Design of Edible Oil Degradation Tool by Using Electromagnetic Field Absorption Principle which was Characterized to Peroxide Number

M Isnen¹, T I Nasution¹, B Perangin-angin¹
¹Department of Physics, Faculty of Mathematics and Natural Sciences, University of Sumatera Utara. Jalan Bioteknologi No.1 Kampus USU, Medan 20155, Indonesia

E-Mail: isnenmaizal@gmail.com

Abstract. The identification of changes in oil quality has been conducted by indicating the change of dielectric constant which was showed by sensor voltage. Sensor was formed from two parallel flats that worked by electromagnetic wave propagation principle. By measuring its amplitude of electromagnetic wave attenuation caused by interaction between edible oil samples and the sensor, dielectric constant could be identified and estimated as well as peroxide number. In this case, the parallel flats were connected to an electric oscillator 700 kHz. Furthermore, sensor system could showed measurable voltage differences for each different samples. The testing carried out to five oil samples after undergoing an oxidation treatment at fix temperature of 235°C for 0, 5, 10, 15 and 20 minutes. Iodometry method testing showed peroxide values about 1.99, 9.95, 5.96, 11.86, and 15.92 meq/kg respectively with rising trend. Besides that, the testing result by sensor system showed voltages values 1.139, 1.147, 1.165, 1.173, and 1.176 volts with rising trend, respectively. It means that the higher sensor voltages showed the higher damage rate of edible oil when the change in sensor voltage was caused by the change in oil dielectric constant in which heating process caused damage in edible oil molecules structure. The more damage of oil structure caused the more difficulties of oil molecules to polarize and it is indicated by smaller dielectric constant. Therefore electric current would be smaller when sensor voltage was higher. On the other side, the higher sensor voltage means the smaller dielectric constant and the higher peroxide number.

1. Introduction
To identify edible oil quality, there are some parameters, i.e. free fatty acid number, saponification number, peroxide number and many others. From these three parameters, peroxide number is the most
important factor to measure to identify edible oil quality [1]. Some methods that are used to measure peroxide number are by identifying its first oxidation product, second oxidation product, or both, or by measure all oxygen consumption along the process occurs. Measuring the concentration of hydrogen peroxide (first product of oxidation) is the most popular method [2]. Peroxide number is the most valuable to measure the degradation level of oil and fat. According to SNI (National Standard of Indonesia) about higher level of peroxide number allowing to be consumed in oil and fat is 2 meq/kg (milliequivalent per kilograms) [3].

Iodometry method is the most popular chemical method to identify peroxide number. However, this method has several weakness, obiter expensive and complicated in use, because it needs laboratory equipments to carry on the measurement. Therefore, it almost impossible to be apply in household for daily use.

Another development way for measuring peroxide number is by electronic equipment namely peroxide meter. It works by measuring the light intensity throughout the oil sample. Firstly the oil sample should be poured a special reagent to get colour change. As the next step, the sample is placed in a special chamber to get light exposure as measurement process and then the peroxide number will be shown in LCD interface of the equipment directly. This process is simpler than iodometry method and has higher accuracy. It is because the utilisation of sensor in measuring colour change has removed some different perceptions among different observer while it is measured manually. In the contrary, the weakness are when the reagent exhausted, the measurement process will not be applicable. Besides that, process of absorbing the emitted light will be able to be disturbed by its original colour as the implication of nutrition contain and another substance dissolved in edible oil that might be caused by frying process or direct air exposure. Some oil may have similar quality, but different brand may present different colour. It will affect the measurement result indeed.

Finding the new way to measure oil degradation is needed by considering some aspects such as simplicity, portability and availability to use in every time.

Edible oil is a lipid which is insoluble in water. This substance has a characteristic as dielectric. Electric current could not pass this layer instead of good insulator properties of the material. To penetrate the layer, oscillated-electric current is applicable because it may produce electromagnetic field which consist of electric and magnetic field as well. This phenomenon is called polarization(P). The molecules of oil will be polarized by electric field around the oil layer. Polarization is defined as moment dipole per volume [4]. The better oil structure caused the higher dielectric constant. The higher in dielectric constant cause the ease of electric current to pass oil layer when it is might also showed as low level of voltage.

By using this principle, the sensor of edible oil quality is possible to produce. To trigger polarisation process, generating electromagnetic field with fix frequency is possible to be produced by oscillator IC, while measurement result could be processed by microcontroller system as system sensor.

2. Methodology

The sensor and its electronic interface consists of parallel flat as a sensor electrode, made from PCB, oscillator circuit with XR2206 IC, signal conditioner with AD620 IC, data processing with ATMega32 microcontroller, monochrome LCD 16x2 characters to show measurement result, and power supply to address the need of power of electric system.
2.1. Sensor Electrode Design
Sensor electrode is a part which will interact to edible oil sample directly. It made from patterned PCB with cooper as its surface, with circle diameter 20 mm and space between two flats is 2 mm. It is shown in figure 1.

