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MICROWAVE DIELECTRIC ANALYSIS OF THERMAL DEGRADATION ON VEGETABLE OILS

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ABSTRACT

This study applied the measurement of dielectric properties and reflection coefficient by using Agilent E8362B slim probe. Slim probe and open-ended coaxial sensor are implemented to measure the dielectric properties and reflection coefficient of the cooking oil samples. The vegetable oils were purchased from the local market and were heated in the oven. Five types of cooking oil are corn oil, olive oil, palm oil; sunflower oil and walnut oil were measured at the temperature of 60^0C, 80^0C and 100^0C for the frequency range of 0.2 GHz to 20GHz. As the oil, undergoes thermal degradation during heating, the chemical chain of oil will be altered and resulting in physical and internal properties change. Dielectric properties are part of physical-chemical properties of cooking oil that can be measured to inspect the oil quality. According to the dielectric properties and reflection coefficient measurement, there are different noticeable signal pattern which indicates the used and fresh cooking oil and the effect of heating period.

Keywords: cooking oil characterization, dielectric properties, loss factor, reflection coefficient, coaxial probe.

INTRODUCTION

In this fast-paced society, frying stays as one of the regular techniques in food preparation of the fast-food chains such as Burger King, McDonald's and Kentucky Fried Chicken's (KFC) restaurant [1]. Consumption of this ready-made deep-fried food is high, particularly in developing countries. Highly oxidized fatty acids are utilized through intake of these fried foods as edible oil is the major ingredient in these fried food products. Consequently, the expense of oil turns into the most vital element to be considered regarding economy. Thus, vegetable oil is often to be repeatedly heated to guarantee cost effectiveness. The oil is subsequently reused until it is discarded and replaced with fresh oil [1].

Repeated heating of the oil accelerates oxidative degradation of lipids, forming hazardous reactive oxygen species and depleting the natural antioxidant contents of the cooking oil. Long-term ingestion of foods prepared using reheated oil could severely compromise one's antioxidant defense network, leading to pathologies such as hypertension, diabetes and vascular inflammation [1]. In Taiwan, a team which includes molecular biologists, toxicologists, and chemists, was formed due to concern about high rates of lung cancer among women living in Shanghai, Singapore, Hong Kong, and Taiwan. The team began investigating the possibility that heated cooking oils might be playing a role since wok cooking with vegetable oils in unventilated space is common in Taiwan [2]. The issue, as we probably aware, is cooking oil can be quickly decayed by temperature [3]. During heating, the cooking oil oxidized, polymerized, hydrolyzed and fission [4]. Lipid from oils and edible fats suffer from thermal degradation when they are subjected to high temperatures or more extended heating period [5]. Besides, the oxidation of unsaturated fats is greatly accelerated at high temperatures; also, the free radical mechanism is changed by the decrease in oxygen concentration in heated fats. Thus, there was a tendency to release a toxic and carcinogenic substance in the oil when repeatedly heated cooking oil and present harmful consumer health features [3].

High consumption of ready-made deep-fried foods negatively affects health due to thermal degradation of repeatedly heated cooking oil. These types of food will affect the health of the consumer in the long term. Hence, due to consumer health concerns, intensive research has been conducted to inspect the quality of cooking oil. Different types of cooking oil give various quality according to its composition. However, other factors can affect its quality, e.g. heating temperature and heating period. High temperature or more extended heating period can cause degradation of the cooking oil. The degradation of cooking oil will release harmful substances that can cause health problems to the consumers. Therefore, it is essential to investigate that does the effect of temperature or more extended heating period affects the quality of the cooking oil through microwave dielectric analysis.

For the quality control of cooking oil, its properties inspection should be conducted and studied [6]. Every type of organic material includes cooking oil, has electrical properties [7]. This property depends on the dielectric properties of the material [7]. In this study, Agilent E8362B P-series Network Analyzer hardware has been introduced to identify the cooking oils' dielectric properties. The reflection coefficient of cooking oil also been considered using an open-ended coaxial sensor.

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METHODOLOGY

Sample Preparation

Five samples of vegetable oil (cooking oil) were purchased from the local market, as shown in Figure-1. They are five different types of cooking oil: corn oil, palm oil, olive oil, walnut oil and sunflower oil. The manufacturers provided the compositions of cooking oils. The ratio of saturated and unsaturated fats is given in Table-1.

