Back scattering method

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Back scattering method based-plastic optical fiber coupler viscosity sensors

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Back scattering method based-plastic optical fiber coupler viscosity sensors

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Abstract. Viscosity determination is necessary in variety of applications such as evaluation of environmental pollution, chemical analysis, and as a material quality assessment. Optical fiber-based viscosity sensors are interested since it has various advantages compared to conventional viscosity sensors such as free from electromagnetic interference, compact and could be applied in hazard environment. This study aims to study the performance of back scattering method based viscosity sensor using optical coupler. The sensor design consists of 2×2 plastic optical fiber coupler connected with un-cladded POF as sensor head (sensor A). Characterization was done by connecting 660 nm LED as light source to the one of the coupler branch and an Ocean Optic USB4000 spectrometer to the other branch as light detector. Meanwhile, the sensor head was immersed in glycerin solution. The glycerin solution concentration was varied for various concentration which are 40%, 50%, 60%, 70%, and 80%. Sensor head without the use of optical coupler was fabricated and characterized as comparison (sensor B). The results show that sensor A has a better performance compared to sensor B in terms of linear range. The sensitivity of sensor A is -0.88584 dB /mPa.s at working range of 8.765-57.265 mPa.s with a correlation coefficient of 95.72%.

1. Introduction

Viscosity determination was very important, especially for the industrial application. In the petroleum industry, viscosity measurements are commonly carried out to determine oil quality [1]. Meanwhile, in the health industry it was used for the treatment of several diseases, one of which was vascular-related diseases [2]. Viscosity measurement can be done using a capillary tube and rotating, but this method requires a large number of samples and a long process [3], expensive, cannot detect viscosity in real time continuously [4], and requires special training to be able to use these tools [5].

Due to the drawbacks of the conventional methods above, various optical fiber-based viscosity sensors have been developed. Optical fiber sensor is attractive since it has various advantages such as very small size, passive, resistant to electromagnetic interference, low-power, high sensitivity, lightweight, and environmental ruggedness [6]. Nowadays, research on the use of optical fiber as a viscosity sensor has been carried out by several researchers by applying various methods. Wu et al., [2] adapted a quartz thickness shear mode sensor to measure viscosity. Lu et al., [7] have conducted viscosity monitoring with a piezoelectric-excited membrane device using the polyvinylidene fluoride (PVDF) membrane's resonant frequency and quality factor responses. In the same year, a similar study was also carried out by Purohit et al., [8] by applying a piezo-resonator disc radial mode for the determination of the ultrasonic viscosity of fluids by correlating changes in resonant frequency with viscosity. Meanwhile, Yunus and Arifin [9] using gamma configuration to develop an optical fiber viscosity sensor. However, these methods still have many weaknesses, such as inaccurate estimation, lack of analytical models, complex calibration procedures, and low range of viscosities [10].

In this study, we propose back scattering method based viscosity sensor using optical coupler. The novelty of this research was the combination of the optical coupler principle with back scattering in a fiber optic-based viscosity sensor design. The advantages of this method is the easy and fast fabrication process. Other than that, the light interference effect that occurs on an optical coupler is expected to improve the performance of the plastic optical fiber (POF) sensor in detecting parameters in the form of viscosity.

Basically, the principle of the coupler was used the effect of optical power transfer between optical fibers that are at such a close distance. The sensing mechanism on this sensor is that the light guided through the coupler will undergo an optical power transfer process with other waveguides (POF). Furthermore, the light will interact with glycerin and experience scattering. The level of glycerin viscosity will affect the total internal reflection process which occurs due to differences in critical angles in the medium. The results of the trend in the value of the light intensity after this process are used to measure the viscosity.

2. Methods

This study used a multimode type of POF. The viscosity sensor was fabricated into two designs, namely a sensor with 2×2 POF coupler connected with un-cladded POF as sensor head (sensor A), and sensor head without the use of optical coupler as comparison (sensor B). The design of the two viscosity sensors are shown in Figure 1.

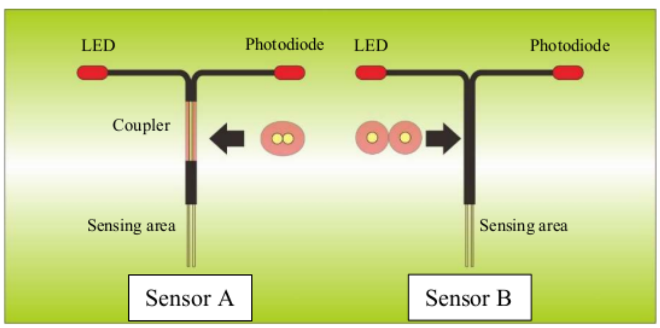

Figure 1. Viscosity sensor based on POF

The sensor fabrication process begins with a chemical etching process using acetone [11]. The aim was to remove the cladding covering the optical fiber core so that the sensing process can take place optimally. The next step was making a coupler using the fused biconical tapered (FBT) method, by gluing certain parts together using dextone epoxy adhesives, then wrapping them with thread. The results of the POF-based viscosity sensor fabrication are shown in Figure 2.

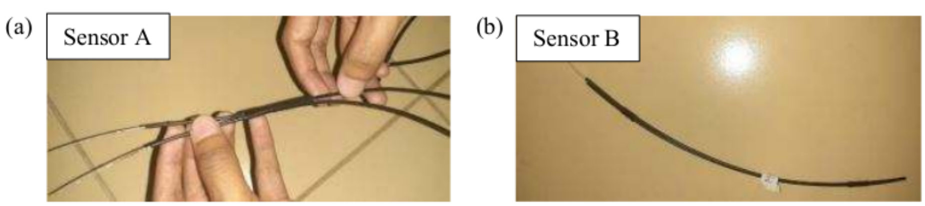

Figure 2. POF-based viscosity sensor: (a) sensor A and (b) sensor B

Next is the characterization process. Characterization was done by connecting 660 nm LED as light source to the one of the coupler branch and an Ocean Optic USB4000 spectrometer to the other branch as light detector. Characterization was carried out using a simple setup as shown in Figure 3.

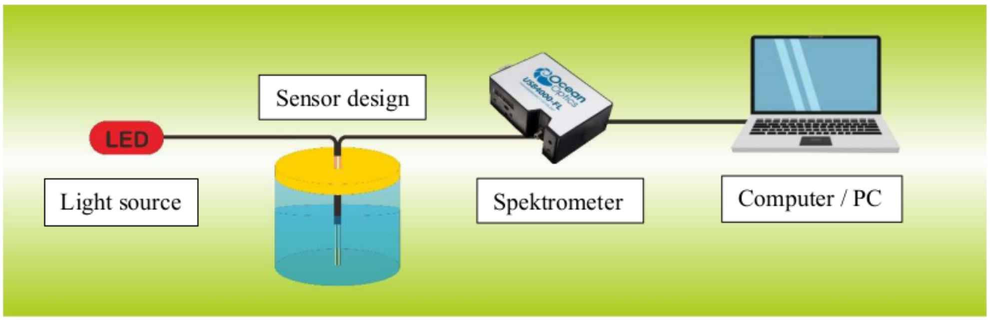

Figure 3. Characterization setup

The characterization was carried out by immersing the sensor in to glycerine solution with various concentration, which are 40%, 50%, 60%, 70%, and 80%. The solution was characterized using BDV-5S (NDJ-5S) to determine the viscosity value of each concentration. The viscosities of the glycerin solutions are shown in Table 1.

Table 1. The viscosity value of glycerin solution

Glycerin solution	Viscosity (mPa.s)
40%	8.765
50%	9.600
60%	15.750
70%	25.815
80%	57.265

3. Results and Discussion

The success rate of the etching process greatly affects the coupler fabrication result. It was because the etching process aims to remove the core casing which can interfere with the light transmission process, considering that the coupler will have an interfering effect between POF's. The POF image used as a coupler after the etching process in this study is shown in Figure 4.

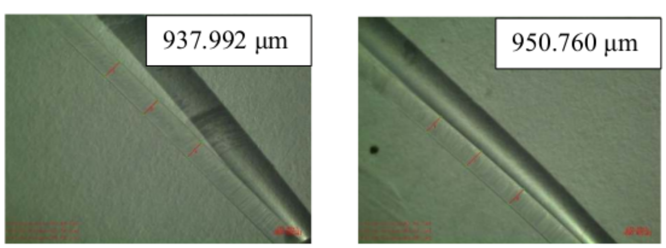

Figure 4. Image of POF core after the etching process

Based on Figure 4, it can be said that the etching process in this study was successful. It was because the diameter core at the POF used in this study was 980 ± 60 μm. It is means that the light transmission process and the interfering effect between POF can run well because the sheath material in the form of a fluorinated polymer that previously covered the core (polymethyl methacrylate) has totally lost. The nice result of the etching process in this research was inseparable from the accuracy in determining the length of the etching process. The etching process cannot be done carelessly because of the characteristics of the POF cores which were easily brittle if they are soaked in acetone for too long. One way to determine the length of the etching process was whit to first calculate the etching rate (e). The etching process in this study was carried out for 83 second because the amount of etching rate obtained was 0.24 μm/second.

The output spectrum of the sensors is shown in Figure 5. Based on the graph in Figure 5, it is shown that the wave spectrum of the two types of POF sensors have a wavelength shift. The shift occurs in the peak section. This shift was caused by a change in the propagation angle when light propagates through a medium with different refractive index [12]. The refractive index value of a material was strongly influenced by the interaction between the electromagnetic field of the propagation wave and the atom, and the way of electromagnetic field was attached in material [13]. Sensor A and sensor B experienced a wavelength shift of 15.88 nm and 10.21 nm, respectively. Figure 5 does not only show wavelength shift, but also decrease of intensity. The decrease in light intensity is due to the results of light scattering by the glycerin surface at a certain distance, some can be captured optimally and some cannot be captured optimally by the optical fiber receiver.

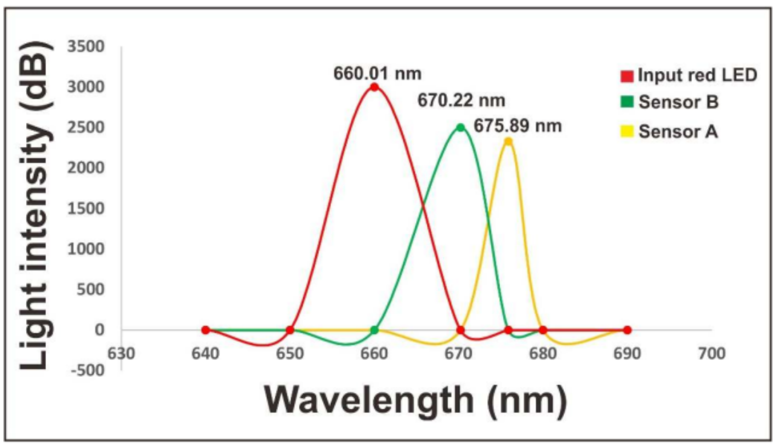

Figure 5. The output spectrum of the sensors at solution with viscosity of 9.600 mPa.s

Meanwhile, the characterization of the performance sensitivity of the two sensors shows a significant result. The characterization results are shown in Figure 6. Based on the graph in Figure 6 (a), it can be show that sensor A, which was a sensor with 2×2 POF coupler connected with un-cladded POF as sensor head, has a linear response at a concentration 8.765 mPa.s until 57.265 mPa.s with a correlation factor of 95.72%. The sensitivity value of sensor A is -0.8584 dB/mPa.s. Meanwhile, the linear response of the sensor B is shown by the graph in Figure 6 (b). The graph shows that sensor B, which was a sensor without a coupler, at concentrations of 9.600 mPa.s until 15.750 mPa.s with a correlation coefficient 100%. The sensitivity value of sensor B was -25.167 dB/mPa.s. Thus, it can be said that the sensitivity of sensor B was better than sensor A, but, sensor A is prone to wider linearity than sensor B. A good sensor is a sensor that has a wide linearity range. The wider the linearity range, it shows that the sensor can be applied for a wider variety of measurements. However, both sensors produce a negative response gradient. That means, the higher the glycerin viscosity, the less light intensity will be transmitted through the POF sensor. The decrease in light intensity that occurs was possible due to attenuation that occurs due to disruption of the light transmission process by the presence of attractive forces between glucose molecules. The attraction between molecules was closely related to the concentration of glucose, where the attraction between molecules in a fluid will be greater if the viscosity of the fluid was also higher [14].

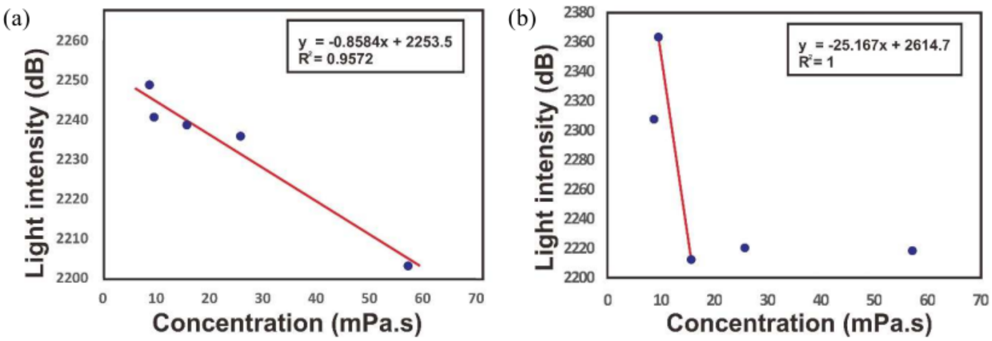

Figure 6. Graph linear response to the light intensity concentration of glycerin on: (a) sensor A (b) sensor B

Based on the description above, it can be seen that sensor A has a better performance than sensor B in terms of linear range. Sensor B has linear response at all of concentration used in this study. The optical coupler will cause the light interference effect that occurs in each POF [15]. Interference will occur between the guided light and the evanescent light from the adjacent POF. The interference varies as a function of propagation distance [16]. The process of light interference in the optical coupler causes the sensor to work in a wide viscosity range.

4. Conclusion

Based on the research that has been done, it can be concluded that the addition of a coupler to the POF based viscosity sensor can improve sensor in terms of linear range. The addition of a coupler can cause the light distribution process to run well so that it can increase the sensitivity of the sensor.

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PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7