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Temperature-dependent Dielectric Properties of Adulterated Honey – A Quality Assessment Measure for Fraud Detection

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Honey has become a main target of adulteration due to its important nutrient commodity of high price and in short supply. It can include illegal adulteration as well as overheating by adding water and sugar syrups. For this purpose, the dielectric assessment kit (DAK) which offers measurements of high precision dielectric attributes such as dielectric permittivity, penetration depth, conductivity and loss tangent over a wide frequency range has been used. Dielectric parameters of pure yellow standard honey (A) and their adulterated samples with moisture levels from 17.5 % to 31.2 % were measured with coaxial-line probe from 600 to 6000 MHz at 25–55 °C. Influence of water content and temperature on dielectric properties (dielectric constant, loss tangent, electrical conductivity and penetration depth) of various honey brands B, C and D were also investigated. Temperature and moisture content have a substantial impact on honey's dielectric properties over the complete frequency range. It was observed that the dielectric constant and dielectric conductivity of honey brand named C were related to that of the pure honey sample A, although the values for various parameters of C and D were drastically different from A. Results show that the 915 MHz frequency is more appropriate for microwave heating of honey than the 2450 MHz frequency due to its deeper penetration depth. Finally overheating and water content of honey directly affects its dielectric parameters and their measurements can be used in quality assessment for degraded honey detection.

Keywords: Honey, Dielectric properties, Overheating, Adulteration, Quality assessment

1 Introduction

Honey is a sweet substance produced naturally by honey bees from the nectar of plants or from the excretions of living components of plants. Bees collect and modify it into honey by combining with the specific substance. About 75 % of the honey sugars are monosaccharides, 10–15 % is disaccharides, and the rest are small amounts of other sugars. Honey typically has 60.7-77.8 % sweetener (of which 0-2 % can be sucrose, 25.2-35.3 % glucose, and 33.3-43 % fructose), 12.4-20.3 % water and less than 0.25 % carbon[1]. The presence of fructose and glucose in honey contributes to its sweetness[2].

The honey's composition is specified by the Codex Alimentarius. Moisture, sugar, sucrose, hydroxymethylfurfural (HMF), electrical conductivity, and free acidity in honey should not exceed 20 %, 60g/100g, 5g/100g, 40 mg/kg, 0.8 mS/cm and 50 milliequivalents acid/100g, respectively[3]. Honey's biological effects and its positive impact on human health is widely documented due to some fascinating properties such as antioxidant, prebiotic, antibacterial and antimutagenic of its certain constituents[4-5].

Honey has found enormous applications throughout the world such as in food product and veterinary medicines. Increased body weight from additional sugar in the diet can lead to an increased risk of high blood pressure and diabetes. As a result, honey may be used to sweeten foods and beverages without having negative health impact of added sugars. Owning of its unique properties, honey is used as antibiotic, antiseptic, anti-oxidant and ingredient of many medicines and various cosmetics[6].

Quality of the honey is affected by the microorganisms (pathogens) present in it and this is controlled by dielectric heating process such microwave (MW) and radio-frequency (RF) heating. This method entails the direct transmission of electromagnetic power inside the materials, resulting in rapid and volumetric heating. Furthermore, RF and MW treatments have a significant advantage over traditional thermal procedures due to its less processing time. The heating is consistent throughout the materials, resulting in improved product quality and pasteurisation efficiency. However,

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microwave oven heating is used for reliquefying crystalline honey for fraud purposes, which affects the hydroxymethyl furfural content in honey, which is a sign of heat damage to honey. The 2450 MHz frequency is the only one registered for usage in food applications in the Czech Republic. 915 MHz is an alternate frequency for food applications in various EU countries[7]. Dielectric characteristics influence the selection of optimum frequency ranges for effective pasteurisation.

Water is one of the main constituent of honey which determines its quality[8]. The water content is extremely indispensable parameter of honey which influences the processing characteristics and storage life. The content of water in honey depends on environmental conditions, the degree of maturity, harvest season and handling by the beekeepers at the time of harvest. Fresh honey is a concentrated liquid containing the more amount of sugar contents than water can normally dissolve. The ripened honey has a low amount of water content in it therefore it can be stored for a longer time. No microorganisms can multiply in the ripened honey because it is highly concentrated. So, it is said that the quality of honey will be better if it has lower content of water[9].

