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Impedance Sensor Probe for Degradation Assessment of Cooking Oil

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Abstract

Repeated use of cooking oil had been proven hazardous due to degradation process that contributes to the formation of polar compounds in the oil. Presently, the rate of cooking oil degradation is indicated by the percentages of its total polar compounds (TPC). In this study, impedance sensor probe was designed to assess the cooking oil degradation at several heating time intervals by measuring the changes on its electrical impedance. The probe was designed using interdigitated electrodes (IDEs) platform. In total of 30 samples of 130 ml palm oil were heated at 180^o C up to 30 hours using a laboratory oven. For each one hour increment, one sample was taken out of the oven and cooled at room temperature before measuring the impedance value using the designed probe which connected to a LCR meter. The TPC of the oil samples was measured using Testo 270 cooking oil tester (InstruMartInc, Germany). The discrimination between the electrical impedance values at different heating hours of oil samples was analyzed and correlated to their TPC measurements. Preliminary results showed good correlation between the oil electrical impedance with their TPC value. The designed sensor probe has good potential for simple and inexpensive way of monitoring cooking oil degradation.

Keywords: Impedance sensor, cooking oil degradation, total polar compound, heating

1 Introduction

Deep frying is a popular way of preparing fast food, which the food is submerged in hot oil or fat at a high temperature of 150^o C to 190^o C. There are several chemical reactions occurring during deep frying, such as thermal oxidation, hydrolysis, and polymerization through a general process of using frying oil in repetitive ways (White, 1991; Choe & Min, 2007; Tyagi & Vasishtha, 1996). These chemical reactions will produce undesired compounds in the cooking oil such as aldehydes, polymeric triglycerides, and free fatty acids (Gertz, 2000).

The condition of cooking oil can affect food flavor, texture, and color since the oil acts as a medium of heat transfer. Subsequently, the change in the cooking oil quality will lead to changes in food taste. Moreover, using cooking oil continuously or repeatedly without monitoring and controlling the quality can affect human health (Lee et al., 2011; Innawong et al., 2004).

Determining the deterioration of cooking oil can be based on the change either in chemical or physical properties of the oil. The advantages of physical parameters comparing to chemicals are, it is obvious to observe, easy to detect, and don't need complex experiments. However, changes in physical properties mostly detected when the oil already unusable. These changes can be seen when the cooking oil becomes dark, has a strong odor, and has too much smoke (Moreira et al., 1999). While, chemical properties are considered the best indicator to evaluate the quality level of cooking oil. The common parameters are total polar compound (TPC), free fatty acid (FFA), peroxide value (PV), polymeric triglycerides (PTG), and iodine value (IV) of the frying oil. A TPC is the most crucial and broadly known parameter that can be utilized to decide whether or not the used oil should be discarded. TPC is considered the best indicator comparing to other chemical parameters since it refers to all the degraded products in frying oil (Bansal et al., 2010).

Many technical approaches are being used to evaluate oil quality, for example image analysis to determine the TPC (Gil et al., 2004), Fourier transform infrared (FTIR) to differentiate between good and unacceptable oils (Vlachos et al., 2006), and column chromatography to measure the TPC percentage in the oil (Cert et al., 2000). However, these methods are time consuming as well as laborious to be performed. Therefore, more fast and easy analytical technique should be considered to develop and assess the quality of cooking oil. In this subject field, development of an impedance sensor probe was conducted using an impedance spectroscopy technique to correlate the impedance measurement with the TPC parameter. The aim of this work was to develop and assess an impedance sensing system for cooking oil quality appraisal.

2 Materials and methods

2.1 Impedance Sensor Probe Design

The impedance sensor probe was designed based on interdigitated electrodes (IDE) structure as shown in figure 1 (a). The IDE configuration have many advantages compare to other configurations. Some of IDE features are flexible in design, ease of fabrication, no moving parts, cost effectiveness, and one-side access to the sensing layer (Staginus et al., 2013). The sensor design was drawn using a CAD software before the photomask of the sensor was created. The sensor consists of two areas; the sensing area, which will be immersed in the testing oil, and the bonding pad area, which connected to the LCR meter using wires. The total area of the designed IDE sensor was 18.5 mm by 11.5 mm.

The electrode material used in this sensor was 100 angstroms titanium/2000 angstroms of gold. The gold has been chosen because it has very low resistance. In addition, there was insulating layer between interdigitated finger electrodes and gold bonding pads made from 1000 angstroms of silicon dioxide (SiO_2). This sensor was supported by a rigid substrate made from highly polished alumina (Al_2O_3) as shown in figure 1 (b).