![Sensor electrode](image)

**Figure 1.** Sensor electrode as a transmitter and receiver will interact with oil directly

2.2. Oscillator Circuit with XR2206 IC
Integrated circuit XR2206 is the main component of oscillator circuit. It has been produced by EXAR Corporation. External resistors and capacitors are used to set up the oscillation frequency. Following the equation below.

\[
f = \frac{1}{RC}
\]  

Refer to its datasheet, maximum frequency from XR2206 is 1 MHz, but it effective in 700 kHz. Follow the first formulation to get suitable frequency, the sensor tested in two different medium i.e. air and edible oil by combining the frequency from 100 kHz to 700 kHz.

2.3. Signal Conditioner AD620
AD620 is high quality amplifier integrated circuit. The advantage of AD620 beside as high impedance amplifier, it only needs one external resistor, to operate and make the change in gaining the signal, following this equation 2.

\[
G = \left( \frac{49.9k\Omega}{R_0} \right) + 1
\]  

2.4. Embedded System with Monochrome LCD 16x2 Characters
As a main circuit for acquisition and data processing, the embedded system circuit use ATmega32 microcontroller. ATmega32 is 8 bit microcontroller with 10 bits ACD (analog to digital converter) included. Monochrome LCD 16x2 characters is used to show its measurement result. LCD is connected to microcontroller circuit directly. Power suplay is included and will transform 220 V alternating current (AC) to +12 volt and –12 volts and 5 volts direct current (DC) to support whole electronics circuit needs in the system. Schematic of the circuit is shown by figure 2.
Mechanism of measurement process until shows the measurement result by microcontroller, it was programmed with C programming language by CodeVisionAVR compiler. The mechanism of measurement process follows steps in figure 3.

**Figure 3.** Measurement mechanism diagram by electronic circuit system

2.5. Sample Preparation
Edible oil was bought from local market. There are 5 edible oil samples with different treatment condition. The edible oil sample was oxidized by heating process in 235°C for 0, 5, 10, 15, and 20 minutes. Therefore, there were 5 edible oil samples with different quality. Iodometry method was chosen to identify its peroxide number before measured by the sensor system.

3. Result and Discussion
3.1. Determine the sensor frequency
The graph in figure 4 shows the comparison between theoretical and practical condition to produce oscillation frequency (hertz) by setting up the external resistor of XR2206 circuit (kOhm). The maximum frequency of XR2206 practically showed 700 Mhz.
The testing result of sensor by varying its frequency from 100 to 700 kHz showed the largest wide of difference voltage between air and oil medium in 700 kHz, shows in figure 5. The testing occurred with placed the electrode sensor in air and fresh edible oil samples.

From comparison of two curves (air and oil) in figure 5 above showed the ability of sensor to distinguish the different medium. Base on the relation $D=\varepsilon E$ ($D$ is displacement current, $\varepsilon$ is dielectric constant and $E$= electric field), displacement current in dielectric substance is proportional to its dielectric constant and electric field. It means that, if electric field throughout the medium with higher dielectric constant, displacement current from transmitter to receiver electrode will be higher too. Following formula 3.
\[ C = \frac{k \varepsilon_0 A}{d} \]

and

\[ C = \frac{q}{v} \]  

\( k \) as dielectric constant and \( v \) as voltage. Therefore, the relation of \( k \) and \( v \) is inversely. Therefore, if sensor voltage was higher, the dielectric constant would be lower. Graph in figure 5 depicts dielectric constant of oil was higher than air.

3.2. Testing of Edible Oil Quality with Iodometry Method

Table 1 reveals testing result of 5 edible oil samples after oxidizing in 235\( ^\circ \)C with time variation by iodometry method.

| Heating time (minutes) | Peroxide number (meq/kg) |
|------------------------|--------------------------|
| 0 (fresh)              | 1.9913                   |
| 5                      | 9.9593                   |
| 10                     | 5.9617                   |
| 15                     | 11.8574                  |
| 20                     | 15.9245                  |

Testing result in table 1 shows a relation that the longer heating time, the higher peroxide number (figure 6). This is a qualitative data and may not be used as standard database of sensor.

![Figure 6](image_url)

**Figure 6.** The graph of relation of peroxide number (meq/kg) and heating time (minutes)
Shah and Tahir (2011) in Journal of Scientific Research with title Dielectric Properties of Vegetables Oil, showed the effect of heating process to dielectric constant. The reduction of dielectric constant followed the heating time. It was caused by the degradation of oil density as well as a relation to density of its molecules dipole. The rise of heating temperature would increased the kinetic energy of former molecules that moved randomly and disturbed the molecules structure which made harder the molecules to be polarized. It caused the lower value of dielectric constant [5].