Food fraud is still a problem all around the world[10-11]. It lures organized criminals with the hopes of making more money. Honey, which is widely used in a variety of applications, has become a popular target for commercially motivated adulteration. Honey fraud is one of the most commonly reported activities[12]. This might include the use of low-cost sugar syrups to boost the amount of honey. Historically, this form of food fraud has been difficult to detect. Honey is frequently contaminated or mistreated, resulting in a loss of consistency and a decrease in medical advantages. Due to adulteration dielectric properties of food are very adversely affected as these properties are dependent on the water content and other ingredients.

For identification of food fraud, different technologies and approaches have been proposed[13-16] specifically for honey[17]. Physical parameters were analyzed with the help of pH-meters, rheometers colorimeters or thermographic images[18]. Chemical analysis involves gas and liquid chromatography and spectroscopy[19-21]. Out of these parameters the electrical conductivity, dielectric constant are excellent measures for honey quality assessment.

Honey is a dielectric material and it gets polarized when placed in an external electric field. Polarization is mainly dependent on the electric field and nature of materials. When the concentration of honey is changed, then, its dielectric properties also get changed. Frequency, temperature and moisture content are the important parameters that affect dielectric properties of honey[22]. As a result, understanding the dielectric characteristics of various agri-foods and biological materials are quite beneficial. Techniques of dielectric properties measurement are used in a variety of industries and research facilities. Chemical approaches consume longer time and require specialized apparatus and equipment. Therefore, researchers develop other effective, fast, and non-destructive techniques. The determination of dielectric properties of honey can be considered as one of the best approach for its quality assessment[23].

There is very little information available related to the study of dielectric properties of honey at different concentrations, temperature and frequencies produced in Indian agro climatic conditions. Therefore, the objectives of the present work are to evaluate dielectric properties of different brands of honey. For this motive, the dielectric assessment kit (DAK) which offers measurements of high precision dielectric attributes such as dielectric constant, electrical conductivity, loss tangent over a wide frequency range of 4 MHz to 67 GHz was used. DAK also provides the most powerful vector network analyzers (VNA) for data interpretation over a wide range of frequency.

2 Materials and methods

The experimental arrangement includes following

Selection of Samples

The standard yellow pure honey (A) as reference was collected from the Department of Entomology, CCS HAU, Hisar. No crystals were present in the honey sample. The initial water content in this yellow pure honey was 17.5 %. The main sugar contents for this pure honey were 46.1% fructose, 31.5% glucose and 1.4 % sucrose. Samples of different honey brands (B, C and D) were collected from the market. The dielectric properties were determined at different adulteration level for quality assessment.

Measurement method

In the present study, the dielectric probe method with strong vector network analyzer (VNA) is used. The dielectric probe method is broadband, convenient, non-destructive and is best for liquid and semi solid. In this approach DAK is used, which provides measures of extreme precision for dielectric permittivity, conductivity and tangent loss over the wider range of frequency for many applications related to research and food industries. It consists of single probe solution, DAK system that is able to measure small volumes of liquids. The broad frequency range can be covered with the help of single probe without compromise on uncertainty. Frequency range of 600 MHz to 6000 MHz is used to analyze our sample with a strong vector network reflecto-meter of model number R140 from Copper Mountain Technologies. The probe is mounting on a movable rod that is attached to high quality cables allowing it to be moved inside the sample being tested. The DAK is also calibrated according SPEAG's high quality standards, which is ideal for measurements with small and well-defined tolerances. Probe of the system is very effective and provides excellent contact with the materials under test. It's also simple to clean so there's no cross contamination between the probe and the materials. The most popular vector network analyzer provides a wide range of graphical and numerical analyses with advance algorithms and choice of complex dielectric parameters reported in a variety of data formats i.e., linear plots, smiths charts, logarithmic plots, cole-cole plots and tabulated form.