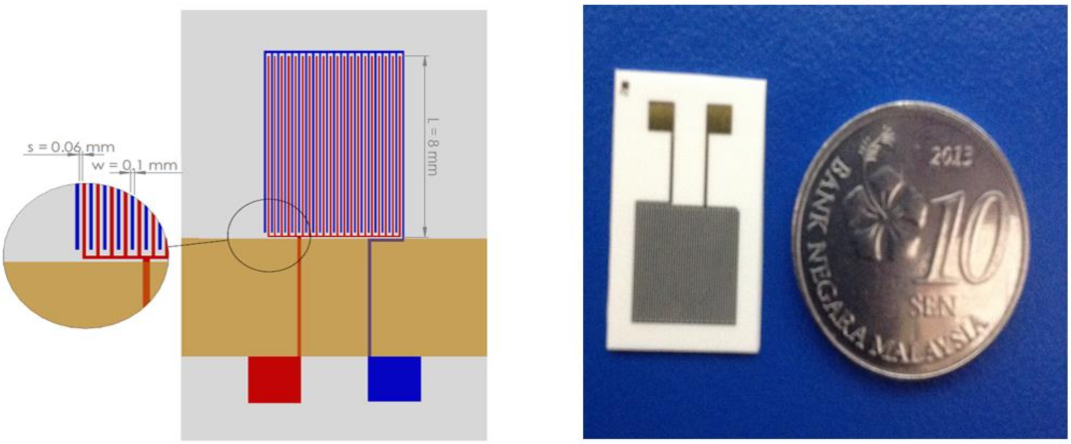
The electrode width (w), spacing (s), length of electrode (L), and the number of electrodes (N) are 100 um, 60 um, 8 mm,and 41, respectively. Where these dimensions have been characterized to fulfill the requirements for detecting the change of cooking oil quality. The equation of impedance is given by:

$$Z = \frac{\mathrm{s}.(\mathrm{N}-1)}{2\pi f \epsilon A}$$

where the f is the input frequency, which in this case the frequency supplied from the LCR meter, є is the permittivity, and A is the sensitive area of the sensor which measured by:

$$A = L.(w.N)$$

The mechanism of this sensor is that as oil oxidatively and thermally breaks down, there an increase in the number of polar molecules, which directly increases the dielectric constant. When an electric field is applied across the faces of IDEs, the dipole and molecular charges in the testing oil are displaced from their equilibrium positions, and those dipole charges laid up through the fingers of the sensor. Thus, as long as the cooking oil produces polar molecules through various chemical reactions during frying the more charges will lay up in the electrodes.



(a) (b)

Figure 1: (a) A top-view illustration of impedance sensor probe, (b) A photograph of prototype device next to a Malaysian coin.

2.2 Sample Preparation

Fresh palm oil samples were bought from a local market in Seri Kembangan, Selangor, Malaysia. The palm oil was divided into 30 amber glass bottles where each bottle contained 130 ml. After that, all oil samples were heated in a laboratory oven at temperature of 180 ^{o}C. The heating time of the oil samples was ranging from 1 to 30 hours and at every hour, a sample was taken out of the oven. Then, the sample was kept at 40 ^{o}C to be used for the further analysis.

2.3 TPC and Impedance Measurements

The percentage of TPC of each heated sample was measured using a cooking oil tester (Testo 270, InstruMartInc, Germany) (Figure 2). Right after that the impedance measurement was carried out using the IDE probe. The probe were connected to a LCR meter (4263B, Agilent, Japan) with two parallel clips as shown in figure 3. The LCR meter has a frequency range from 100 Hz and to 100 KHz to measure the impedance of the oil samples. After each measurement the sensor and the probe were cleaned by soft tissue before the next measurement. Each measurement was conducted three times.

*Figure 2: TPC measurement using (*Testo 270, InstruMartInc, Germany*).*

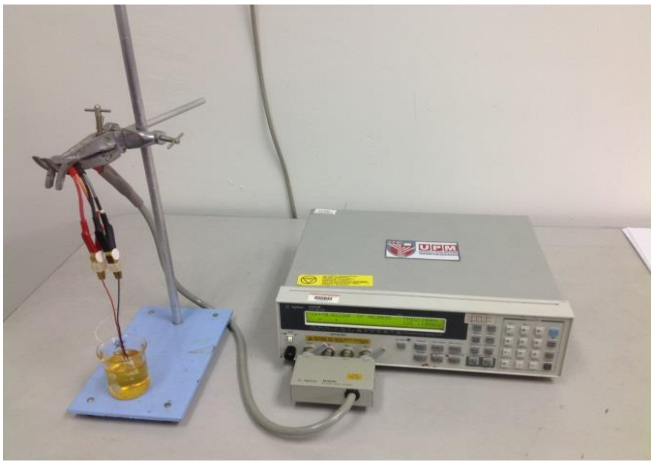


Figure 3: IDE impedance sensor probe connected to a LCR meter for impedance measurement.