Figure-1. Samples of cooking oil from the local market.

Table-1. Characteristic of the oil used in this study.

Type of oil/fat	Saturated fats (g)	Mono-unsaturated (g)	Poly-unsaturated (g)	Ratio of Saturated: Unsaturated
Corn oil	14.4	26.8	49.8	5.32
Olive oil	12.0	72.0	7.0	6.58
Palm oil	43.0	43.0	14.0	1.32
Sunflower oil	11.0	25.0	64.0	8.09
Walnut oil	10.0	16.5	69.9	8.64

First, the sample was placed in the cubicle and was weighted by electronic weighting scale before it was put inside the oven. The measurement value of 35g for every oil samples were recorded. The cooking oil samples were heated at 60ºC, 80ºC and 100ºC for 30 minutes. Then let it be cooled down to room temperature before conducting the dielectric properties measurement. The process was repeated for each cooking oil.

Dielectric Properties Measurement

The open-ended coaxial probe is a cut-off section of the transmission line. For a dielectric measurement, the probe can be touched on the flat surface of a solid material or immersed into a liquid [6]. Figure-2 shows the coaxial probe method, and Figure-3 shows the open-ended coaxial probe used to measure dielectric properties in this study.

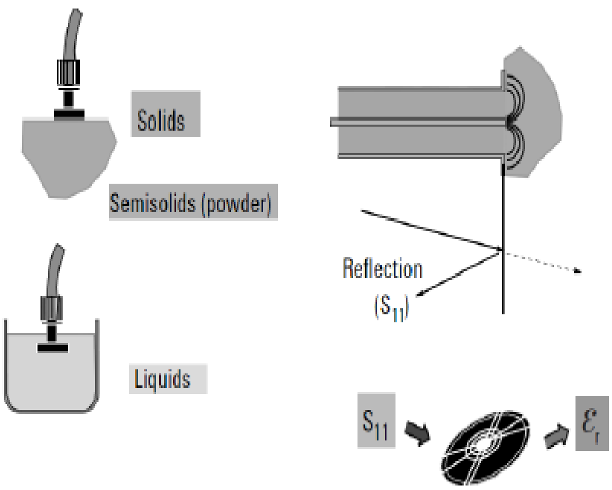

Figure-2. Coaxial probe method.

Figure-3. Open-ended coaxial probe.

For the dielectric properties measurement, the required apparatuses include an open-ended probe, shorting block for calibration, Agilent PNA Network Analyzer, 85070 Material Measurement software, a coaxial cable and 85052 D 3.5 mm Economy Calibration Kit. Calibration on the coaxial cables should be carried out before any measurements are conducted. By conducting the calibration process, it can eliminate the systemic measurement errors caused by the system and remove undesired errors like noise in the coaxial cable. For open-ended probe calibration, shorting block and water at room temperature is adopted.

Reflection Coefficient Measurement

For reflection coefficient measurement, the technique of free space measurement is applied. It is usually implemented without any installation of waveguide or transmission line. The types of equipment are needed for conducting this technique include Agilent PNA Network Analyzer, a coaxial cable, an open-ended coaxial sensor, a pair of retorts stand and 85052 D 3.5 mm economy calibration kit. Coaxial cable calibration will be conducted first before carrying out the reflection coefficient measurement. The measurement is conducted in the frequency range between 2GHz -8GHz.

RESULT AND DISCUSSIONS

Relationship of dielectric constant, loss factor and reflection coefficient with frequency for 5 samples of cooking oil at room temperature

Figure-4 shows the frequency dependence of dielectric constant for the cooking oil at room temperature between 0.2GHz and 20GHz. The comparison of dielectric constant values of all these cooking oils shows that the dielectric constant value of olive oil is the highest, followed by walnut oil, sunflower oil, and corn oil. Palm oil is recorded as the lowest dielectric constant at room temperature. Similar behavior for all-natural esters is explained with structural similarity for all the samples. This similarity does confirm the conclusion in the study of [7] that olive oil has a higher dielectric constant in a higher frequency range due to the higher amount of monounsaturated fatty acid than the other esters. According to Figure-4, it is indicated that the dielectric constant of all the cooking oils shows a plateau in the frequency range of 3GHz-20GHz. The same observation has been made in the previous research [8]. It may be due to the equilibrium between the orientation of the oil molecule and the electric field. Thus, the value of dielectric constant showed virtually no frequency dependence in this frequency region.