Preparation of samples and measurement

Above mentioned distinct kind of four honey samples were procured. Four different concentrations of standard honey were prepared with adulteration levels of 5 %, 10 %, 15 %, and 20 % (w/w). The standard honey sample has inherent water content 17.5 %. To prepare honey samples with water content of 21.4 %, 25 %, 28.2 % and 31.2 % as a ratio of mass of honey to the mass of solution at room temperature, distilled water content of 5g, 10g, 15g and 20g added in each 100g of pure honey respectively and stirred thoroughly to prepare a uniform mixture. The masses were measured with an accuracy of 0.0001g using an electronic balance. In a 200 mL glass beaker, a sample of honey was collected at each water content level. After that, the coaxial-line probe was calibrated, and the DAK probe was dipped into the test solution until it was completely immersed in the sample. When no bubble was observed between probe and sample, temperature of the sample was maintained with the help of a constant temperature water bath to prevent moisture loss; a rubber lid of 2mm in thickness was used to cover the beaker. For each sample the dielectric parameters were measured at 25, 35, 45 and 55 °C. The temperature of each sample was measured using a pre-calibrated digital thermometer. Water circulating in the water bath controlled the temperature of the samples. A frequency sweep was performed within 1 minute after the sample temperature neared the required test point to evaluate the dielectric characteristics over the full frequency spectrum. After three consecutive measurements at every temperature value, the water bath was calibrated to the next temperature level, and the sample temperature set the point in around 15 minutes. The probe was properly washed with water for each measurement. For standard honey samples and different brands of honey, all of the results were reported at each temperature for each water content level.

Analysis of dielectric parameters

Debye equation that explain complex permittivity of honey is expressed as

$$\in(w) = \in'(w) - j\in''(w) = \in'(w) - \frac{jk}{w\in_o} \quad ...(1)$$

Where, ε' and ε'' denotes permittivity and dielectric loss, respectively, ω is angular frequency and k denotes conductivity. Permittivity shows amount of electrical energy stored by the material while dielectric loss reflects energy dissipation during reversal of polarity[24]. A plot of ε' and ε'' where, ε' is on abscissa and ε'' on ordinate keeping frequency as a parameter on Argand plane represents complex permittivity of honey. Tangent loss is represented by tanδ where, δ is the angle between the line from a point on the Argand plane to the origin and the abscissa. Tangent loss is defined as the amount of heat lost in a dielectric when polarization changes direction under the influence of an electric field. It is given by the following equation,

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \quad ...(2)$$

There are mainly four types of polarization process, electronic polarization: due to electron displacement under the application of applied field, ionic polarization: due to moment of ions under the applied field, space charge polarization: due to accumulation of charge at the interface between two region within a dielectric material, orientational polarization: the partial alignment of polar molecules free to rotate in the electric field. Dielectric spectra of honey undergo electrical polarization (EP) especially orientational polarization. Some dipolar molecules rotate in the radio frequency band when an alternating electric field is applied. There is some opposition offered to the rotation of the dipole like damping forces, such as viscous drag, molecular vibration hindrance; these type of resistance is mainly depends upon the nature of material as a result, the every dipole has a specific relaxation time, which is given by $\tau = \frac{1}{\omega_0}$ where at ω_o is the frequency, where the maximum energy gets absorbed called frequency of resonance. When ω is much less then ω_o, there is no absorption of energy as all and the dipoles are in phase with applied field on the other hand when ω is much greater than ω_o, again there is no absorption of energy because the dipoles cannot respond to the applied field. At low frequencies, contribution of dipoles to permittivity is high, whereas at high frequencies, they have little effect. Polarization mechanisms are time dependent and can be written as $P(t) = P_o \exp\left(-t/_{\tau}\right)$ where τ is the relaxation time. We can write this in the frequency domain as

$$P(w) = \frac{P_o}{w_o + iw} \quad ...(3)$$

We knew that polarization is characterize by permittivity, so instead of a complex polarization we shall use a complex permittivity of the same form

$$\in (w) = \frac{A}{w_o + iw} + B \quad ...(4)$$

where, **A** and **B** are constants which can be calculated by taking ω = 0 and ω = ∞. The permittivity at zero frequency is the static permittivity, denoted by ε_s. Taking ω = 0 and $\omega = \infty$, we got $\boldsymbol{B} = \varepsilon_\infty$ and $\boldsymbol{A} = \omega_o(\varepsilon_s - \varepsilon_\infty)$. Put these values again in equation (4) and we got

$$\in (w) = \frac{\in_s - \in_\infty}{1 + \frac{iw}{w_o}} + \in_\infty \quad ...(5)$$