3 Results and Discussions

Figure 4 illustrates the changes of cooking oil impedance as a function of frequency at various heating hours. According to the figure, it was revealed a clear difference in impedance value between samples at low frequencies (100 Hz to 1000 Hz), while almost all samples has impedance values overlapping at high frequencies. From the results, the trendlines of the samples at low frequencies showed that 5 hours heated sample has the highest value of impedances, while the 30 hours heated sample has the lowest value of impedances. It looks possible that these results are because of the increasing of dipole content in the fat of oil particularly the phospholipid as the increasing of heating time (Aditama, 2005; Khaled et al., 2014). The dipole density and electric susceptibility increased, as the quantity of the polar materials in the oil increased. This caused the impedance of the cooking oil samples decreased.

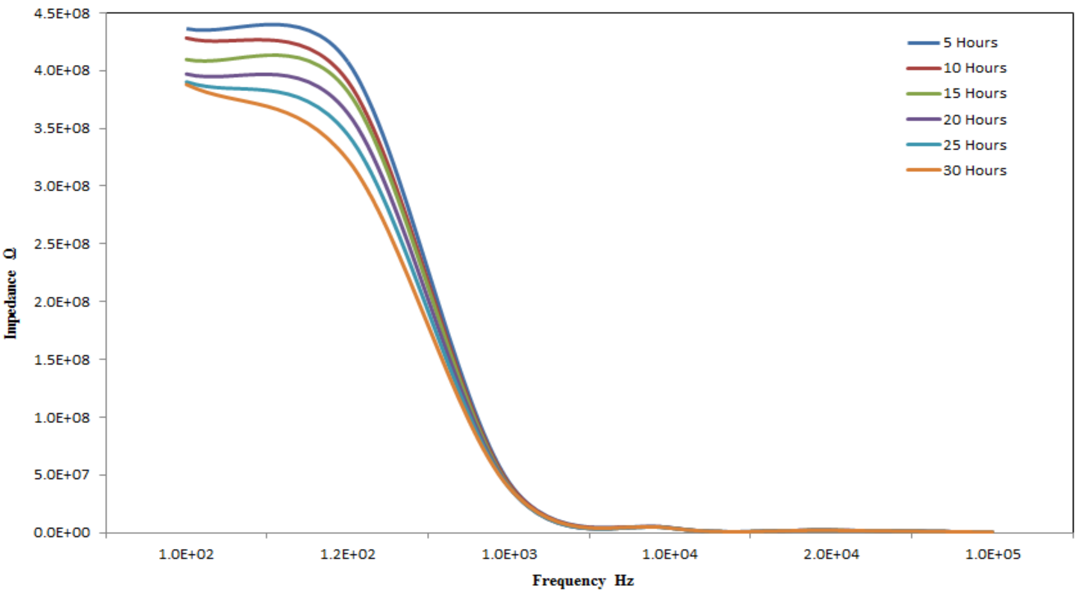


Figure 4: Impendence measurements across frequency at different heating hours.

Figure 5 depicts the correlation between impedance measurements of cooking oil with their TPC values. This figure illustrated that when the impedance increases the TPC decreases. As a result, the correlation value of the impedance with TPC is -0.94. Figure 6 shows the changes of impedance of the cooking oil as a function of TPC at different heating times. Based on the graph, it can be seen that there was a high negative correlation between impedance and TPC at frequency of 100 Hz, where this frequency point has the highest value of correlation coefficient (R^2) of 0.88 (Table 1). It also was clearly shown that in table 1 all R^2 values have a high negative correlation except at frequency 120 Hz. The low value of R^2 at 120 Hz might be due to unstable measurement or measurement error during handling the LCR meter. Moreover, the R^2 values are significantly decreasing as long as the frequency increasing. Thus, it can be concluded that the impedance can be correlated well with TPC specifically when the frequency is low.

