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Performance of Fiber Optics with Response Low Fat Milk and Full Cream Milk Towards Hydrogen Peroxide

Nurul Ain Mohad Yusoff Shah[1], Nurul Nadia Adnan[2]*, Nurul Athirah Mohd Taib[3]

[1] *Department of Physics and Chemistry, Faculty of Applied Sciences and Technology, University Tun Hussein Onn Malaysia, Pagoh Educational Hub,84600 Pagoh, Johor, Malaysia*
[2] *Photonics Devices and Sensor Research (PDSR), Department of Physics and Chemistry, Faculty of Applied Sciences and Technology, University Tun Hussein Onn Malaysia, Pagoh Educational Hub, 84600, Pagoh, Johor, Malaysia*
[3] *Faculty of Science and Technology, University Sains Islam Malaysia, Bandar Baru Nilai, 71800 Nilai, Negeri Sembilan, Malaysia*

*Corresponding Author: nadia@uthm.edu.my
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Abstract

A Fiber Optic Displacement Sensor (FODS) utilizing reflective intensity modulation to assess hydrogen peroxide concentrations in low-fat and full-cream milk. The chemiluminescence technique approach which is currently used to measure hydrogen peroxide concentration in milk, has limitations such as suffering from the interference of some cations, which may affect the accuracy of the detection process. Thus, an intensity-modulated based sensor composed of optical fiber was developed to determine the concentration of hydrogen peroxide in low-fat milk and full-cream milk. The developed transmissive optical sensor, focusing on the 0% - 10% range of hydrogen peroxide concentration. The sensor exhibits the performance with yielding a sensitivity of 0.008 V/% for low-fat milk with a linearity exceeding 97%, and 0.007 V/% sensitivity for full cream milk with a linearity surpassing 97%. The approach outlined offers a practical solution for assessing hydrogen peroxide levels, a potential adulterant and ensuring consumers' milk products' safety.

1. Introduction

The idea of reflecting light intensity modulation, which has numerous applications in the construction of fiber optic displacement sensors, serves as the basis for the optic fiber displacement sensor. For standard reflective intensity modulated fiber bundles, which comprise a single fiber for both the emitting and receiving fibers (EF and RF), the structure of the sensor is different [1]. Detection of liquid solution's concentration and refractive has been produced widely using various types of optical fiber sensor.

Milk and dairy products are a crucial source of nutrition for people of all ages, providing essential nutrients such as calcium and protein necessary for growth and development. In recent years, many people have turned to canned or bottled milk products as a more convenient option for instant consumption. These products often come in different forms, such as whole milk, reduced-fat milk, or skim milk, which contain varying fat levels. The two main types of milk are full - cream milk and low - fat milk. Full cream milk contains a higher percentage of fat, typically around 3.5 – 4%, while low fat milk has had some or all of its fat removed, resulting in a lower fat content of around 0.5 – 2%. The Malaysian Food Composition Database (MyFCD) indicates low-fat milk has a lower fat

content than full cream milk, with only 1.7 g of fat per 100 ml compared to 3.4 g of fat per 100 ml in full cream milk. However, low - fat milk has a higher calcium content than full - cream milk, with 132 mg of calcium per 100 ml compared to 109 mg of calcium per 100 ml in full - cream milk. Additionally, low-fat milk and full - cream milk are good sources of proteins, with 4.1 g and 3.5 g of protein per 100 ml, respectively [2].

