Modelling, characterization and quality analysis of heated oil using electric moment and chemical properties

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Abstract The effect of temperature (30–90 °C) on the electrical parameter: dielectric constant (ϵ_r) of Sunflower, Olive and Corn oil exposed to three cycles of heating to frying temperature (175 ± 5 °C) was studied to exhibit the quality analysis of oil. Dielectric constant of heated oil was measured using designed inter-digitated electrode capacitor at different frequency (10 kHz–5 MHz) and temperature (30–90 °C). Dielectric constant (ϵ_r) of oil samples increases with cycles of heating. Variation of dielectric constant with frequency was premeditated using quadratic equation and the dependency factor was observed to be $R^2 > 0.914$. Chemical kinetic dielectric constant with temperature was studied using Arrhenius law and observed that activation energy increases with cycles of heating. Andrade's equation was also fitted with the variation of ϵ_r with temperature and the dependency factor (R^2 between 0.978 to 0.999) was observed to be highly correlated. Experiential physical properties like density, refractive index and ϵ_r were significantly correlated with the pragmatic peroxide value. The observed relation between ϵ_r with chemical property divulges the suitability of measured dielectric constant in

real time and continuous evaluation of edible oil quality analysis in food industry.

Keywords Dielectric constant · Peroxide value · Density · Refractive index · Oil · Polarisation

Introduction

Deep fat frying at high temperature (150–200 °C) is a common and traditional method of cooking food. Fried foods are highly attractive because of their crispiness, light brownish colour, aroma, texture, taste, flavour etc. Quality of fried food is highly related with oil and food that are used for frying (Armarego and Perrin 1996). Water content present in food stuffs for frying reacts with air and temperature that leads to chemical reactions like oxidation, hydrolysis and polymerization (Moretti et al. 2012). On chemical breakdown of oil, the primary product produced is peroxide, which contributes non-volatile polar compounds (PC) (Al-Kahtani 1991; Choe and Min 2007; Rubalya Valantina et al. 2015). Polar compounds in oil can be estimated using capacitive sensor (Prevc et al. 2013; Khaled et al. 2015; Rubalya Valantina et al. 2017). Permittivity of oil is the ratio of capacitance in oil to capacitance in air, which can be considered as an index to measure the quality of oil (Prevc et al. 2013; Rubalya Valantina et al. 2017). Testing kits available in market like Testo 270, Food oil monitor 310, Capsens 5000 etc., though acclimatise the same concept in monitoring the quality of oil, they are quite expensive. Hence such instruments are used in high-end restaurants and food industry of Europe countries (El-Shami et al. 1992).

Traditional methods for accurate quality analysis include sensory evaluation method, column

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chromatography, chemical system and infrared detection method (Hamparsum et al. 2011). Many of these techniques are already discussed by many researchers in the past decades (Fritsch 1981; Hui 1999; Prevc et al. 2013; Khaled et al. 2015). However available methods are costly, need experts to handle the instrument, not portable and are time consuming.

Chemical amendment produced in oil on frying affect the physical and chemical properties of oil. Formation of polar compounds influences the change in permittivity of oil (Inoue et al. 2002). Density, viscosity, refractive index, peroxide value (PV) and dielectric constant are important properties in quality analysis of oil (Augustin et al. 1987; Velasco et al. 2004). Density of oil increases due to the molecular clustering of lipid polymer formed on hydrolyses glycerides of glycerol with fatty acids and lower amount of lipid polymer (Rubalya Valantina et al. 2017). Viscosity of oil increases with increase in saturated fatty acids (SFA) that darkens the oil. This colour change and saturated fatty acid content influences the refractive index of oil. Peroxides are the primary product formed on rancidity, when oil is exposed to high temperature of heating (Inoue et al. 2002; Rubalya Valantina et al. 2013).