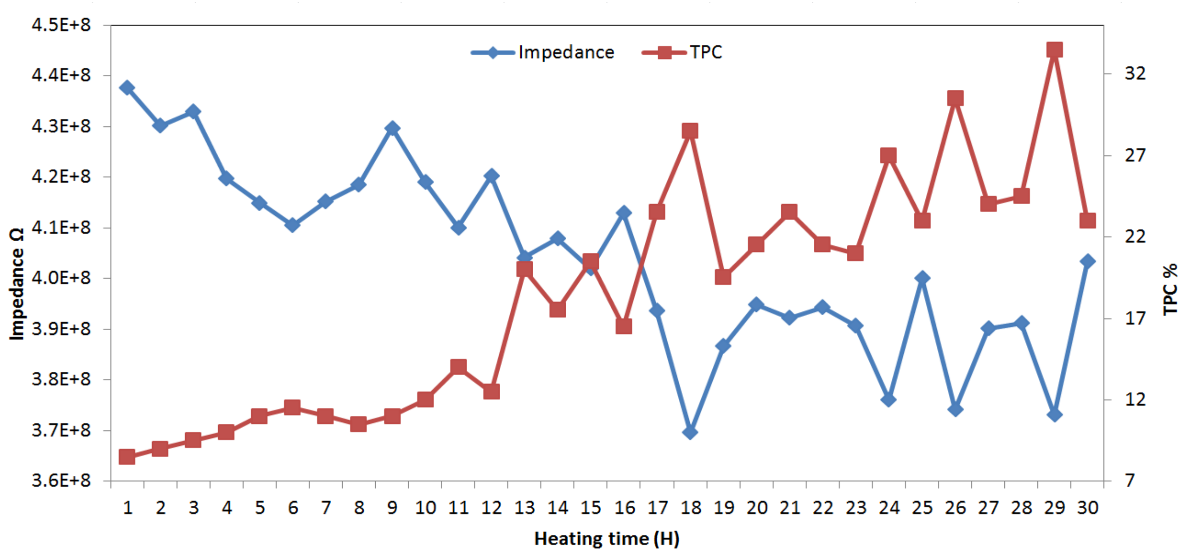


Figure 5: The correlation of impedance and total polar compound at different heatingtime.

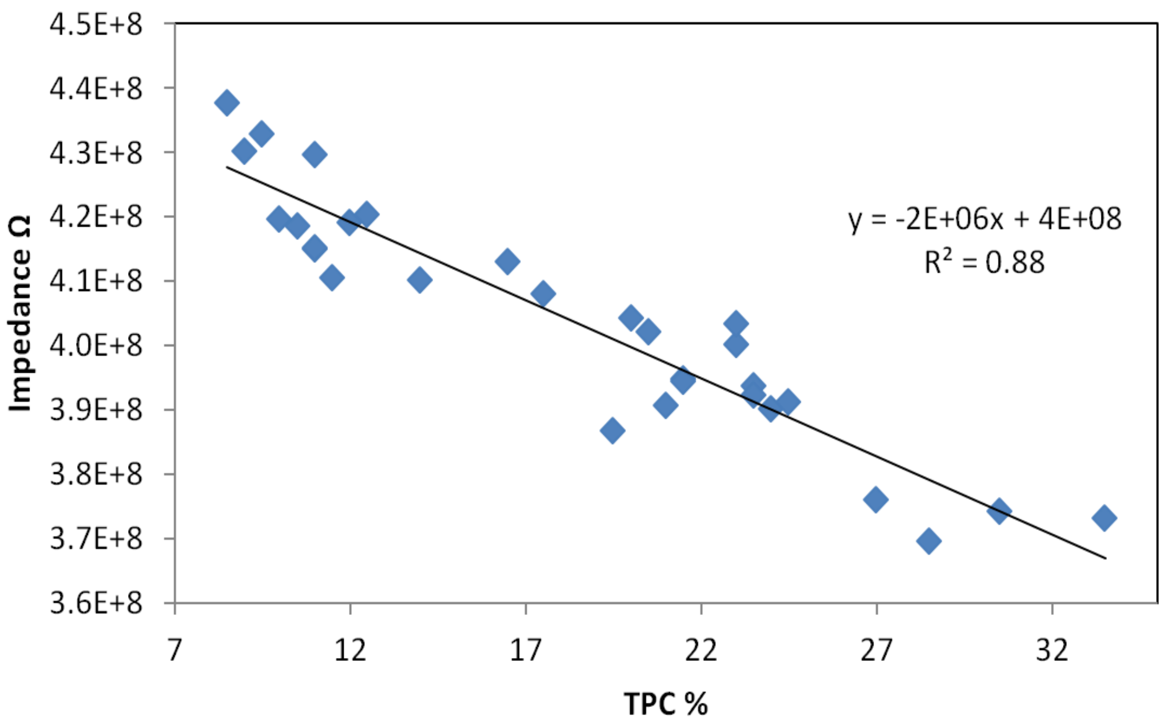


Figure 6: Impedance measurements at 100 Hz of heated cooking oil regressed on their TPC values.

Table 1: The R-squared values and the regression equations of impedance with TPC value at different frequencies.

Frequency	R-squared value R^2	The equation
100 Hz	0.88	-2E+06x + 4E+08
120 Hz	0.12	-3E+06x + 4E+08
1000 Hz	0.87	-211600x + 4E+07
10 KHz	0.83	-21296x + 4E+06
20 KHz	0.82	-10466x + 4E+06
100 KHz	0.80	-1976.8x + 434540

4 Conclusions

The impedance value of heated cooking oil decreased as the heating time increased which consiquently increased its TPC value. These changes can be detected using the designed IDE probe constructed in this study with R^2 up to 0.88. The impedance spectroscopy technique has good potential in developing a simple and inexpensive way of monitoring cooking oil degradation.

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