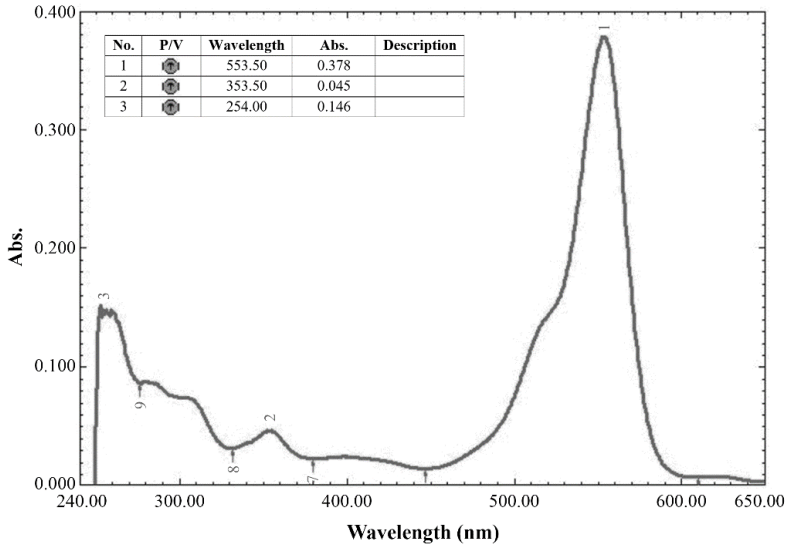

Figure 3. Measurement results of the absorption spectrum of rhodamine B solution at a concentration of 1 ppm.

The last (fourth) step is the sensor stability test. This step is carried out by recording the detector output voltage every 30 seconds for 15 minutes when detecting concentrations of rhodamine B in distilled water for specific concentrations, namely 0 ppm, 10 ppm, and 20 ppm. During the experiment, the room temperature was recorded to be constant at 24 °C.

3. Result and Discussion

The measurement results of the absorption spectrum of a solution of rhodamine B with a concentration of 1 ppm are shown in Figure 3, with the highest absorption peak at a wavelength of 553.5 nm. From these results, the laser used as a light source with a wavelength of 543 nm is still in the wavelength range absorbed by the rhodamine B solution [5], [15], [16]. The measurement of the refractive index of the rhodamine B solution for a concentration of 0–20 ppm results in the same value, which is 1.338. From the measurement results of the absorption spectrum and refractive index of the rhodamine B solution as a sample, the assumption that changes in the detected light intensity occur because it is absorbed by the sample changing its concentration, not because of refraction due to changes in the sample's refractive index, becomes true.

The step of scanning the detector output voltage when the probe away from the sample surface produces detector output voltage data as a function probe to the sample surface. The results are shown in the graph in Figure 4. From the data in Figure 4, the position probe, when generating a peak voltage, is 2500 mm for using a fiber coupler and 4400 mm for using a fiber bundle. This data is used as the static position probe of the sensor [14], [17].

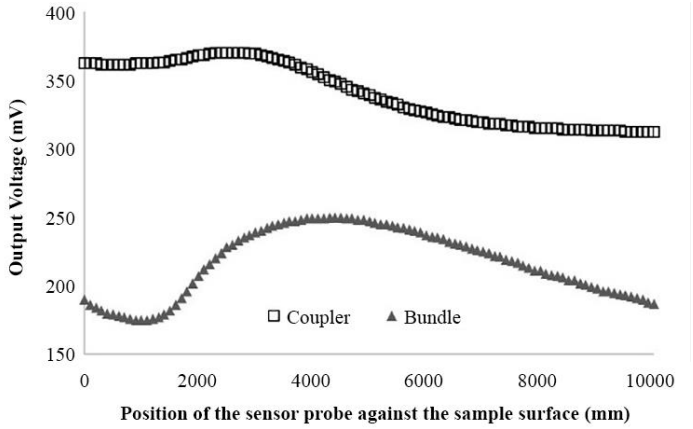

Figure 4. Graph of detector output voltage data as a function probe to the sample surface.

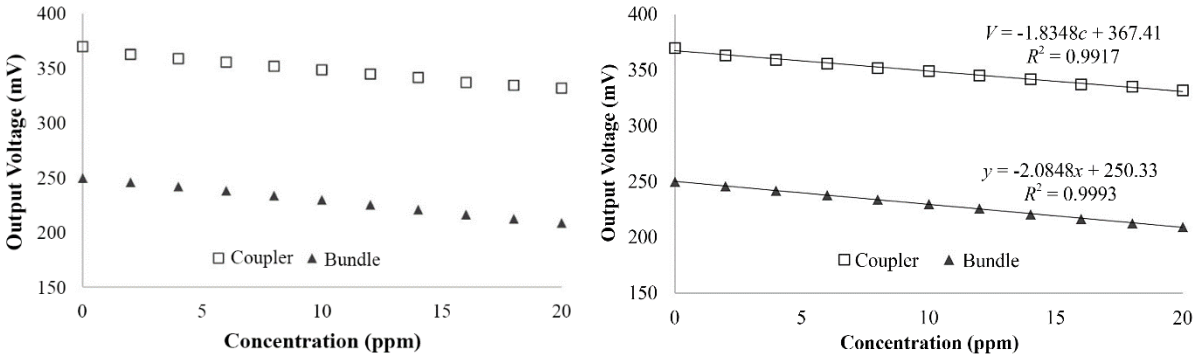

Figure 5. (a) The detection of rhodamine B concentration in distilled water and (b) linear regression test results of detector output voltage data on the concentration of rhodamine B in distilled water using a fiber coupler and fiber bundle.