Dielectric constant (DC) of a material is highly influenced by temperature and frequency (Ahmed et al. 2014). It is a measure of polarised compound that moves towards the electrode with respect to the applied electric field at constant frequency. Increase in dielectric constant is due to increase in storage of electric charges produced on chemical breakdown (Shah and Tahir 2011; Phebee Angeline et al. 2016). At low frequency, increase in DC (permittivity) is due to the space charge and atomic polarisation of polar compounds in sample. However as frequency increases, it is hard for the polar molecule to react with the applied electric field; hence DC value decreases. In vegetable oil, the dipoles are reactive at frequency > 900 Hz, and the DC value ranges from 2 to 3.2 (Pace et al. 1968; Ahmed et al. 2014). The long chain aliphatic fatty acids in oil, forms degraded hydro-peroxide as an oxidation product, which causes an increase in capacitance of oil which in turn increases the DC value of oil (Lizhi et al. 2008; Kumar et al. 2013; Rubalya Valantina et al. 2016). Hence the dielectric constant of oil can be correlated with the peroxide value and can be considered as a quality index to determine the degradation level of oil.

This proposed work reports the design of an interleaved capacitance sensor to find the variation of capacitance of oil by changing the frequency and temperature parameters. From the measured capacitance value, dielectric constant of the oil sample was calculated. The composition of sample of fresh Sunflower oil (Saturated Fatty Acid: SFA—12.9%, Monounsaturated Fatty Acid: MUFA—74.6%, Polyunsaturated Fatty Acid: PUFA—10.3%), Corn

oil (SFA—5.1%, MUFA—62%, PUFA—31.8%) and Olive oil (SFA—9%, MUFA—65%, PUFA—23.2%); was noted from the packing cover; the heated oils after each cycle of heating to frying temperature up to three cycles was taken for the study. Variation of dielectric constant with temperature was fitted with different mathematical empirical equations for data analysis using least square fitting. Specific and orientation polarisation was premeditated from the experimented DC, refractive index and density. DC value was correlated with density, refractive index and peroxide value measured at room temperature (31 °C). It was observed that all the factors correlated well with dielectric constant. Thus from the correlation dielectric constant of oil can be used as a vivacious factor in oil quality analysis.

Experimental work

Materials and methods

Popular branded refined Olive oil (*Olea europaea*), Corn oil (*Zea mays*) and Sunflower oil (*Helianthus annuus*) were bought from a local grocery store in Chennai, Tamil Nadu; India. These oils were selected as they contain large percentage of unsaturated fatty acids (UFA) and are also generally used as frying oils. Samples were prepared as fresh oil (sample 1) without heating condition. Oil was exposed to three cycles of heating 175 ± 5 °C (ORBON G Electric heater) using stainless steel vessel for ½ h (sample 2), 1 h (sample 3) and 2 h (sample 4). Each sample was taken in three sets of glass bottles. Thus 36 samples for the investigation were stored at dark conditions to offer protection from external atmospheric conditions and to maintain ambient temperature condition. Chemicals needed for the peroxide studies: Potassium Iodide, Sodium thio-sulphate, acetic acid and isooctane were procured from Sigma Aldrich Chemicals (India Private Ltd, India).

Fabrication of capacitor sensor

A low cost interconnected electrode printed on printed circuit board was designed to measure the relative permittivity of oil from the ratio of capacitance in medium to air. Electrodes were arranged in comb shape, which were interconnected to form capacitive plates. Capacitance value changed with varied distance between the plates, area of plates and nature of the dielectric medium that fills the plate. In this study, dielectric constant changed with the nature of the medium and accordingly the capacitance changed. Capacitance of a parallel plate capacitor is given in Eq. (1) (Khaled et al. 2015).

$$C = \frac{\epsilon_0 \epsilon_r A}{d} F \quad (1)$$

where ϵ_0 is the permittivity of free space (8.854×10^{-12} F/m), ϵ_r permittivity of the medium, A area of the plates and d distance between the plates.

Using CAD software, the sensor scheme was drawn and printed on a transparent sheet. The image was imprinted on a Copper Clad Board thereby fabricating the sensor. Figure 1 illustrates the schematic of dielectric constant measurement using designed capacitor sensor with the capacitance 18.8×10^{-12} F.

