Analysis effect of temperature changes on measurement of oil viscosity based on plastic optical fibres sensor and microcontroller

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Abstract. Testing of sensor based on plastic optical fiber can be applied to analyze the effect of temperature changes on the measurement of oil viscosity. This measurement uses gamma configuration at length of 3 cm peel on a plastic optical fiber sensor with cladding and without cladding. Testing of sensor on measurement of oil viscosity is using a microcontroller to determine the effect of temperature on the sensor output voltage. The output voltage of the differential amplifier in the form of an analog signal converted to a digital signal by the microcontroller and displayed on the computer. The output voltage increases with the increase of temperature changes occurring in the oil sample. The best results were obtained on sensor without cladding with the value 4.85 mV/oC. Measurement of the effect of temperature changes on oil viscosity based on plastic optical fiber sensor has advantages such as simple measurement system, low cost, easy fabrication and can be connected to computer.

1. Introductions
Advances in computer and microcontroller technology are so rapidly having more productive and effective results in manufacturing systems. Microcontroller is an electronic and hardware device consisting of a chip that can perform data processing digitally in accordance with the assembly language command that is used for the development of a research. The advantages of the microcontroller that consists of processors, memory, input and output integrated in a single control system arranged in single chip so that it can work innovatively in accordance with the needs of the system [1,2].

Microcontroller is widely applied as one of the electronic devices in testing the sensor. Nowadays, testing the sensor using a microcontroller highly developed is sensor based on optical fiber. Optical fiber sensor have advantages such as small, lightweight, resistant to electromagnetic interference, resistant to harsh environments and have the ability to perform distributed sensing [3,4]. Optical fiber consists of two based on the type of material, namely plastic optical fiber and glass optical fiber. Plastic optical fiber is cheaper, resistant to electromagnetic interference, as well as suitable for use as sensing devices compared to glass optical fiber [5].

There are several studies that utilize fiber optics as sensors. One example is the development of oil viscosity sensor based on plastic optical fiber [6]. Research on fiber optic sensor testing for Lossy Mode Resonances (LMR) based synthetic oil applications and temperature measurements by utilizing the refractive index of oil using single-mode fiber optic configuration [7,8]. In addition, the testing of optical fiber sensor to measure oil viscosity has also been studied using the method of peel and bend...
on optical fiber structures. This method used to determine the refractive index value of oil viscosity based on the effect of temperature [9]. The weakness of the method of some of these studies is to have complex measurement processes, difficult fabrication processes, low sensitivity, and very expensive prices.

In this research, the development will be done such as design, fabrication, testing, and measurement of oil viscosity sensor based on plastic optical fiber. The novelty of this research is the testing of oil viscosity sensor using the effect of temperature changes method based microcontroller. This method is expected to increase the loss of power on the fiber optic sensor and produce high sensitivity in a simple measurement system. The advantage of this method such as to measure the level of oil viscosity accuracy is more accurate, easy fabrication, real time, low cost, and can be connected to the computer.

2. Method
Measurement of the effect of temperature on oil viscosity sensor is using Arduino Uno microcontroller. Design and manufacture of the sensor includes the manufacture of the differential amplifier circuit and the power supply circuit is ± 12 Volt and 5 Volt as the source of electrical voltage. The sample used was lubricant oils 20W-40 and 20W-50 Mesran SAE types with various predetermined mixing concentrations up to 10 samples and had viscosity variation from 270 mPa.s to 350 mPa.s. The level of oil viscosity was measured using viscometer. The sample was heated using a magnetic stirrer type hot plat, while the temperature was measured using a thermometer.

Plastic optical fiber sensor of a step index type made of polymethyl metacrylate (PMMA) material having a coat diameter of 2.2 mm, a cladding of 1 mm, and a core of 0.98 mm. The core refractive index and cladding of these optical fibers are 1.492 and 1.402 respectively with numerical averture NA values of 0.5. The light transmitted on the optical fiber is sourced from the IF-E91A type infrared LED with a wavelength of 950 nm, then received by the IF-D92 type phototransistor and differential amplifier. The output voltage of the differential amplifier is analog signal converted to digital signal by Arduino Uno microcontroller and displayed on the computer. The schematic of test circuit of effect of temperature on oil viscosity sensor shown in figure 1 below:

![Figure 1. Schematic of testing circuit of effect of temperature on oil viscosity sensor](image)

The working principle of oil viscosity sensor based on optical fiber to temperature change that is light from LED propagate into plastic optical fiber, then accepted by phototransistor and differential amplifier. The output voltage of the differential amplifier is analog signal converted to digital signal by Arduino Uno microcontroller and displayed on the computer. Fiber optic sensors will experience power losses due to the addition of refractive index of oil when dipped in the oil sample, so that the initial voltage of the sensor decreased. However the output voltage will change when the sensor gets the temperature change that occurs in the oil sample. Increasing the temperature detected by the sensor results in output voltage displayed by the computer is increasing.
3. Result and Discussion

Testing of sensor based on plastic optical fiber using microcontroller on the measurement of oil viscosity sensor output voltage to determine the effect of temperature changes. The selection of sensor used in this method is the type of sensor that has the best characterization. Based on the results of tests that have been done by previous research, the best characterization of the sensor is using gamma configuration a 3 cm in the length of peel with a diameter of 0.25 cm [6]. So this configuration is used in the measurement using the method of temperature change. Measurements were made by dipping the sensor into the oils sample at viscosity of 270 mPa.s to 350 mPa.s. This method is using a constant temperature of 30°C, 35°C, and 40°C respectively. Further measurement is done by giving effect of temperature using magnetic stirrer heaters from temperature 30°C to 70°C. Measurements are limited to these temperatures because plastic optical fibers have an operating temperature of -45°C to +85°C. Intake of output voltage data is done at every temperature rise 5°C. Each measurement is performed using the same sensor for all types of oil viscosity, sensors with cladding and sensor without cladding. The result testing of the sensor based temperature changes shown in figure 2 below:

![Figure 2](image.png)

**Figure 2.** Measurements of the output voltage sensor (a) with cladding versus viscosity, (b) without cladding versus viscosity, (c) with cladding versus temperature, and (d) without cladding versus temperature.

Based on figure 2 (a) and figure 2 (b) are show that the output voltage decreases with increasing oil viscosity. Increased oil viscosity causes the refractive index of oil to increase, thus affecting the refractive index around the sensor is increasing. This causes the loss of power that occurs in the greater the sensor, so that the intensity of light received by the phototransistor decreases. Reduced
light intensity causes the output voltage to decrease. While in figure 2 (c) and figure 2 (d) indicates that the temperature rise causes the viscosity of the oil to decrease which causes the refractive index of oil to decrease. Refractive index of oil acts as a substitute for the cladding of the fiber optic sensor. When the refractive index of the cladding is decreasing, the critical angle at the core of optical fiber decreases as well. This event causes internal total reflection increases, so the intensity of light also increases. This proves that the increase in the temperature of the oil causes the intensity of light on the optical fiber is increased so that the resulting output voltage is also increasing. This study corresponds to previous research about temperature sensors based on optical fiber which states that the output voltage increases with increasing temperature rise [10, 11]. The measurement of oil viscosity using the effect of temperature based on plastic optical fiber and microcontroller is very suitable because it has simple measurement method, real time, easy fabrication, low cost, and can be connected with computer.

The relationship between output voltage with cladding and without cladding sensor, oil viscosity and temperature can be determined using a matrix of equation (1) as follows:

$$\begin{bmatrix} \Delta V_1 \\ \Delta V_2 \end{bmatrix} = \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} \begin{bmatrix} \Delta \eta \\ \Delta T \end{bmatrix}$$

Where, $\Delta V_1$ is the output voltage on the sensor with cladding and $\Delta V_2$ is the output voltage on the sensor without cladding. $\Delta \eta$ is oil viscosity, while $\Delta T$ is temperature. $K_{11}$ is the matrix coefficient for $\Delta V_1/\Delta \eta$, $K_{12}$ is the matrix coefficient for $\Delta V_1/\Delta T$, $K_{21}$ is the matrix coefficient for $\Delta V_2/\Delta \eta$, and $K_{22}$ is the matrix coefficient for $\Delta V_2/\Delta T$. Based on the result data from figure 2 (a)-(d), we can determine the coefficient data matrix of equation (2) as follows:

$$\begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} = \begin{bmatrix} -1.2 \pm 0.1 \text{ mV/mPa.s} \\ -2.4 \pm 0.3 \text{ mV/mPa.s} \end{bmatrix} \begin{bmatrix} 3.70 \pm 1.6 \text{ mV/$^\circ C$} \\ 4.85 \pm 0.75 \text{ mV/$^\circ C$} \end{bmatrix}$$

Hence,

$$\Delta V_1 = K_{11}\Delta \eta + K_{12}\Delta T$$

$$\Delta V_2 = K_{21}\Delta \eta + K_{22}\Delta T$$

Based on the data from equation (2), the largest slope value can be seen in the sensor without cladding is $K_{21} = -2.4 \pm 0.3 \text{ mV/mPa.s}$ for the relationship of output voltage to viscosity and $K_{22} = 4.85 \pm 0.75 \text{ mV/$^\circ C$}$ for the relation of output voltage to temperature. The value of the slope can be interpreted as sensitivity value of the sensor. When the output voltage with cladding and without cladding sensors can be measured simultaneously using a plastic optical fiber sensor, equations (3) and (4) can be used to determine oil viscosity and temperature.

4. Conclusion

In this research has successfully designed and manufactured sensors based on plastic optical fiber and microcontroller on the measurement of oil viscosity using the effect of temperature changes. The greater the temperature experienced in the oil, the greater the output voltage. The best sensor sensitivity is obtained in the without cladding sensor of $4.85 \text{ mV/$^\circ C$}$ for measuring the output voltage to temperature. This indicates that the sensor without cladding is better than the sensor with cladding.

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