Hydrogen peroxide is a powerful oxidizing agent, which means it readily gives up one of its oxygen atoms to other molecules, thereby oxidizing them. This property makes hydrogen peroxide useful in a various of applications [3]. The dairy industry has long used hydrogen peroxide (H_2O_2) as a preservative to keep dairy products from spoiling and to increase their ability to last. Hydrogen peroxide (H2O2) also plays a significant role in soil remediation processes aimed at the degradation of organic contaminants. Pesticides, industrial chemicals, and other pollutants that can be hazardous to the environment are frequently found in contaminated soil. In soil remediation approaches, hydrogen peroxide is used as an oxidizing agent to accelerate up the breakdown and oxidation of these pollutants. In addition to soil remediation, hydrogen peroxide finds applications in air quality monitoring. It is utilized as a reagent in analytical methods employed for assessing air pollutants. Hydrogen peroxide facilitates the monitoring and analysis of selected pollutants by reacting with them, assisting in the estimation and management of air pollution levels. Milk and milk-based products are consumed worldwide. Dairy products possess a higher quality because H_2O_2 efficiently inhibits the microbial development that ruins milk and activates the lactoperoxidase enzyme system. Regular monitoring of the H_2O_2 level can help prevent the risk of potential health hazards caused by its residue in dairy products [4]. Several classical techniques that have been extensively applied to detect hydrogen peroxide in milk such as chemiluminescence [5] and electrochemiluminescence [6]. For biochemical analysis, all approach methods are either too insensitive or too sensitive. It has significant limitations such as the interference of some cations, which may affect the accuracy of the detection process [7].

Therefore, in this work, the transmission method is proposed to involve measuring the intensity of FODS in milk with different hydrogen peroxide concentrations. The response curve from the change of intensity modulation will be exploited. Thus, examining FODS performance in milk containing hydrogen peroxide will help in the advancement of advanced and sensitive sensor technologies.

2. Materials and Methods

2.1 Sample Preparation

The hydrogen peroxide solution used in this experiment will contain a 35% starting concentration. The sample solutions with different concentrations were created from this concentrated solution. The proper quantity of the concentrated solution and distilled water required to achieve the desired concentrations of the sample solutions was determined using the dilution formula (1).

$$C_1V_1 = C_2V_2 \tag{1}$$

The required concentration of the diluted solution (C2) was established before the dilution process began. Hydrogen peroxide concentrations in this experiment will range from 2% to 10%. To ensure uniformity in the volume of the working solutions used during the measurements, the volumes of the diluted solution (V2) for each concentration were maintained at 50 ml. The volume of concentrated hydrogen peroxide solution (V1) required to reach the desired concentration was determined using the dilution formula. After calculating the volumes, the concentrated hydrogen peroxide solution was carefully added to each volumetric flask. The final volume of 50 ml was then added to each flask using distilled water.