In order to take the lead wires from the electrode, a 1.5×10^{-3} m drill was bored on the board. Subsequently two copper wires were soldered for the terminal leads for capacitance measurement. In order to improvise the usage of the capacitor, a thin film of gold was plated over copper. This coating prevents copper which is reactive to oil and also moderates the overall cost. Thus gold coating avoids degradation of sensor, while measuring capacitance of oil at high temperatures repeatedly. The corresponding equation for finding the dielectric constant of oil is given below in Eq. (2).

$$\epsilon_r = \frac{(N-1)sC}{A\epsilon_0} \quad (2)$$

where ϵ_0 is the permittivity of free space (8.854×10^{-12} F/m), ϵ_r relative dielectric constant of oil, s space between each of the electrode and it is equal to 0.2×10^{-3} m, N number of electrodes and A —area of the inter-leaved capacitance, where $A = L(s \times N)$ in which L is the length of the copper electrode.

Dielectric constant

Using the developed capacitive sensor, dielectric constant was measured using LCR meter ranging from 10 kHz to

Fig. 1 Illustration of dielectric constant measurement with fabricated capacitive sensor

5 MHz frequency (Rubalya Valentina et al. 2016). The instrument was calibrated using regular procedure. The capacitive sensor was dipped in oil fully, and the corresponding change in capacitance was noted from the LCR meter DCK-001 (Mittal Enterprises, New Delhi, India). Dielectric constant was calculated using Eq. (2). Dielectric constant of carbon tetra chloride and benzene was measured for calibration. It was observed with 0.2% of accuracy.

Density

Density of oil was precisely measured using a Pycnometer with an accuracy of $\pm 0.2 \text{ kg m}^{-3}$ in accordance with ASTM standard method D891-09 (Rubalya Valentina et al. 2017).

Refractive index

Carl Zeiss Abbe's refractometer (Sinotech) was used to measure (ASTM D1218) and calibrate the refractive indices by measuring triply distilled water and toluene at room temperature with an accuracy of ± 0.001 .

Peroxide value

Peroxide value of oil samples was determined by the standard AOCS official method Cd 8-53 Method. The oil sample was dissolved in acetic acid and isooctane, added potassium iodide and titrated for free iodine to get the end point with 0.01 mol/L sodium thiosulfate (Crowe and White 2001; Phebee Angeline et al. 2016).

Statistical analysis

The independent parameter temperature and dependent parameter dielectric constant was fitted with different model equation and analysed as illustrated in Table 1. The table elucidates the value of specific constants A, B, C and D along with the correlation coefficient and standard error estimate (SEE) using least square approximation. The statistical analysis of the data, correlation and regression was carried out with graphPad prism and Microsoft Excel 10.0 software.

Results and discussion

Variation of dielectric constant with frequency

Olive oil, Corn oil, Sunflower oil as fresh oil and heated for I, II and III-times, were the considered samples for which DC value was acquired for change in frequency ranging

Fig. 2 Variation of dielectric constant with log frequency of **a** Sunflower oil, **b** Corn oil, **c** Olive oil

from 10 kHz to 5 MHz. Figure 2 illustrates the variation of DC versus frequency for all the samples respectively. It is observed that, for all the considered fresh oil samples, obtained DC value ranges from 2.51 to 2.76 and is found to be increasing while the oil is subjected to repeat cycles of heating. In fresh oil, amount of UFA present will be more for which reason DC of fresh oil is less.

However, when the oil is subjected to cycles of heating, the amount of UFA decreases on dilapidation, because of which DC value is found to increase, which can be contingent from Fig. 2a–c for Sunflower oil, Corn oil and Olive oil. Also greater the DC value of oil, greater the content of polar compounds: peroxides, free fatty acids (FFA), ketones, aldehydes, triglycerides, SFA etc. Hence, from the obtained DC value, one can conjecture whether the oil is fit for further frying usage or not.