By comparing equation (5) with the equation (1), we got the value of real and imaginary part of the complex dielectric constant as

$$\varepsilon' = \varepsilon_\infty + \frac{(\varepsilon_s - \varepsilon_\infty)}{\{1 + (\omega/\omega_o)^2\}} \text{ and } \varepsilon'' = \frac{(\omega - \omega_o)(\varepsilon_s - \varepsilon_\infty)}{\{1 + (\omega/\omega_o)^2\}}$$

The frequency dependence of dielectric permittivity is associated with the material's polarization mechanisms, such as space charge, ionic, orientational and electronic relaxation processes. Also there are corresponding peaks in dielectric loss and reductions in permittivity as the frequency increases. Because electrons respond extremely fast to electric field changes, the absorption peak for electronic polarization occurs at very high frequencies in the ultra-violet or optical region. Ionic motion is thousands of times slower than orientational motion; ionic polarization produces peaks in the infrared, whereas orientational polarization produces peaks at ultra high frequency and microwave frequencies. When the electromagnetic field changes the polarization of individual molecules or causes ionic movement inside the material as it alternates at high frequency, heat is generated within dielectric materials. Because of the minimal dielectric losses, low frequency heating may be particularly effective when applied to systemic packaged food products in large boxes. We employ dielectric properties to detect honey frauds in this study, as well as how heating at different frequencies affects the dielectric parameters of honey.

Penetration depth

The distance from the material's surface at which the power density of electromagnetic radiationis reduced to 1/e or 37 % of its surface value is known as penetration depth (DP)[25]. It describes the level to which electromagnetic radiation can penetrate a substance. The materials with higher loss factor show higher absorption of electromagnetic wave and there is decrease in the penetration distance. Penetration of electromagnetic waves plays an important part in evaluating heating uniformity and designing dielectric heating for many food products for pasteurizing purpose and food fraud detection. The depth of penetration is likewise a feature of temperature, consistent with research on dielectric traits of diverse materials. Penetration depth depends upon dielectric properties of the materials, and can be calculated by equation (6).

$$D_P = \frac{C_o}{2\pi f\left[2\epsilon'\left(\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} - 1\right)\right]^{\frac{1}{2}}} \quad ...(6)$$

Where, C_o = 3.0×10^8 m/s is the speed of light in vacuum and f is the frequency of electromagnetic wave. According to studies on dielectric characteristics of various materials, D_P is also a function of temperature[26].

3 Results and discussion

3.1 Dielectric Constant

The variation of dielectric constant of the standard sample of honey (A) with frequency at different temperatures of 25 °C, 35 °C, 45 °C and 55 °C is represented in Fig. 1(a) Similarly, the Fig. 1(b) represent variation of the dielectric constant with frequency at water content of 21.4 %, 25 %, 28.2 % and 31.2 % at temperature of 25 °C. These plots show that frequency and temperature significantly affect the dielectric constant of honey. It is shown that dielectric constant decreases with the frequency at a given temperature. At lower frequencies, the decrease in dielectric constant is sharp whereas on high frequencies this decrease is very small and finally on higher frequencies, this dependency totally diminishes. It is observed that due to increase in frequency, the net polarization of material drops as each polarization mechanism cease to contribute therefore, the dielectric constant decreases with increase in frequency. For a given value of frequency, dielectric constant rises with the temperature rises as predicted. The same trend has been observed for honey sample with water content of 17.4 % at temperature ranges 20-80 °C at frequency range 10 MHz to 1000 MHz[27]. Over the entire frequency range, the dielectric constant was observed to have minimum value at 25 °C.