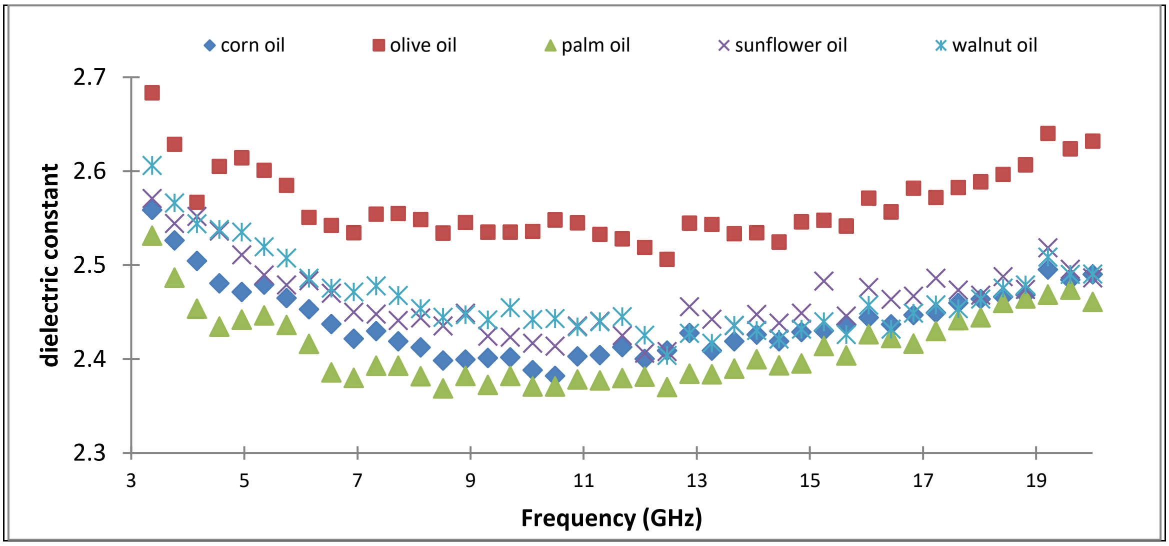

Figure-4. Frequency dependence of dielectric constant for cooking oil at room temperature.

Figure-5 shows the frequency dependence of loss factor for the cooking oils at room temperature. It shows the decreasing value of loss factor for all the cooking oils. Dielectric loss factor is a typical measurement of the dielectric losses or energy dissipated as heat in an insulating fluid when exposed to an alternating field. It is an important indicator of contamination or deterioration [9]. Corn oil, palm oil, sunflower oil, and walnut oil show a decrement in loss factor value over frequency, but the values are too small to differentiate them clearly from each other. The loss factor of olive oil increasing from approximately 3 GHz to 5 GHz. Beyond 5 GHz, it decreases steadily until 20GHz as evidently revealed in Figure-5.