The non-linear variation of DC with frequency of fresh oil and heated oil of all samples were fitted to $\epsilon_r = Af^2 + Bf + C$ quadratic equation with least square fitting and the related constants, and dependence factor R^2 value ranges between 0.914 and 0.998 were estimated. Lizhi et al. (2008) also observed a slight decrease in dielectric constant for frequencies > 1 MHz for the vegetable oil. It is because at static low frequencies, dipoles have enough time to respond to the applied electric field but at radiofrequency, the dipoles could not follow the increasing frequency and hence the DC value decreases.

Variation of dielectric constant with temperature

Figure 3 illustrates that the variation of DC value decreases with increase in temperature. However, the dielectric constant decreases as the viscous nature of the oil get reduced and the mobility of polar compounds varies. Very few researchers have addressed the correlation of viscosity and DC with temperature (Risman and Bengtsson 1971; Dilip Kumar et al. 2013; Rubalya Valentina et al. 2016). It can be inferred that increase in temperature increases the kinetic energy of the moving polar molecules leading to a greater randomness of motion and thus decreases the dipole orientation which in turn results in low dielectric constant. From 30 to 90 °C temperature, DC value of unheated oil decreases to 6.1% for Sunflower oil, 6.6% for Olive oil and 5.6% for Corn oil. Increase in DC value with time of heating is due to the conversion of large amount of PUFA into SFA on oxidation. *Trans* form of fatty acids that are formed on isomerization are saturated fatty acids that are quantified with percentage of SFA in oil.

Table 1 illustrates the variation of electric permittivity with temperature fitted to the following empirical equations.

(i) Arrhenius equation:

$$\epsilon_r = A e^{\frac{E_a}{RT}} \quad (3)$$

where E_a is the activation energy (kJ/kg), R is universal gas constant (8.314×10^3 J/kg mol K) and A is a constant

Fig. 3 Variation of dielectric constant with temperature of **a** Sunflower oil, **b** Corn oil, **c** Olive oil

Table 1 Constants and regression coefficients for empirical equations between dielectric and temperature in range of 30–90 °C

Sample	Empirical equation	Order of model	A	B	C	D	SE	R ²
Sunflower oil	Arrhenius model	I	2.96	0.167	–	–	0.109	0.985
Corn oil			2.63	0.157	–	–	0.160	0.961
Olive oil			3.01	0.247	–	–	0.241	0.934
Sunflower oil		II	4.98	0.148	– 47.09	–	0.441	0.995
Corn oil			5.92	0.126	– 76.91	–	0.450	0.994
Olive oil			8.17	0.198	– 120.6	–	0.491	0.995
Sunflower oil		III	1.22	0.187	– 255.7	4611	1.403	0.999
Corn oil			7.33	0.117	– 145.5	1044	0.017	0.994
Olive oil			14.63	0.157	– 436.3	4808	0.011	0.998
Sunflower oil	Andrade model	I	0.263	– 0.09 × 10 ^{–2}	–	–	0.003	0.978
Corn oil			0.263	– 0.0909 × 10 ^{–2}	–	–	0.004	0.978
Olive oil			0.369	– 0.1109 × 10 ^{–2}	–	–	0.001	0.996
Sunflower oil		II	0.287	– 0.1809 × 10 ^{–2}	7.4 × 10 ^{–6}	–	0.005	0.998
Corn oil			0.286	– 0.1809 × 10 ^{–2}	7.4 × 10 ^{–6}	–	0.004	0.996
Olive oil			0.379	– 0.1409 × 10 ^{–2}	3.1 × 10 ^{–6}	–	0.003	0.998
Sunflower oil		III	0.283	– 0.1609 × 10 ^{–2}	3.7 × 10 ^{–6}	8.8 × 10 ^{–8}	0.017	0.995
Corn oil			0.283	– 0.1609 × 10 ^{–2}	3.7 × 10 ^{–6}	2.0 × 10 ^{–8}	0.016	0.999
Olive oil			0.3849	– 0.1709 × 10 ^{–2}	8.4 × 10 ^{–6}	2.9 × 10 ^{–8}	0.011	0.998

