Design of Oil Viscosity Sensor Based on Plastic Optical Fiber

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Abstract. A research of plastic optical fiber based sensors have been studied for measurement of oil viscosity. This sensor was made with straight configuration, U configuration, and gamma configuration have two types, there are optical fiber sensor with cladding and without cladding. Viscosity sensor was made, dipped into an oil sample with a concentration of viscosity percentage about 270 mPa.s – 350 mPa.s. The light from the LED propagated into the optical fiber, then it was received by the photodetector converted to output power. When plastic optical fiber dipped into an oil sample, viscosity of oil affect increase of refractive index on optical fiber resulting in a bigger loss of power so the light intensity will be smaller, consequences the measured output power will be smaller. Sensitivity and resolution viscosity sensor without cladding peel showed the best result rather than viscosity sensor with cladding peel. The best result in the measurement showed in gamma configuration with 3 cm length of cladding peel and the diameter of bending 0.25 cm is the range 103,090 nWatt, sensitivity 1,289 nWatt/mPa.s, and resolution 0,776 mPa.s. This method is effectively and efficiently used as an oil viscosity sensor with high sensitivity and resolution.

1. Introductions
The rapid development of science and technology in the field of electronics and instrumentation has made possible measurements that work precisely and practically. Optical fiber is developed towards a sensor system that can be used for the measurement of various types of physical variables [1]. Scientists have developed many optical fiber based sensors as versatile sensors with advantages such as not using electrical signals, low noise due to no interference with electromagnetic waves, high sensitivity and measurement accuracy, smaller size and lighter, and can be connected with communication systems data via interface device [2]. Application of optical fiber as a sensor one of them can be used to measure the level of oil viscosity. Optical fiber has many advantages such as speed, resistance to rusting, and relatively affordable price [3].

The testing on plastic optical fiber as a sensor has been made in various applications such as detecting UV radiation [4], temperature measurement [5]. In the application the measurement of the solution concentration level [6], water turbidity [7], in load measurements [8, 9], to the application of viscosity sensors on engine oil [10]. So far, the testing of optical fiber as the oil viscosity sensor has been done by using the method of peeling and bending on the fiber optic sensor. This method is used to measure the refractive index of oil on the effect of temperature on oil viscosity. The disadvantage of this method is to use only one type of oil and one type of sensor model, having a more complex measurement process and a more difficult manufacturing process so that the resulting data is not very varied in the determination of sensor characteristics [11].

Based on the results of previous researchers above, it will be developed about the determination of the characteristics of plastic optical fiber sensor to the variation of the level of oil viscosity. The
novelty of this study is using gamma configuration, it is expected to produce better sensitivity and sensor resolution. The advantage of this oil viscosity sensor is to measure the level of oil viscosity more accurately with a simple measurement system, easy fabrication, low cost, and can be connected with other measurement system devices.

2. Experimental SET-UP
In the design study for the oil viscosity sensor uses a circuit of power supply ± 12 volt and 5 volt as a source of electrical voltage to power the light source. The light source used is the IF-E91A infrared LED that transmits light at a wavelength of 950 nm. While the light receiver uses photodetector type S120C with wavelength 400-1100 nm and power range 50 nW-50 mW at Optical Power Meter (OPM). Both ends of optical fiber are connected with LED and photodetector. The optical fiber used is made of polymethyl metacrylate (PMMA) polymethyl metacrylate (PMMA) plated fiberglass optical fiber with coat, cladding, and core diameters of 2.2 mm, 1 mm, and 0.98 mm, respectively. The refractive index of the core and cladding of the plastic optical fiber are respectively $n_{\text{core}} = 1.492$ and $n_{\text{cladding}} = 1.402$ with numerical on slot value $NA = 0.5$. The oil samples of the Mesran SAE 20W-40 and 20W-50 with various mixtures yielding 10 samples and having viscosity variation from 270 mPa.s to 350 mPa.s. The viscosity of oil is measured using a viscometer.

The schematic circuit of oil viscosity sensor based on plastic optical fiber shown in figure 1. The sensor is made with 3 configurations is the straight, U and gamma configurations shown in figure 2. Each configuration is made by varying the length of peeling and the diameter of bending with cladding and without cladding.