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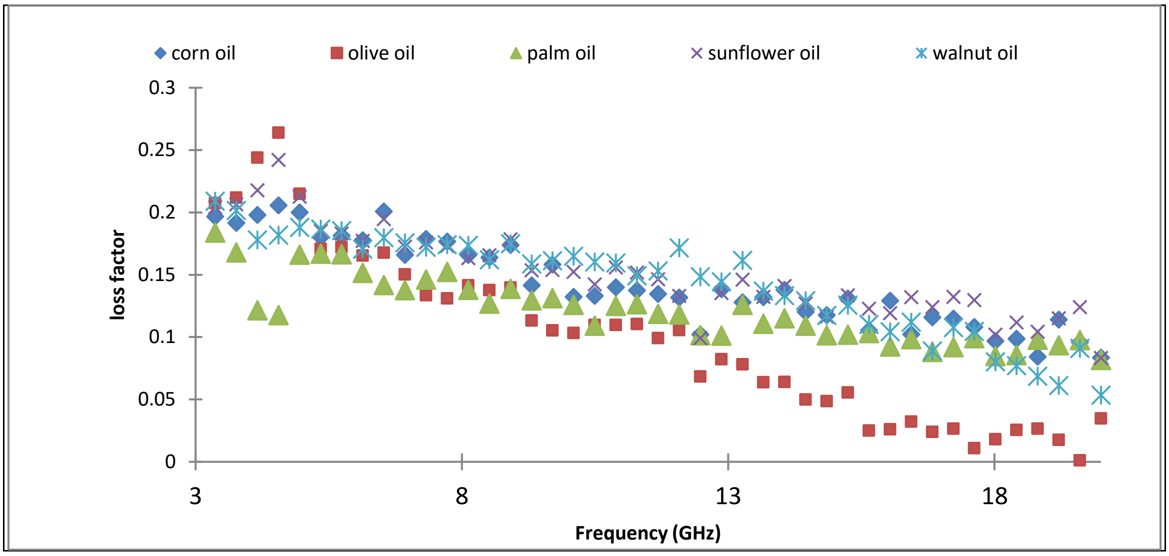

Figure-5. Frequency dependence of loss factor for cooking oils at room temperature.

Figure-6 illustrate the frequency dependence of reflection coefficient's magnitude and phase for the cooking oils at room temperature in the linear format for open-ended coaxial cable. It is found that the values of reflection coefficient from P- series network analyser (PNA) are within the frequency range of 0.2GHz to 20GHz, where all the magnitude and phase of the cooking oils have a similar pattern of trend line over the frequency. The magnitude shows ripple form from 4GHz to 20GHz, whilst the magnitude values are randomly scattered as the frequency increasing. It shows the weak correlation for the magnitude measurement in cooking oils using open-ended coaxial sensor due to multiple wave reflection between the extended inner conductor and cooking oils [9].

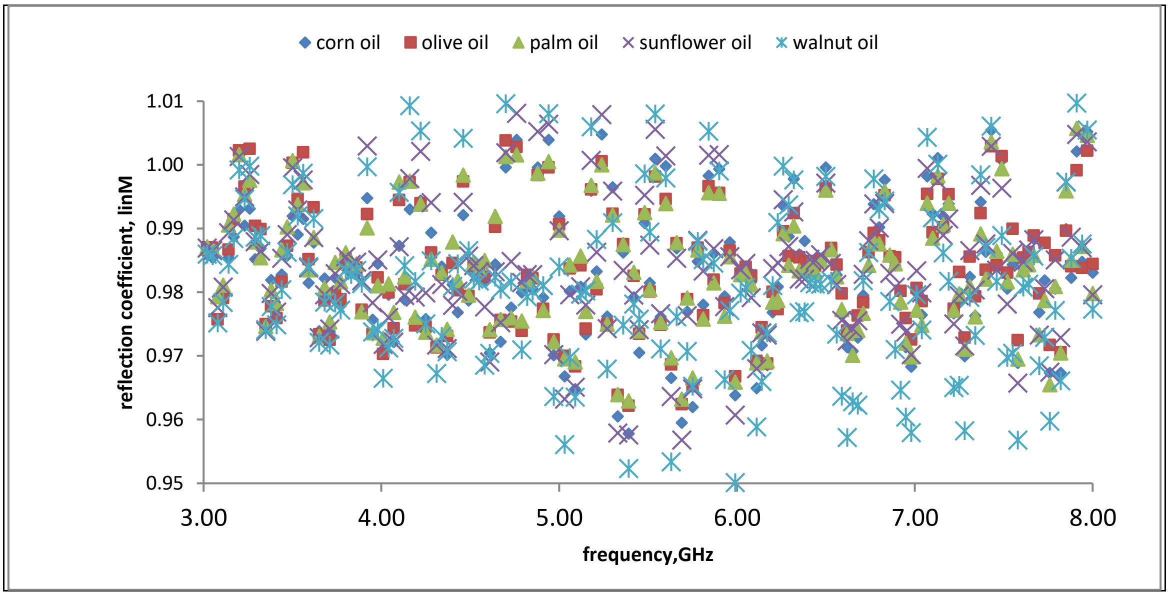

Figure-6. Frequency dependence of reflection coefficient' magnitude for cooking oils.

Relationship of dielectric constant and loss factor with frequency for various heated cooking oils at (a) 60ºC, (b) 80ºC and (c) 100ºC

Figure-7(a) to 7(c) show the frequency dependence of dielectric constant for the samples cooking oil at the temperature of 60ºC, 80ºC and 100ºC. There is little decrement of dielectric constant values of cooking oils with the increase of frequency. This decreasing tendency is also in close agreement with earlier result [8] in which the research reported that the dielectric constant of cooking oil decrease as the frequency increase. This change is observed in cooking oils because the dielectric medium has orientation polarization. The figures also show that there is a little decrement in the dielectric constant when the temperature increases. The increase of temperature causes an increase in kinetic energy, i.e. the velocity of the molecules, therefore causing an increase in the chaotic movement and decreases in the dipole orientation, which decreases the dielectric constant [8].

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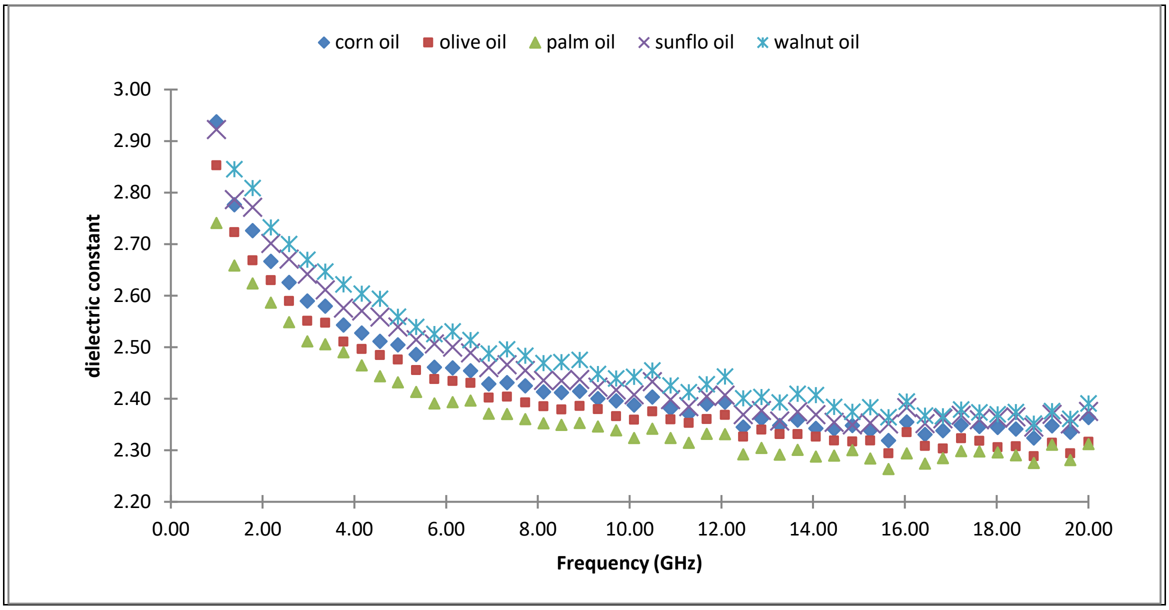

Figure-6(a). Frequency dependence of dielectric constant for cooking oils at 60ºC.

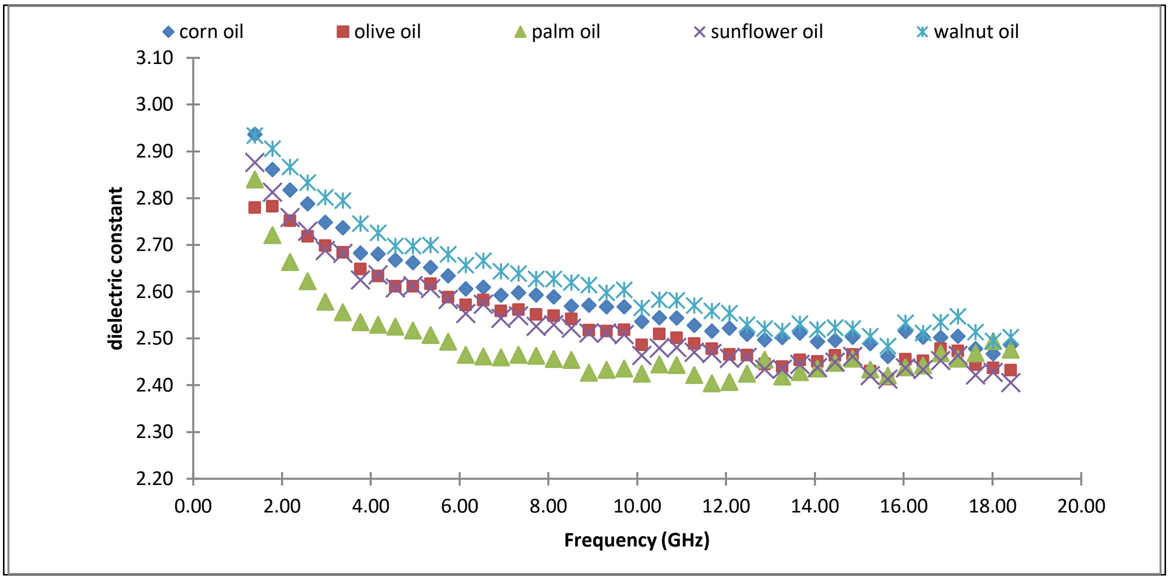

Figure-6(b). Frequency dependence of dielectric constant for cooking oils at 80ºC.

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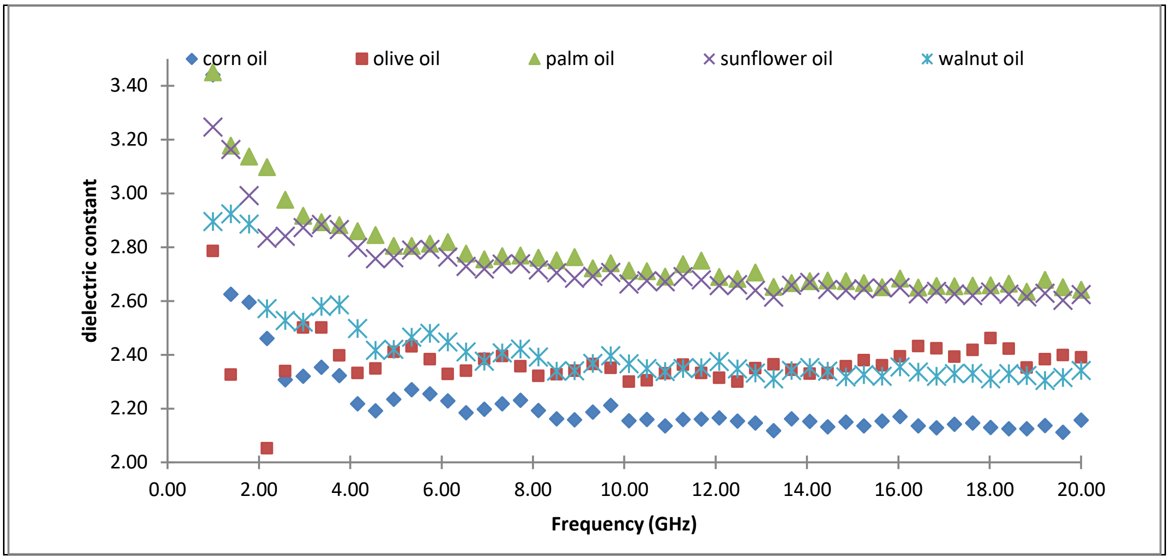

Figure-6(c). Frequency dependence of dielectric constant for cooking oils at 100ºC.