3.3. Testing by Sensor System
This measurement equipment or sensor system use electromagnetic field absorption principle which the sensor was formed from two parallel flats. The electromagnetic field was established by oscillator electronic IC that produced weak electromagnetic field. Electromagnetic field is consists of magnetic and electric field. Electric field has a function as polarization agent of dielectric substance. Therefore, dielectric constant will measurable. Dielectric constant shows the easiness of polar structure in oil molecules to be polarized. The higher dielectric constant, the easier polar structure in oil molecules to be polarized. It is represent as good structure of dielectric molecules. Then, by measuring this parameter, the oil quality will be identified and it is represent the peroxide number, one of the most important parameter of oil quality.

The interaction between electric field and dielectric substance follow this formula:

\[ E + 4\pi P = \varepsilon E \]  

\( E \) is number of electric field, \( P \) is density of polarization and \( \varepsilon \) is defined as dielectric constant of a substance. Because it tells about electromagnetic wave, Maxwell equation explained this case.

\[
\begin{align*}
\text{div}E &= 4\pi \rho \\
\text{div}B &= 0 \\
\text{curl}E &= \frac{1}{c} \frac{\partial B}{\partial t} \\
\text{curl}B &= \frac{1}{c} \frac{\partial E}{\partial t} + \frac{4\pi}{c} J
\end{align*}
\]

Derivation result of fourth Maxwell equation is:

\[ \text{curl}B = \frac{1}{c} \left( \varepsilon \frac{\partial E}{\partial t} - 4\pi J \right) \]  

\( \varepsilon.E \) means displacement current (\( D \)), therefore:

\[ \text{curl}B = \frac{1}{c} \left( \frac{D}{\partial t} - 4\pi J \right) \]

It means that the interaction of electromagnetic wave with dielectric substance (edible oil) is caused current displacement of its substance.

Figure 7 reveals the testing result in five different samples in 10 times repetition. However the data did not show a linear trend but the sensor showed an ability to determine the different edible oil quality.
The graph portrays, the longer oil samples heating time, the higher sensor voltage or the worst quality of oil, the sensor will show higher sensor voltages. By identifying its dielectric constant with calculation, the relation is presented in table 2 and figure 8.

**Table 2.** The relation of samples heating time with peroxide number, dielectric constant and sensor voltages only.

| Sample heating time (minute) | Peroxide number (meq/kg) | k (dielectric constant) | Sensor voltage (volt) |
|-----------------------------|--------------------------|-------------------------|-----------------------|
| 0 (fresh)                   | 1.9913                   | 3.231                   | 1.13948               |
| 5                           | 9.9593                   | 3.231                   | 1.14778               |
| 10                          | 5.9617                   | 3.181                   | 1.16559               |
| 15                          | 11.8574                  | 3.161                   | 1.17315               |
| 20                          | 15.9245                  | 3.153                   | 1.18                  |

**Figure 7.** The relation between sensor voltages and edible oil samples heating time in 10 repetitions

**Figure 8.** The relation between sensor voltages and oil samples heating time in 10 repetitions
Therefore it was clear that the longer oil heating time, the worst oil quality will be. It was shown by reduction of dielectric constant. The reduction of dielectric constant showed the difficulties of polar structures in oil molecules to be polarized and the displacement of current was harder. The smaller electric current reflects the higher sensor voltage.

From table 2 and figure 8 are found a proportional relation between sensor voltages and peroxide number or degradation level of oil. It is explained by figure 9.

![Illustration of structure charge in dielectric substance molecules](image)

Figure 9. Illustration of structure charge in dielectric substance molecules, (a) before heating treatment, (b) after heating treatment

The well-order of polar structure, the easier of dielectric substance to be polarized. Then, the easier of dielectric substance to be polarized is shown by the higher dielectric constant itself. The heating treatment ruined the structure itself. The ruin structure was shown by random structure that disturbed the mechanism of charge displacement. The charge was harder to move from transmitter electrode to receiver electrode. Therefore, unbalance happened and it produced the high difference of potential energy and it was known as sensor voltages. However, if the structures are well-structured, the charges displacement will be easier and the different of potential energy will be lower. From this analysis was known that voltages sensor would be higher if the structure of dielectric substance was random or the edible oil was in bad condition.

4. Conclusion
By measuring dielectric constant of edible oil, the degradation of edible oil or cooking oil will be identified in which dielectric constant has a close relationship with peroxide number. In particular, the dielectric constant portrays how the structure of oil is. The higher of dielectric constant reveals the better of its structure which is showed as low sensor voltage.

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