Figure 1. Schematic circuit of oil viscosity sensor based on optical fiber plastic.

Figure 2. (a) The straight configuration, (b) the U configuration of the length of peeling variation, (c) the U configuration of the diameter of bending variation, (d) the gamma configuration of the length of peeling variation, (e) the gamma configuration of the diameter of bending variation.

The working principle of oil viscosity sensor based on optical fiber based on figure 1 is that LED light is transmitted through plastic optical fiber and received by photodetector, then forwarded to the
amplifier and will be read on OPM and computer. Changes of oil viscosity levels causes a change in the refractive index of oil around the sensor. The higher of the oil viscosity causes the higher of refractive index. This will cause the loss of power be increases and the sensor output power be decreases.

3. Result and Discussion
The results obtained in this study, optical fiber are made as oil viscosity sensors in straight, U, and gamma configurations with cladding and without cladding. Each sensor configuration of the length of peel is made at 1 cm, 2 cm, and 3 cm. The sensor is dipped into an oil sample at 10 different viscosity levels. The measured results on OPM are the sensor output power to oil viscosity for straight configuration in the length of peel variation as shown in figure 3 below:

![Graph of the changes output power sensor on the oil viscosity of the straight configuration](image)

Figure 3 shows the response changes the output power of the straight configuration sensor. Increased levels of oil viscosity results in decreased output power. The graph illustrates the characteristics of the oil viscosity sensor based on plastic optical fiber. Characteristics of sensor can be analyzed using the calculation of output voltage range values, sensitivity, and resolution. The value of the output voltage range for the sensor is determined using the following equation [8, 12]:

$$\Delta = V_{\text{max}} - V_{\text{min}}$$

With $V_{\text{max}}$ as the output voltage at maximum viscosity and $V_{\text{min}}$ as the output voltage at minimum viscosity.

Sensitivity of the sensor is a measure to find out how much sensor sensitivity to the quantity of a measured solution. The sensitivity of the oil viscosity sensor can be measured using the following equation [8,12]:

$$S = \frac{V_{\text{max}} - V_{\text{min}}}{K_{\text{max}} - K_{\text{min}}}$$

Next calculate the sensor resolution to know the value of the smallest quantity that can be measured by the viscosity sensor. The sensor resolution of the oil viscosity can be measured using the following equation [8,12]:

$$R = \frac{N}{S}$$

With N as the smallest scale value of the Optical Power Meter used is 0.001 μWatt and S is the sensitivity value of the oil viscosity sensor.
Determination of oil viscosity sensor characteristics for each configuration can be known by using the above equation. Characteristic of oil viscosity sensors for straight configuration can be seen in Table 1 below:

| Characteristics of Sensor | With Cladding | Without Cladding |
|---------------------------|---------------|------------------|
|                           | 1 cm | 2 cm | 3 cm | 1 cm | 2 cm | 3 cm |
| Output Power Range (nW)   | 11,000 | 17,000 | 20,000 | 32,000 | 44,000 | 55,000 |
| Sensitivity (nW/mPa.s)    | 0,138 | 0,212 | 0,250 | 0,400 | 0,550 | 0,688 |
| Resolution (mPa.s)        | 7,273 | 4,706 | 4,000 | 2,500 | 1,818 | 1,455 |

Table 1 shows the calculation of range, sensitivity, and resolution of variations in length of the peel sensor with cladding and without cladding. Can be seen that the range, sensitivity, and resolution of the sensor the better with the length of peel be increase. The best results were obtained on the length of peel at 3 cm without cladding, sensitivity 0,688 nW/mPa.s and resolution 1,455 mPa.s.

The oil viscosity sensor based on plastic optical fiber on U configuration of the length of peel variation and the diameter of bending using the same sample with oil viscosity sensor in straight configuration. The same way of testing is by dipping the sensor into the sample at different viscosities. The result of the testing of the oil viscosity sensor based on plastic optical fiber for U configuration is shown in figure 4 below:
Figure 4 shows the response changes output power sensor of U configuration. Increasing of the oil viscosity level causes result in decreasing output power. The characteristics of oil viscosity sensor on U configuration can be seen in the following table 2 and table 3:

**Table 2. Characteristics of oil viscosity sensor on U configuration for the length of peel variation.**

| Characteristics of Sensor | With Cladding | Without Cladding |
|---------------------------|---------------|------------------|
|                           | 1 cm          | 2 cm             | 3 cm |
| Output Power Range (nW)   | 12,600        | 53,100           | 69,400 |
| Sensitivity (nW/mPa.s)    | 0.158         | 0.664            | 0.868 |
| Resolution (mPa.s)        | 6,349         | 1,506            | 1,153 |
|                           | 1 cm          | 2 cm             | 3 cm |
| Output Power Range (nW)   | 56,216        | 78,130           | 87,214 |
| Sensitivity (nW/mPa.s)    | 0.703         | 0.977            | 1,090 |
| Resolution (mPa.s)        | 1,423         | 1,024            | 0.917 |

**Table 3. Characteristics of oil viscosity sensor on U configuration for the diameter of bending variation.**

| Characteristics of Sensor | With Cladding | Without Cladding |
|---------------------------|---------------|------------------|
|                           | 1 cm          | 2 cm             | 3 cm |
| Output Power Range (nW)   | 69,400        | 66,900           | 38,000 |
| Sensitivity (nW/mPa.s)    | 0.868         | 0.836            | 0.475 |
| Resolution (mPa.s)        | 1,153         | 1,196            | 2,105 |
|                           | 1 cm          | 2 cm             | 3 cm |
| Output Power Range (nW)   | 87,214        | 75,881           | 56,820 |
| Sensitivity (nW/mPa.s)    | 1,090         | 0.948            | 0.710 |
| Resolution (mPa.s)        | 0.917         | 1,054            | 1,408 |

In table 2 shows the values of range, sensitivity, and resolution of sensors affected by the length of peel variation with cladding and without cladding. The longer of the peel sensor has results of the sensor characteristics will be better. The best sensor characteristics were obtained on a 3 cm peel. While table 3 on at 3 cm constant length of peel indicates that the diameter of bending affects the sensor characteristics. The smaller the diameter of bending sensor causes the higher the range and sensitivity of the sensor and the smaller the resolution sensor. The best measurements of the U configuration are shown in 3 cm length of peel and 3 cm in diameter of bending without cladding, with a sensitivity value of 1,090 nW/mPa.s and a resolution of 0.917 mPa.s.

Testing of oil viscosity sensor based on plastic optical fiber on gamma configuration with cladding and without cladding using the length of peel and the diameter of bending variation sensor. The test results of the oil viscosity sensor based on plastic optical fiber in gamma configuration are shown in figure 5 below:
In figure 5 for the measurement on gamma configuration in the length of peel and diameter of bending variations with cladding and without cladding indicates that the sensor without cladding has the highest change of output power response compared to the sensor with cladding. Characteristics of the gamma configuration oil viscosity sensors are shown in the following table 4 and table 5:

**Table 4.** Characteristics of oil viscosity sensor on gamma configuration for the length of peel variation.

| Characteristics of Sensor | With Cladding (cm) | Without Cladding (cm) |
|---------------------------|--------------------|-----------------------|
|                           | 1 cm | 2 cm | 3 cm | 1 cm | 2 cm | 3 cm |
| Output power Range (nW)   | 22,000 | 35,700 | 39,200 | 23,046 | 37,406 | 49,987 |
| Sensitivity (nW/mPa.s)    | 0,275 | 0,446 | 0,490 | 0,288 | 0,468 | 0,625 |
| Resolution (mPa.s)        | 3,636 | 2,241 | 2,041 | 3,471 | 2,139 | 1,600 |

**Table 5.** Characteristics of oil viscosity sensor on gamma configuration for the diameter of bending variation.

| Characteristics of Sensor | With Cladding (cm) | Without Cladding (cm) |
|---------------------------|--------------------|-----------------------|
|                           | 0,25 cm | 0,50 cm | 0,75 cm | 0,25 cm | 0,50 cm | 0,75 cm |
| Output power Range (nW)   | 76,400 | 51,600 | 20,400 | 103,090 | 55,206 | 29,201 |
| Sensitivity (nW/mPa.s)    | 0,955 | 0,645 | 0,255 | 1,289 | 0,690 | 0,365 |
| Resolution (mPa.s)        | 1,047 | 1,550 | 3,922 | 0,776 | 1,449 | 2,739 |

The results of the measurements in table 4 show the range values, sensitivity and resolution of the sensors affected by in the length of peel variation with cladding and without cladding. While in table 5 for variations in the diameter of bending sensor shows that the smaller of the diameter of bending sensor better the characteristics of sensor. The best results were obtained on sensors without cladding at the length of peel 3 cm with the diameter of bending 0,25 cm is sensitivity value of 1,289 nW/mPa.s and resolution of 0,776 mPa.s.

Testing of oil viscosity sensors in straight, U, and gamma configurations obtained response changes values of varying the power output sensor. The best of output power sensor change response of the various configurations is shown in figure 6 below:


**Figure 6.** Graph of the changes output power sensor on oil viscosity with various configurations (a) with cladding, (b) without cladding.

In figure 6 shows the result of various configurations sensor at a constant length of peel 3 cm. It can be seen that the sensor without cladding has the highest output power changes response compared to the sensor with cladding. The characteristics of the oil viscosity sensor of various configurations are shown in table 6 below:

| Characteristics of Sensor | With Cladding (nW) | Without Cladding (nW) |
|---------------------------|--------------------|-----------------------|
|                           | Straight  | U         | Gamma      | Straight  | U         | Gamma      |
| Output power Range (nW)   | 20,000    | 69,400   | 76,400     | 55,000    | 87,214   | 103,090    |
| Sensitivity (nW/mPa.s)    | 0.250     | 0.868    | 0.955      | 0.688     | 1.090    | 1.289      |
| Resolution (mPa.s)        | 4,000     | 1,153    | 1,047      | 1,455     | 0,917    | 0,776      |

From figure 6 and table 6 are a composite result of straight, U, and gamma configuration sensor of the length of peel 3 cm with cladding and without cladding. The graph illustrates the characteristics of the sensitivity sensor. The best characteristic was obtained in the gamma configuration sensor without cladding of length of peel 3 cm and diameter of bending 0.25 cm sensor has results the range 103,090 nWatt, sensitivity 1.289 nWatt/mPa.s and resolution 0.776 mPa.s.

The results of this study has consistent with result of previous studies on mixing the concentration of glycerin solution to water using on U configuration based on plastic optical fiber sensor for measuring the transmission of sensor output power using OPM. Increasing the glycerin solution to the water solution results in a refractive index of the solution increasing so that the sensor output power decreases [6]. Likewise, on the measurement of water turbidity using a straight configuration based on plastic fiber optic sensor. The increased concentration of water turbidity causes the refractive index of the solution to increase so that the sensor output voltage decreases [7]. The use of plastic optical fiber sensors for straight configuration on increasing the concentration of sugar and salt solution to water causes the refractive index of the solution to increase and the lost power value is greater [13]. Neither the suitability is the smaller the diameter of bending sensor causes the sensitivity and resolution of the sensor the better [8]. So in this research has experimented the measurement of sensor output power to the level of oil viscosity based on plastic optical fiber sensor using straight configuration and U configuration with a novelty method using gamma configuration. The results show that the best characteristics of sensor are obtained on gamma configuration on plastic optical fiber sensors compared with straight and U configurations. The advantage of this method is that it has a simpler measurement and easy fabrication.
4. Conclusion
The results showed that the change of sensor output power is inversely proportional to the level of oil viscosity. The higher of oil viscosity levels causes the output power decreases. The longer of peel sensor and the smaller the diameter of bending sensor causes result sensitivity and resolution sensor the better. The result of the measurement of oil viscosity sensor based on plastic optical power shows that the gamma configuration sensor without cladding length of peel 3 cm and diameter of bending 0.25 cm has the best result output power range, sensitivity and resolution is range 103,090 nWatt, sensitivity 1.289 nWatt/mPa.s, and resolution 0.776 mPa.s compared with straight and U configurations.

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