Figures 7(a)-7(c) show the measured dielectric loss factors (Ɛ'') of cooking oils over the frequency range 0.2GHz-20GHz at three temperatures, i.e. 60°C, 80°C and 100°C. The loss factor for insulating materials used in electrical constituted two components: the losses related to conduction processes and the polarization phenomena. Cooking oils have polar nature, and their conductance also increases with the rise in frequency at a particular temperature [8]. Thus, conductance and polarization of cooking oils will increase loss factor at higher frequencies. Figure-7(a) indicates the loss factor of the oils. It exhibited a similar effect to frequency, i.e., a decrease of loss factor from 0.2GHz to 6GHz, mainly due to the increase of polarization effect, and it causes reductions in loss factor value. The loss factor will keep flatten up to 18GHz and then following by a slight decreasing from 18GHz-20GHz. For Figure-7(b) and Figure-7(c), the oils are heated to the higher temperature of 80°C and 100°C, it is observed that some loss factor peaks are appearing and fluctuating at the intermediate frequency range. This observation mostly is attributed to the accumulation of free fatty acids or other impurities at the electrode surface. This effect is more significant at higher temperatures due to the lower viscosity of the medium.

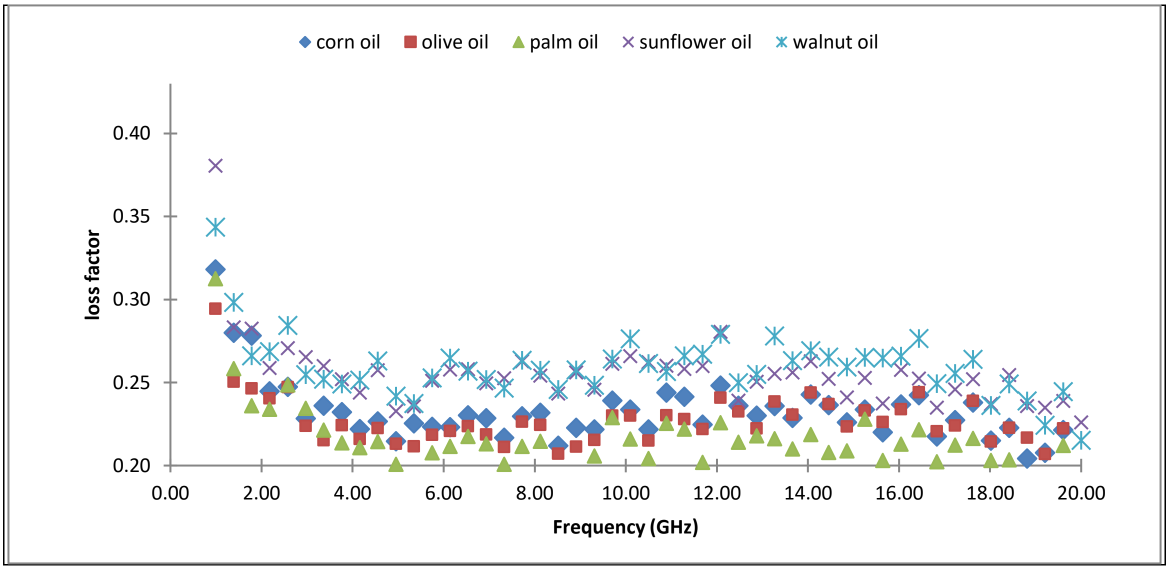

Figure-7(a). Frequency dependence of loss factor for cooking oils at 60ºC.