Experimental detection of rhodamine B concentration in distilled water using a fiber coupler and fiber bundle resulted in data in the form of detector output voltage against the tested rhodamine B concentration. The data is shown in the graph in Figure 5. The experiment was repeated three times, resulting in the most significant deviation of the detector output voltage data (ΔV) of 0.6 mV, each using a fiber coupler and fiber bundle. The data in Figure 5a shows that the greater the concentration of rhodamine B, the smaller the output voltage of the detector produced. As explained in the previous section, the working principle of the rhodamine B concentration sensor is based on the sample's absorption of the light that passes through it [13]. On the other hand, the output voltage of the detector represents the intensity or optical power of the light detected by the optical detector. Because the light beam that enters the optical detector is a light beam after passing through the sample, the greater the sample concentration, the greater the absorbed light beam. As a result, the smaller the light beam that enters the optical detector, the smaller the output voltage of the optical detector [18]–[20].

The results of the linearity test between the detector output voltage data and the concentration of rhodamine B in distilled water are shown in Figure 5b. Thus, the sensor sensitivity values are 1.8 mV/ppm and 2.1 mV/ppm for using a fiber coupler and fiber bundle, respectively. The ratio of the deviation value of the detector output voltage measurement data to the sensor sensitivity value is used to determine the sensor resolution value [10], [11], [21]. Thus, the resulting sensor resolution values are 0.33 ppm and 0.29 ppm for the fiber coupler and fiber bundle, respectively.

Sensor stability test results obtained detector output voltage data as a function of time with a measurement interval of 30 seconds and a test duration of 15 minutes. The results are shown in the graph in Figure 6. The standard deviation values for 0 ppm, 10 ppm, and 20 ppm concentrations are 0.18 mV, 0.38 mV, and 0.26 mV for using a fiber coupler and 0.15 mV, 0.32 mV, and 0.32 mV for the use of fiber bundles, respectively. With the resulting standard deviation value below 1 mV, which is the smallest value detected by the experimental device used and the voltage order reads hundreds of mV, the stability of the sensor can be said to be very good.

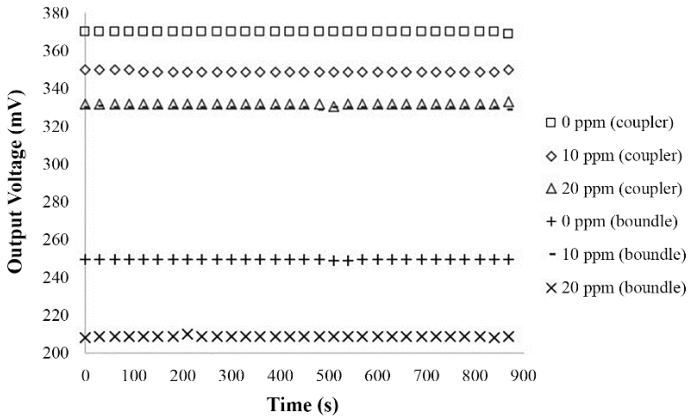

Figure 6. Graph of sensor stability test data using fiber coupler and fiber bundle.

Table 1. Characteristics of the rhodamine B concentration sensor using a fiber coupler and fiber bundle.

Parameter	Value	
	Coupler	Bundle
Sensor range (ppm)	0–20	0–20
Linear region (ppm)	0–20	0–20
Linearity (%)	99	99
Sensitivity (mV/ppm)	1.8	2.1
Resolution (ppm)	0.33	0.29

Overall, the performance of the rhodamine B concentration sensor in distilled water using a fiber coupler and fiber bundle is shown in Table 1. From the data in Figure 5, the difference in performance is seen in the sensitivity and resolution of the sensor. For these two parameter values, the sensor's performance using a fiber bundle is better than using a fiber coupler when detecting the concentration of rhodamine B in distilled water. However, the difference between the two is pretty slight. This not-too-big difference occurs because the working principle of the two sensors is the same, namely based on the sample absorption of the light that passes through it [5], [23]. In addition, the refraction of light by the sample does not occur because the change in the concentration of the sample being tested is tiny, so the refractive index of the sample is constant. Compared with the performance of the same sensor but based on the shift sensor [10], [11], the sensor's performance with the probe made static is also similar. So, placing the probe in a static state will make the sensor performance more efficient regarding data retrieval time and the amount of data that must be measured.

4. Conclusion

The method of detecting the concentration of rhodamine B in distilled water using a fiber coupler and fiber bundle as a probe with a static position and not in direct contact with the sample has similar performance results. A slight difference occurs in the sensitivity and resolution of the sensor. The resulting sensitivity values are 1.8 mV/ppm and 2.1 mV/ppm for using a fiber coupler and fiber bundle, respectively. At the same time, the resulting resolution is 0.33 ppm and 0.29 ppm for using a fiber coupler and fiber bundle, respectively.

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