Dependency of the dielectric constant on water content in honey, at a particular temperature, is shown in the Fig. 1(b) Honey is known to have a concentrated solution of sugars in which fructose and glucose are the predominant monosaccharide. Owing to sugar solutions, the permittivity of honey is smaller than water. At a given frequency and temperature, dielectric constant is found to increase with the increase in water content. The results are in agreement with the already reported work[28]. The dielectric constant of pure honey sample is found minimum as honey is concentrated and water content is in bound state. Therefore, it gives rise to the minimum polarization and hence low value of the dielectric constant. With the increase in water content of honey, the dielectric polarization gets increased due to free water content and hence, the dielectric constant is found to increase with water content. Because the dielectric constant increases with water content at a particular temperature and frequency, it will be used to simply test the quality of honey for water adulteration. Fig. 1(c) represents the variation of dielectric constant of various honey brands with frequency at a particular temperature. It is clear that at the given temperature, the dielectric constant of all the honey samples decrease with rise in frequency. The dielectric constant shows a dip at 2100 MHz, this may be due to the presence of some impurities or instrumental error. The dielectric constant v/s frequency pattern of honey sample C coincides with that of the standard sample A. This depicts the purity level of sample C and it matches with that of A. The dielectric constant v/s frequency pattern for honey samples B and D deviates drastically from that of standard sample A. The dielectric constant of sample B and D are substantially greater than that of a typical sample A at a given temperature and frequency. The value of dielectric constant in honey greatly relies on the polarization of water. As the water content in pure honey (sample A) is 17.5 % which is lesser than that of the water content present in sample B and D (*i.e* 21.4 %), which further results in lower polarization and thus lower dielectric constant value in comparison of other two samples Band D. These results clearly demonstrate that the samples B and D have been adulterated with water, and these graphs can further be utilized to determine the amount of adulteration present in samples.

3.2 Dielectric loss

The material's dielectric loss tangent indicates the quantitative electrical energy dissipation caused by variety of various physical processes such as relaxation of dielectric, electrical conduction, resonance of dielectric and other non-linear processes.

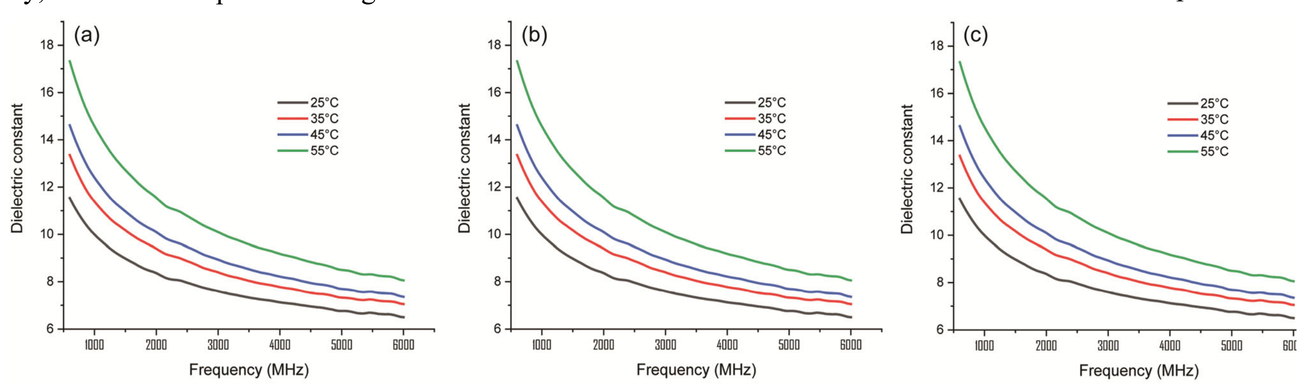

Fig.1 — (a) Dielectric constant verses frequency at different temperature. (b) Dielectric constant verses frequency at different moisture level. (c) Dielectric constant verses frequency for different brands at temperature (25 °C).

The dielectric loss is mainly due to two factors *i.e.* dielectric conduction and the applied electric field. The variation of dielectric loss of honey sample with frequency over the temperature range of 25 to 55 ^{o}C is shown in the Fig. 2(a). At a lower level of frequency, it has been observed that dielectric loss factor of pure honey sample increases with increase in frequency and decreases with increase in temperature. The graph also shows that there is dielectric resonance at frequency 2100 MHz where dielectric loss is high for every temperature value. It is found that the loss factor also increases with increase in temperature when the frequency in set more than 600 MHz. After the resonance, there is a decrease in dielectric loss factor with frequency but this occurs at a very slow rate. At lower frequencies, the dielectric loss factor decreases with the temperature as ionic conduction play important role, at that time, the frequency of polarization does not match with the frequency of applied A.C. field[29]. At high temperature, dielectric loss factor increases with temperature as the ionic conduction increase, and that causes maximum loss in dielectric. