Fabrication of Milk Fat Sensor based on Plastic Optical Fiber

F Angrasari1, A Arifin1 and B Abdullah1

1Department of Physics, Hasanuddin University, Makassar, 90245 Indonesian

*Corresponding author: fifi@anrasari1303@gmail.com, arifinpe@gmail.com

Abstract. The research about milk fat content based on plastic optical fiber sensor using gamma and spiral spring without cladding configurations has been reported. LED light transmitted through the plastic optical fiber to be received by the phototransistor. Changes in milk fat content affect the light intensity received by the phototransistor. Sensor output voltage amplified by a differential amplifier and then the analog signal converted into the digital signal by the Arduino Uno microcontroller furthermore, the output voltage read on a computer. The milk fat content sample with a percentage of 0.773 % to 4.473 % affect the propagation of light in the core of plastic optical fiber results in power losses that occur so that the light intensity decreases and the output voltage measured becomes smaller. The results showed that the higher the milk fat content, the sensor output voltage decreases. The best measurements obtained on the spiral spring configuration with 4 windings produce value range 0.044 V, sensitivity 11.887 mV/%, and a resolution of 0.084 %. This method is effective as well as efficiently used as milk fat sensor because it has good sensitivity and resolution.

1. Introduction
The last few years of research on biosensor has been developed as a sensor, one of the sensor application is the milk sensor. It can be used to monitor the milk quality by utilizing the biophysical properties contained like pH value [1]. Consideration of fat content percentage and the chemical structures of the milk have been investigated thoroughly by the refractive index, absorbance, and simple prisms as a substitute refractometer developed by using optical fiber as a sensor [2,3]. It uses is plastic optical fiber (POF). Some scientists have developed various types of POF as sensor with the advantages that no interference occurred with electromagnetic waves so that the noise can be minimized, its use without any electrical signal, lighter, accuracy, small size, and high sensitivity. Another advantage of the optical fiber consists of corrosion resistance, high light speed, and low cost [4,5].

The using of optical fiber as sensor can be made in several measurements, such as temperature and displacement sensors [6,7]. Besides, applications of optical fiber as sensor were used in the measurements of solution concentration levels, water turbidity, light intensity, preservative detection in milk, and testing of milk fat content (MFC) [8-12]. Testing of the MFC by using POF sensor has been carried out by using the methods of paring and bending. These methods used in the study presents POF sensor type-W to measure the MFC with evaluating all models at different temperatures and illustrates that the 40°C. It is the optimum temperature in the MFC. The weakness of the method was used one type of sensor model and measurement was done in a long process to maintain a stable temperature of the milk [10].

In this study, we will develop a milk fat sensor based on POF and different MFC levels. It affects the propagation of light in the core of POF and results in power losses. It is caused by changes in the
refractive index and bending so that the light intensity passing through the core of POF becomes smaller and the measured output voltage becomes smaller. The novelty of this research using gamma and spiral spring configurations, with the expectation produce the sensitivity value of the sensor is better. The advantage of milk fat sensor has simple measurement and fabrication, more economical, and can be used at different MFC levels.

2. Method
Milk fat sensor research based on POF made of polymethyl metacrylate (PMMA) step-index type. This type has diameters of layer core is 0.98 mm, cladding is 1 mm, and coat 2.2 mm. It functions as transfer media and sensing changes of light intensity. Core and cladding have a refractive index of 1.492 and 1.402 and the value of the numerical aperture (NA) of 0.5. In this study, design of MFC sensor by using the power supply ±12 V and 5 V. The power supply with 12 V is used as a voltage source for differential amplifier and 5 V as a power supply voltage source connected to the light source. LED IF-E91A types capable emitting light at a wavelength of 950 nm as light source. The phototransistor used is a detector IFD92 type of wavelength 400-1100 nm as light receiver. A phototransistor is connected to the differential amplifier, and then to the arduino uno microcontroller as a converted analog signal into a digital signal and displayed on the computer. Milk samples were used namely 500 ml of fresh cow’s milk which is divided into several samples with fat content varies from 0.773% to 4.473%. MFC measured by using Butyrometer and solvent extraction method.

Milk fat sensor circuit diagram based on POF is shown in Figure 1. Configuration of the sensor used for fat in milk, namely gamma and spiral spring configurations in Figure 2. At the gamma configuration made with varying diameters of 0.3 cm, 0.5 cm, and 0.7 cm land a peel length of a sensor made constant is 5 cm. At spiral spring configuration made constant is peel length and diameters, but the number of windings altered. The peel length used at spiral spring configuration is 5 cm, a diameter of 2.2 mm, with the number of windings are 2 windings, 3 windings, and 4 windings.

![Flowchart of milk fat sensor based POF](image1)

**Figure 1.** Flowchart of milk fat sensor based POF

![Gamma and spiral spring configurations](image2)

**Figure 2.** (a) Gamma configuration with variation in diameter, (b) spiral spring configuration with the variation in the number of winding
The working principle of milk fat sensor based on POF utilizing light intensity changes as a result of several varieties of MFC concentrations. LED transmits light through the POF to the phototransistor. Light received by the phototransistor produces an electrical signal in the form of the output voltage. The output voltage is amplified by the difference amplifier and then to the arduino uno microcontroller. In the next, arduino uno will change the output voltage of the analog signal form into a digital signal and it will be read on the computer.

3. Result and Discussion
In this study about milk fat sensor based on POF, measurements of MFC were carried out in various milk samples. Milk solutions are divided into several samples with a volume of 50 ml. The percentage of milk solution from 30% to 100% is based on mixing milk with aquades. 30% milk solution contains 15 ml of milk, 40% contains 20 ml of milk, 50% contains 25 ml of milk and so on to 100% with a 50 ml milk content. Furthermore, the milk solution was measured for MFC using a butyrometer with a solvent extraction method. The result of measuring MFC levels is shown in Figure 3.

![Figure 3. The graph percentage of measured fat content based on variations in milk solution](image)

Based on research that has been done, it has obtained the milk fat sensor based on POF in gamma and spiral spring configurations without cladding. The measurement process was carried out by using gamma configuration with variation in diameters and spiral spring configuration with the variation in a number of windings. Sensor output voltage changes in response to changes in MFC on the gamma configuration with variation diameters and spiral spring configuration with the variation in a number of windings shown in Figure 4.

![Figure 4. The graph the sensor output voltage changes in the MFC (a) gamma configuration and (b) spiral spring configuration.](image)
Great light intensity of received by POF bent at gamma and spiral spring configuration experiencing interference due to the bending and the refractive index of the sample, thus causing power losses in POF. The reduction of light intensity in POF is directly proportional to the power loss and output voltage if the MFC increases.

Calculation of sensor characteristics value were analyzed by using equations of range, sensitivity, and resolution. To determine the result of range value used equation (1) [4]:

$$\Delta = V_{\text{max}} - V_{\text{min}}$$  \hspace{1cm} (1)

With $V_{\text{max}}$ is the maximum voltage value in the MFC and $V_{\text{min}}$ is minimum voltage in the MFC.

The sensitivity of sensor is measurements to calculate the sensitivity of the sensor on measured a solution parameter. The equation used to calculate the value of the sensitivity of the sensor in equation (2) as following [4]:

$$S = \frac{V_{\text{max}} - V_{\text{min}}}{K_{\text{max}} - K_{\text{min}}}$$  \hspace{1cm} (2)

With $K_{\text{max}}$ is maximum MFC and $K_{\text{min}}$ is minimum MFC.

Next calculating the value of resolution is calculating the smallest value that measurable by sensor. Calculating of resolution using equation (3) as following [13]:

$$R = \frac{N}{S}$$  \hspace{1cm} (3)

With $S$ is sensitivity of the milk fat sensor and $N$ is smallest scale value of the microcontroller is 0.001 V. The measurement result of milk fat sensor as shown in Table 1.

Table 1. Characteristics of milk fat sensor on gamma configuration in diameters variation

| Sensor characteristics | d = 0.3 (cm) | d = 0.5 (cm) | d = 0.7 (cm) |
|------------------------|--------------|--------------|--------------|
| Range (V)              | 0.037        | 0.024        | 0.010        |
| Sensitivity (mV/%)     | 9.906        | 6.484        | 2.642        |
| Resolution (%)         | 0.101        | 0.154        | 0.379        |

Table 1 shows in calculating result of range, sensitivity and resolution on gamma configuration in diameter variations. It’s known that the smaller diameter distance on gamma configuration, the better of the value range, sensitivity, and resolution. The best sensor characteristic at a diameter of 0.3 cm compared on the diameter range at 0.5 cm and 0.7 cm. Milk fat Sensor at 0.3 cm in diameter gamma configuration shows the value of the best characteristics with the values range 0.037 V, sensitivity 9.906 mV/%, and a resolution of 0.101 %. The results of determination of range, sensitivity, and resolution on the gamma configuration in diameter variations using equation (1), (2), and (3) are displayed in Table 1.

Table 2. Characteristics of milk fat sensor on spiral spring configuration in the number of windings variation

| Sensor characteristics | 2 windings | 3 windings | 4 Windings |
|------------------------|------------|------------|------------|
| Range (V)              | 0.020      | 0.039      | 0.044      |
| Sensitivity (mV/%)     | 5.283      | 10.566     | 11.887     |
| Resolution (%)         | 0.189      | 0.095      | 0.084      |

In Table 2 shows that the number of windings in the spiral spring configuration affects the value of sensor characteristics. The greater the number of windings are used, then the value of the greater range and sensitivity and decreased the value of the sensor resolution. Characteristics of the best sensor
showed at spiral spring configuration is 4 windings with the value range of 0.044 V, sensitivity of 11.887 mV/%, and resolution of 0.084%.

Based on the results of the sensor characteristics of the two configurations are used, the best sensor characteristic values are spiral spring configuration at 4 windings compared to the gamma configuration. It is caused by the number of bending that occurs in POF thus affecting power losses in the sensor based on evanescent wave effect. The evanescent wave is a missing wave on waveguide in optical fiber [7]. The research conducted by Omer, et al (2016) about POF sensor to detect the quality of milk with low MFC reviewing gets the value of sensor resolution of 0.4% [9]. While in this research, we get the value of smaller sensor resolution is 0.084%. The smaller value of sensor resolution causes the good of sensor characteristic. Furthermore, Sensor based on POF is suitable for measuring the levels of MFC with good sensitivity and resolution.

4. Conclusion
The results showed that the greater the milk fat content used, the smaller the output voltage changes. Milk fat sensor based on POF in small diameter and the great number of windings will produce the best values of range, sensitivity, and resolution. The best measurement results of the milk fat sensor based on POF obtained on spiral spring configuration at 4 windings with a value range of 0.044 V, sensitivity of 11.887 mV/%, and resolution of 0.084%.

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