(m²/s). Activation energy (AE) varies from 18.81 to 29.7 × 10³ J/mol. The potential barrier height in transition of state increases with cycle of heating. Taking logarithm on both the sides of Eq. (3) is given below:

$$\ln \varepsilon_r = A + \frac{E_a}{RT} \quad (4)$$

$$\ln \varepsilon_r = A + B \left(\frac{1}{T} \right) \quad (5)$$

Taking logarithm on both the sides of Eq. (3) and the corresponding II and III order, empirical equations are given below in Eqs. (6) and (7) respectively

$$\ln \varepsilon_r = A + B\left(\frac{1}{T}\right) + C\left(\frac{1}{T^2}\right) \quad (6)$$

$$\ln \varepsilon_r = A + B\left(\frac{1}{T}\right) + C\left(\frac{1}{T^2}\right) + D\left(\frac{1}{T^3}\right) \quad (7)$$

Table 1 lists the values of specific constants A, B, C, D, standard estimated error (SEE) and the correlation coefficient. The correlation coefficient varies from 0.934 to 0.999 and the cohesive or thermal energy of activation for polar molecules range from 12.2 to 14.63×10^3 J/mol. Accuracy of data varies from 1 to 6%. It was observed that cubic Eq. (7) relates more with the data compared to linear and quadratic equation. From the constant listed in Table 1, DC of oil at any temperature can be predicted. The non-linear variation of DC with temperature was also correlated with other 3 sets of empirical equation in which (ln) of ε_r is directly related with temperature.

(ii) Andrade Model:

Andrade equation is given below

$$\varepsilon_r = A e^{RT} \quad (8)$$

Logarithm is taken on both the sides of Eq. (8) and fitted the values to I, II and III order Eqs. (9)–(11) as given below:

$$\ln \varepsilon_r = A + B(T) \quad (9)$$

$$\ln \varepsilon_r = A + B(T) + C(T^2) \quad (10)$$

$$\ln \varepsilon_r = A + B(T) + C(T^2) + D(T^3) \quad (11)$$

Table 1 also illustrates the values of specific constants A, B, C, D, SEE and the correlation coefficient varies from 0.978 to 0.999. The accuracy of data varies from 1–2.2%. It was observed that cubic Eq. (11) relates more with the data compared to linear and quadratic equation. From the constant listed in Table 1, DC of oil at any temperature can be predicted.

Dielectric constant and other oil quality indices

Electrical permittivity ε_r of the oil samples without heating, I, II and III time heated were measured at room temperature 31 °C at 2 MHz frequency. Table 2 exhibits the measured capacitance value, calculated dielectric constant, observed density, peroxide value, refractive index, specific refractive index, polarisation and orientation polarisation. Capacitance of the designed capacitor in air is 18.8×10^{-12} F; it was observed that in samples value increases with time of heating. When electric field is applied at room temperature, the orientation of dipoles

varies the capacitance value. After thermal exposure, the sample might have undergone ionic polarisation due to rancidity. The capacitance increases by 3.2% for Sunflower oil, 1.65% for Corn oil and 7.5% for Olive oil. The rise in the capacitance value is due to the movement and storage of charges or polar chemical species formed on duration of heating. There is no steep increase in C value, as the temperatures to which the samples were heated are not to its smoke point at which a drastic chemical breakdown takes place. Hence, usages of oil at multiple times below smoke point do not produce high toxic effects.

Similarly, the DC value increases by 8.3% for Sunflower oil, 6.9% for Corn oil and 1.7% for Olive oil after III cycle of heating. Less increase in % of DC in Olive oil is due to the presence of larger amounts of unsaturated fatty acids. Retaining the percentage of unsaturated fatty acids in oil even after third cycle of heating is due to the presence of high potent antioxidant in oil (Rubalya Valantina et al. 2015). Formation of peroxides is compared between the fresh oil and III time heated oil. The increase in ratios was observed as follows: (i) Sunflower oil: 9.32 times, (ii) Corn oil: 3.64 times and (iii) Olive oil: 3.5 times. The observed peroxide value of Sunflower oil after third heating is found to be 30.1. This is greater than the PC value limit of Hazard Analysis and Critical Control Points (HACCP) for discarding the oil. Increase in peroxide value of Sunflower oil is due to the evaporation of tocopherol on heating, which induces the formation of hydro-peroxides (Choe and Min 2007, Rubalya Valantina et al. 2013). The study exemplifies that Sunflower oil cannot be used after second cycle of heating. Density, which decides the number of molecules per unit volume, shows the increase in Sunflower oil by 13.66%, Corn oil 2.4% and Olive oil 2.84%. This study shows that molecular clustering is more in Sunflower oil compared to the other two oils.