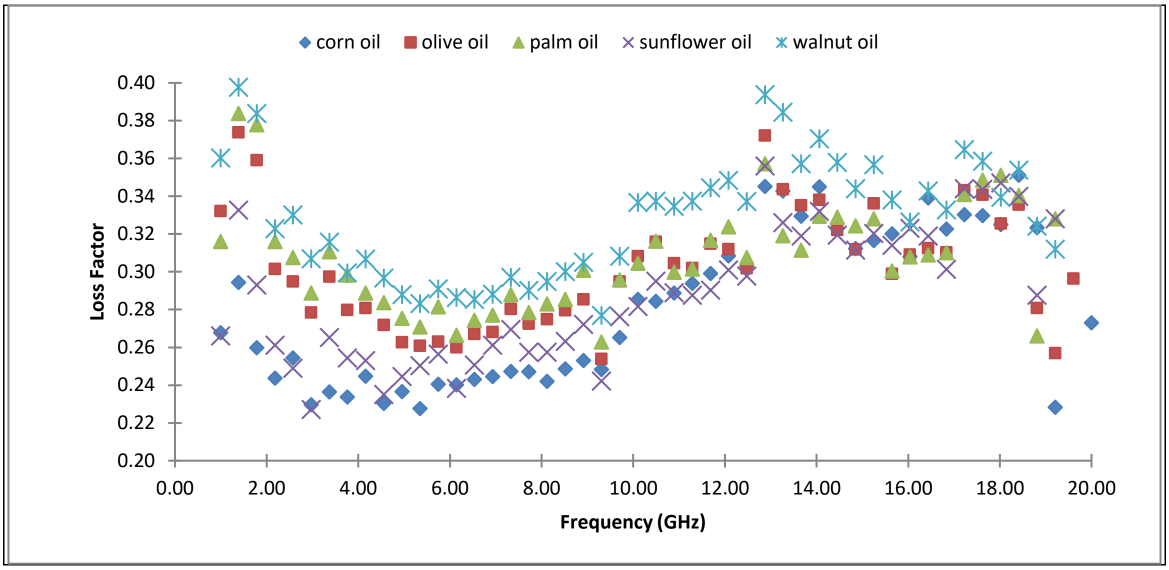

Figure-7(b). Frequency dependence of loss factor for cooking oils at 80ºC.

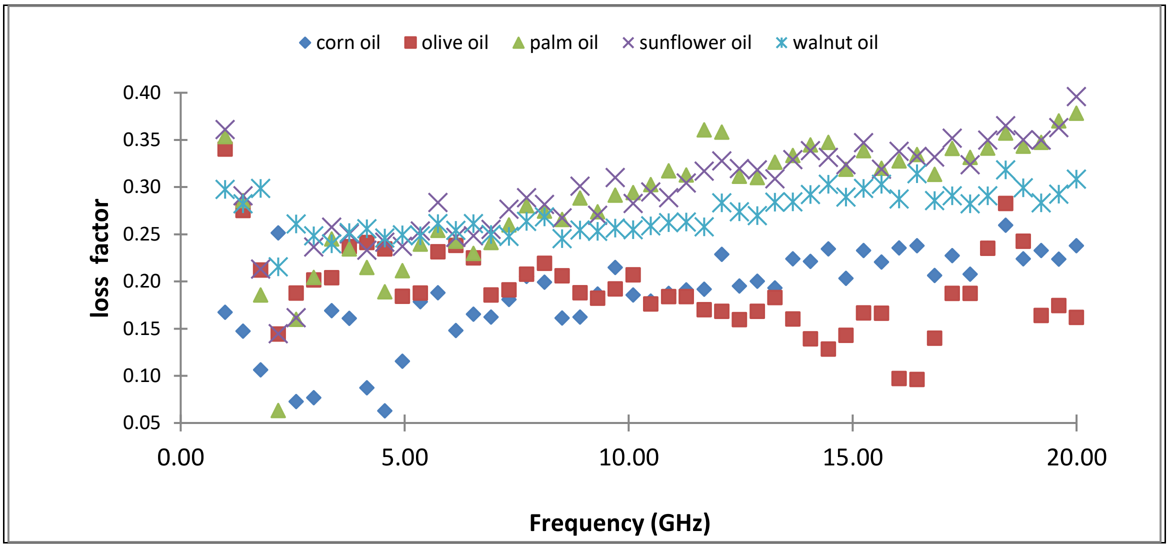

Figure-7(c). Frequency dependence of loss factor for cooking oils at 100ºC.

CONCLUSIONS

This study has successfully achieved the objectives. This study's main intention is to distinguish the fresh and used cooking oil by investigating the effect of heating cooking oil. The findings of this study were able to provide vital information for cooking oil identification. The factors that differentiate the performance of cooking oil include the characteristic of cooking oils. In this study, the cooking oil can be classified by the dielectric properties and reflection coefficient of cooking oils. The cooking oils' dielectric properties had been investigated at the temperature of 60ºC, 80ºC and 100ºC for the frequency range from 0.2GHz to 20 GHz. The variation in these properties with temperature is considered appreciable for quality inspection of cooking oil. The dielectric constant of various cooking oils shows the same frequency dependence trend among cooking oil samples. The dielectric spectra exhibited a broad plateau and the maximum value at lower frequencies and a decrease significantly at dielectric dispersion area.

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