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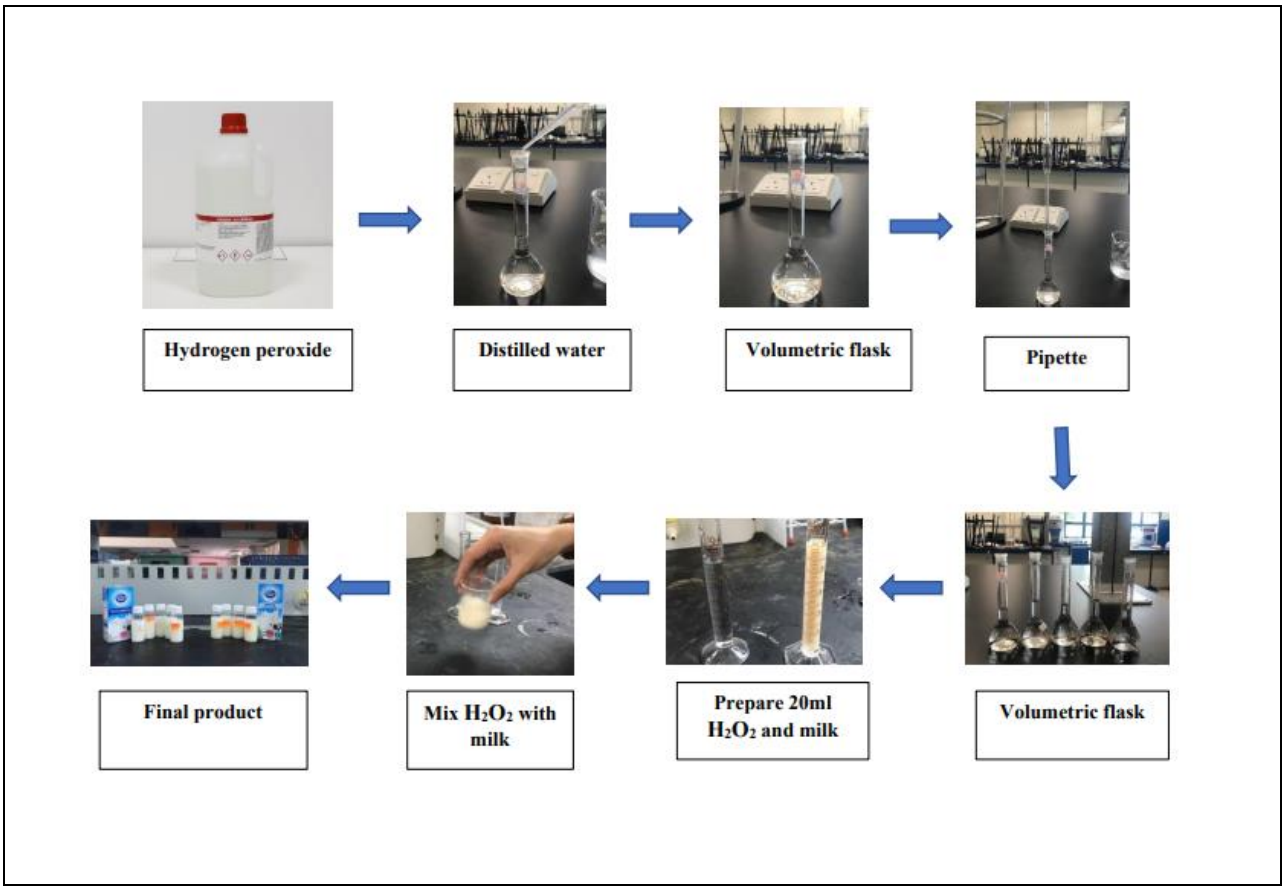

Fig. 1 *Sample preparation flow*

Table 1 *Volume of hydrogen peroxide solution needed to dilute in 50ml volumetric flask*

Concentration of H_2O_2 solution used as manipulated variable (%)	Volume of H_2O_2 solution with 35% concentration (ml)
2	2.90
4	5.70
6	8.60
8	11.40
10	14.30

The hydrogen peroxide solutions are combined with two types of milk: full cream and low-fat milk. In this study, the focus is on measuring the hydrogen peroxide content in sample milk using an optical detector. By using low-fat milk and full-cream milk as samples is a common method in evaluating performance of fiber optic displacement sensors in response to hydrogen peroxide in milk. This is because low-fat milk and full-cream milk have different amounts of fat content and this can affect the response of fiber optic displacement sensor. Low-fat milk has lower fat content which can lead to less interference in the signal, meanwhile full-cream milk has higher fat content which can result in greater signal noise. By using both samples, the sensor performance can be compared and evaluated more accurately. The experiment involves hydrogen peroxide solutions with five different concentrations: 0, 2, 4, 6, 8, and 10 %. This range of concentrations may have been chosen to ensure that the sensor's response can be accurately measured across a spectrum of relevant hydrogen peroxide concentrations in the milk samples. The specific concentrations within this range may also be related to the levels of hydrogen peroxide typically found in low fat and full cream milk, allowing for a practical assessment of the sensor's performance in real-world scenarios. The sample preparation of sample is shown in Fig. 1.

2.2 Experimental Setup

The experimental setup consisted of a few of the components shown in Fig. 2. It utilized a light source, more precisely the laser diode with a 650 nm working wavelength. A pair of optical fiber probes were employed to transmit and receive light. The procedure began by attaching the light emitted from the diode laser to the transmitting fiber (TF) of the concentric fiber bundle probe's transmitting fiber (TF).

The liquid meniscus was then illuminated by the light that was then released at the fiber bundle's end. The probe was moved away from the zero point, which is where the mirror and the probe are in close contact, at a

speed of 1 mm/second in order to capture the incoming fiber signal. The laser light was transmitted through the sample by the TF probe, and the RF probe captured the refraction cone of light that resulted. A photodiode (DET100A2) was then employed to process the light that had been gathered. An oscilloscope measured the electrical signal that the photodiode transformed from the incoming light signal. Software is installed in the laptop to control the displacement controller attached to the sensor probe. The displacement controller moves upwards from the sample until the distance is 40 mm from the sample. The performance of the sensor is analyzed based on sensitivity and linearity.

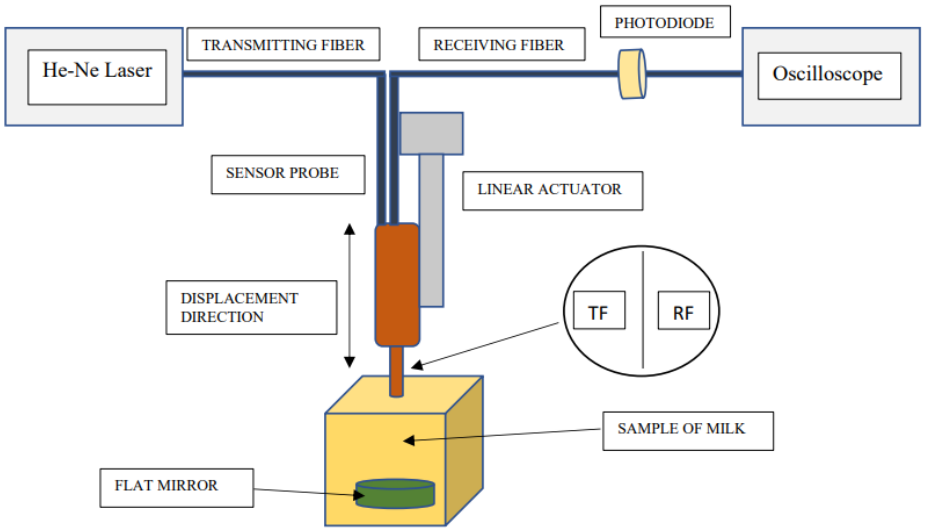

Fig. 2 *Schematic diagram for experimental setup*

3. Results and Discussion

The discussion will be focused on the overall performance of the optical response to different hydrogen peroxide concentrations in full-cream milk and low-fat milk.

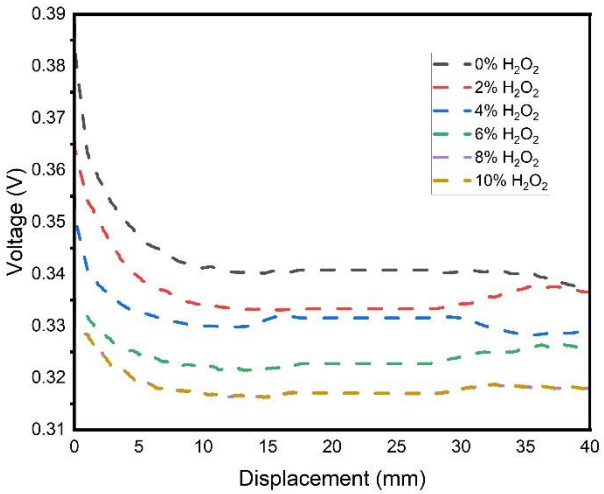

Fig. 3 *Voltage against displacement for low-fat milk*

Fig. 3 shows a graph of output voltage versus displacement at different concentration of hydrogen peroxide in low-fat milk from 0% to 10%. Based on the graph, the output voltage measurement decreases as the distance between the transmitting fiber probe and the tested sample increases. The output voltage represents the improved intensity of the light as it passes through the sample content. The response curve shows how voltages change with probe distances, and its dip-like shape indicates meniscus characteristics. A similar pattern occurs where all concentrations result in one maximum output voltage at a distinct position. The curve demonstrates

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how the liquid meniscus changes based on the displacement response. At small displacements, minimal voltage readings occur because only a tiny emitted light cone enters the RF, given the proximity of the probe position and meniscus. With larger displacements, as the probe moves away from the meniscus, rapid decreases in voltage intensity led to the first minimum point. It occurs as the overlapping region between the emitted light cone and the core of the RF becomes larger. Maximum reflectivity is indicated by the peak voltage in the optimized displacement sensor. Consequently, as shown in Fig. 3, the peak voltage will act as this calibration curve's indicator. According to this similarity, the results seem to be consistent with the principles of a displacement sensor using a beam-through approach [8].

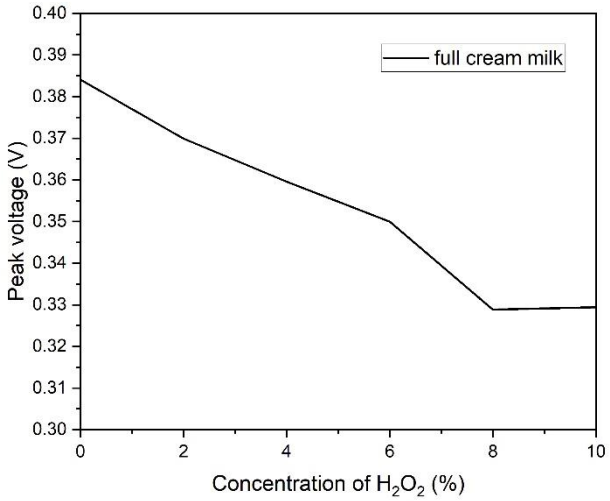

Fig. 4 *Voltage against percentage of H_2O_2 for low fat milk*

In unadulterated milk, Fig. 4 illustrates that light collected by the sensor's receiving fiber probe was seen up to a hydrogen peroxide level of 6%. There were no peak voltages found above that limit due to the addition of hydrogen peroxide solutions made low-fat milk more complex, which reduced the amount of light that could travel through and reach the receiving fiber probe [9]. The limited ability of light intensity to pass through higher concentrations of hydrogen peroxide can be explained by this lack of peak voltage. As a result, only samples with hydrogen peroxide contents between 0% and 6% showed a linear correlation. Because that milk is a colloid solution, the peak voltage exhibited an inverse relationship to the hydrogen peroxide concentration. The contaminated milks had higher viscosities at higher hydrogen peroxide concentrations, which reduced light transmission and led to lower voltage signal detection.

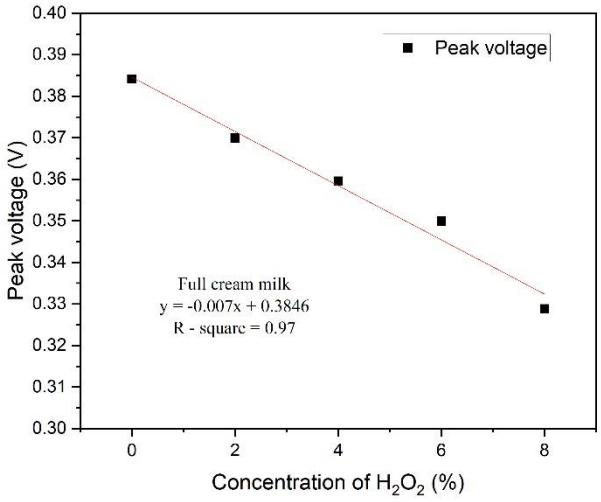

Fig. 5 *Performance of FODS at different concentrations of H_2O_2 in low-fat milk*

Fig. 5 shows that the peak voltage decreases as hydrogen peroxide increases in concentration. The negative slope represents the results following with the principles of a displacement sensor using a beam-through approach The sensitivity value of the sensor was calculated to be 0.008V/%. This outcome, greater than 97%, indicates a high degree of linearity. Therefore, it can be stated that the sensor worked effectively within the range of hydrogen peroxide concentrations that impact human health.

Table 2 *Sensor performance towards hydrogen peroxide detection in low-fat milk*

Parameter	Peak Voltage
Concentration range (%)	0 - 10
Sensitivity (V%)	-0.008
Linearity (%)	>97

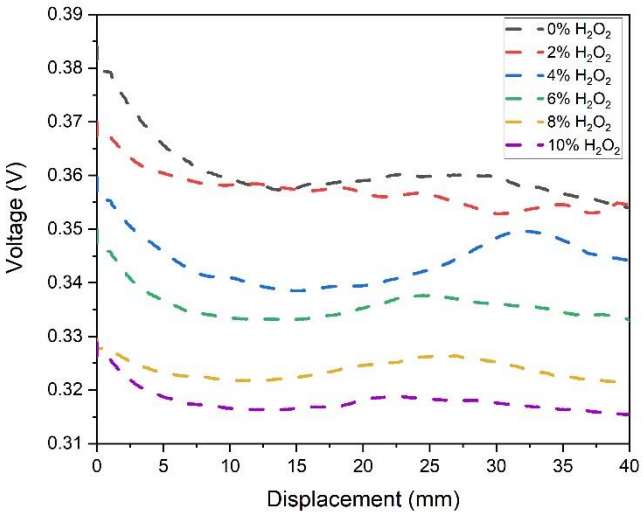

Fig. 6 *Voltage against displacement for full cream milk*

Fig. 6 illustrates the variations in output voltage readings obtained from transmitted light intensity for full cream milk. Non-adulterated milk and different concentrations (0% to 10%) of hydrogen peroxide in full cream milk were among the substances reviewed. Additionally, the graph illustrates that as the distance between the tested sample and the transmitting fiber probe increases, the output voltage measurement decreases. The output voltage is a measure of the different light intensities that are passing through the medium of the samples. The response curve's dip-like shape indicates meniscus characteristics and illustrates how voltages shift with probe distances. A similar pattern occurs where all concentrations result in one maximum output voltage characteristic. The curve demonstrates how the liquid meniscus changes based on the displacement response. At small displacements, minimal voltage readings occur because only a tiny emitted light cone enters the RF, given the proximity of the probe position and meniscus. With larger displacements, as the probe moves away from the meniscus, rapid decreases in voltage intensity led to the first minimum point. It is due to overlapping region between the emitted light cone and the core of the RF becomes larger. The peak voltage in the optimized displacement sensor signifies maximum reflectivity. The voltage levels were initially high and linked with the milk's hydrogen peroxide content, but as the displacement stage developed, they began to shift significantly. The observed pattern, however, remains to correspond with the basic principles of a displacement sensor based on transmission [8].

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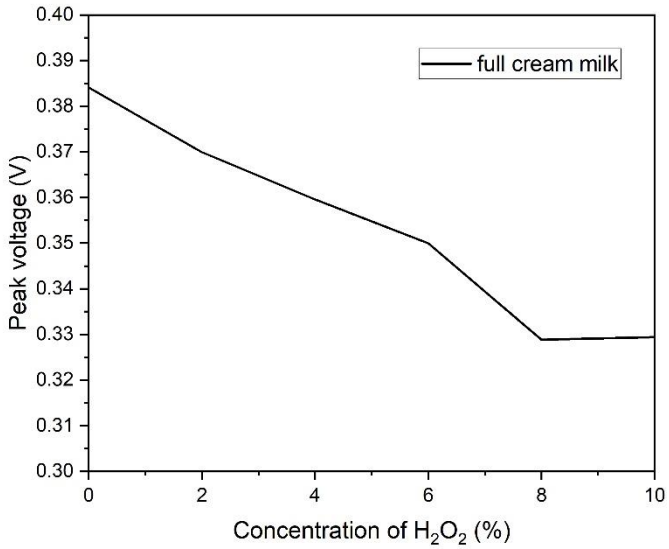

Fig. 7 *Voltage against the percentage of H_2O_2 in full-cream milk*

The peak voltage observed was inversely correlated with the milk's hydrogen peroxide content, as shown in Fig. 7. As the concentration of hydrogen peroxide increased the voltage reading decreased. The relation can be explained by the colloidal composition of milk. Full cream milk became more complex at higher hydrogen peroxide concentrations, which reduced the amount of light that could pass through the milk and reach the receiving fiber probe. This increased viscosity of the contaminated milk has brought on this reduction in light transmission. The unpattern voltage measurements for full cream milk started at 8% hydrogen peroxide concentration while those for low-fat milk started at 6% hydrogen peroxide concentration, which is an interesting difference compared to low-fat milk. Fewer voltage signals could be observed because less light passed through the milk at higher hydrogen peroxide concentration [9,16].

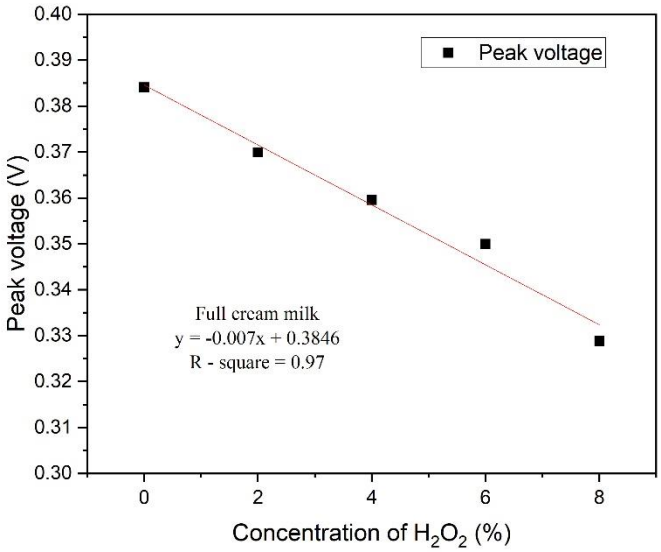

Fig. 8 *Performance of FODS at different concentrations of H_2O_2 in full-cream milk*

Fig. 8 shows that when the concentration of hydrogen peroxide increases, the peak voltage decreases. The sensor sensitivity is determined by the graph's slope. The sensitivity of full cream milk, which was obtained at 0.008 V/% with a good linearity of more than 97%, suggests that the sensor appears to work effectively in the hydrogen peroxide concentration range that may have an impact on people's health.

Table 3 *Sensor performance towards hydrogen peroxide detection in full-cream milk*

Parameter	Peak Voltage
Concentration range (%)	0 - 10
Sensitivity (V%)	-0.007
Linearity (%)	>97

4. Conclusion

Fiber optic displacement through the reflective intensity modulation technique was successfully employed as a potential device for detecting hydrogen peroxide in milk. One peak voltage found from the displacement curves during the evaluation of the H2O2 concentration from 0% to 10% shows obvious characteristics. Low-fat and full-cream milk were found to have similar sensitivity values for the concentration parameter. Particularly, full-cream milk demonstrated a sensitivity of 0.008 V/% with a slope linearity greater than 97%, and low-fat milk demonstrated a sensitivity of 0.007 V/%. These results highlight the potential of the proposed technique, characterized by its simplicity, affordability, and real-time capabilities, making it a promising method for hydrogen peroxide detection in milk.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design, data collection, methodology, analysis and interpretation of results:*** *Nurul Ain Mohad Yusoff Shah, Nurul Nadia Adnan and Nurul Athirah Mohd Taib. All authors reviewed the results and approved the final version of the manuscript.*

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