Refractive index of the oil was measured using standard method. Table 2 illustrates that the value of the refractive index (n) increases with cycles of heating. The oil undergoes chemical reaction that changes the colour of oil on successive cycles of heating. The radicals produced in oil alter the quantity of UFA and increase SFA that varies the colour of the oil. This in turn changes the refractive index of oil (Rudan-Tasič and Klofutar 1999; Agrawal and Deepak 2005; Rubalya Valantina et al. 2017). From the measured refractive index (n), the specific refractive (r) value, which is the refractive index upon specific volume, was calculated using the equation:

$$r = \frac{(n - 1)}{\rho} \quad (12)$$

Using Lorenz–Lorentz Eq. (13), specific refraction R was calculated and exemplified in Table 2.

Table 2 Dependence of the indices dielectric constant, density, PV, refractive index, specific refractive index, polarisation and orientation polarisation with time of heating

Sample type	Sunflower oil								Corn oil							
	C in pF	ϵ_r	PV mEqO ₂ /kg	ρ 10 ³ kg/m ³	n	R 10 ⁻³ m ³ /kg	P 10 ⁻³ m ³ /kg	P _o 10 ⁻³ m ³ /kg	C in pF	ϵ_r	PV mEqO ₂ /kg	ρ 10 ³ kg/m ³	n	R 10 ⁻³ m ³ /kg	P 10 ⁻³ m ³ /kg	P _o 10 ⁻³ m ³ /kg
NH	50.5	2.76	3.228	0.846	1.473	0.332	0.437	0.105	54.6	2.51	4.822	0.850	1.470	0.326	0.394	0.068
I-H	50.8	2.81	7.782	0.850	1.474	0.331	0.443	0.112	54.8	2.64	11.24	0.859	1.471	0.322	0.411	0.089
II- H	51.1	2.90	13.42	0.852	1.475	0.330	0.455	0.125	55.1	2.67	13.99	0.866	1.472	0.321	0.413	0.092
III-H	52.1	3.01	30.10	0.854	1.476	0.330	0.470	0.14	55.5	2.71	16.89	0.871	1.474	0.319	0.417	0.098

Sample type	Olive oil							
	C in pF	ϵ_r	PV mEqO ₂ /kg	ρ 10 ³ kg/m ³	n	R 10 ⁻³ m ³ /kg	P 10 ⁻³ m ³ /kg	P _o 10 ⁻³ m ³ /kg
NH	49.4	2.69	1.169	0.856	1.473	0.330	0.421	0.091
I-H	51.9	2.80	10.71	0.868	1.474	0.327	0.432	0.105
II- H	52.5	2.82	18.72	0.872	1.475	0.325	0.433	0.108
III-H	53.1	2.84	21.57	0.881	1.477	0.324	0.434	0.109

NH not heated, I-H first time heated, II-H second time Heated, III-H third time heated

$$R = \frac{(n^2 - 1)}{(n^2 + 2)} \left(\frac{1}{\rho} \right) \quad (13)$$

It was observed that specific refraction value decreases with time of heating due to increase in peroxide content and decrease in unsaturation level of long chain fatty acids. It was also observed that high value of peroxide limits Sunflower oil for further cycles of heating.

Specific polarisation (P) was calculated using Debye's equation using the electric permittivity of oil at different time of heating by:

$$P = \frac{(\epsilon_r - 1)}{(\epsilon_r + 2)} \left(\frac{1}{\rho} \right) \quad (14)$$

As the cycles of heating increases, induced dipole moment per unit electric field in the oil samples also increase and can be measured as specific polarisation exemplified in Table 2.

Calculation of orientation polarisation (P_o) from the specific polarisation and specific refraction is given by the equation:

$$P_o = P - R \quad (15)$$

Table 2 illustrates increase in orientation polarisation by 26% in Sunflower oil exposed to III cycles of heating compared to fresh oil. The variation is due to the formation of SFA that upsurges the amount of polar compounds in oil on heating. In Corn oil, the increase is observed to be more in the first time of heating and later drops to 0.5% after third cycle of heating. This variation is due to the restoration of UFA by strong antioxidants in oil. It is

observed that Olive oil does not show any variation due to the sustained percentage of unsaturated fatty acids even after third cycle of heating.

Correlation of peroxide value with dielectric constant, density and refractive index

Vegetable oil on oxidation produces the first degraded product peroxide (Rao et al. 2014). Hence correlation of this factor with other parameters calculates the dependency relation between them. Relations between the physical, electrical and chemical properties were studied to exemplify the usage of simple and low cost measuring parameter in quality analysis of oils. Table 3 gives the dependency relation between peroxide and the other factors like dielectric constant, density and refractive index. The dependency factor DC, density and refractive index are related with the independent factor peroxide value and are fitted in a quadratic equation with least square fitting ($R^2 = 0.948$ to 0.999). All the three factors were observed to have high dependency; anyhow DC and refractive index have maximum correlation. Peroxide values are correlated with DC, refractive index and density. Hence DC can be used as the universal measure for quality assurance of all types of oil.

In extensive perspective, the electric moment of fresh oil that was investigated is experimental to be low as the oil samples contain large amount of UFA and the oil was not degraded. However on degradation of oil when exposed to cycles of heating, UFA decreases causing increase in DC value which can be considered as a quality index of oil.

Table 3 Regression coefficient and correlation of peroxide value with dielectric constant, density and refractive index

Oil sample	Parameter	A	B	C	R ²	SE
Sunflower oil	Dielectric constant	7.033×10^{-4}	0.364	2.555	0.995	0.021
Corn oil		5.371×10^{-4}	0.273	2.599	0.994	0.011
Olive oil		9.979×10^{-4}	3.753×10^{-4}	2.854	0.997	0.003
Sunflower oil	Density	1.552×10^{-5}	2.209×10^{-4}	0.8486	0.989	1.720×10^{-4}
Corn oil		5.744×10^{-5}	8.36×10^{-4}	0.8501	0.995	4.021×10^{-3}
Olive oil		2.336×10^{-5}	3.114×10^{-4}	0.8424	0.948	1.348×10^{-2}
Sunflower oil	Refractive index	5.042×10^{-5}	2.800×10^{-4}	1.472	0.968	2.981×10^{-5}
Corn oil		3.312×10^{-5}	3.926×10^{-4}	1.471	0.984	5.210×10^{-4}
Olive oil		3.804×10^{-5}	9.174×10^{-4}	1.478	0.989	0.012

Conclusion

Thus an interleaved copper plate capacitive sensor with gold coating was designed. With the developed sensor, dielectric constant of three different types of oils samples was measured. In addition peroxide value, refractive index and density were the other parameters measured. These parameters taken at three different cycles of heating were used in the calculation of specific refractive index and polarisation. Modelling was also carried out to validate the data and also to predict the parameter at any frequency and temperature. Correlation between the parameters was carried out to validate the results and significant association was obtained between the various parameters. Comparing the peroxide values and dielectric constants of three oils, Sunflower oil has attained the maximum limit of Total Polar Compounds at third cycle of heating. It has been experiential that among the three oils, Sunflower oil cannot be used after second cycle of heating. Consumption of degraded oil leads to chronic diseases in human being; hence simple parameter dielectric constant could be used as a vital index with which the oil quality can be estimated.

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Compliance with ethical standards

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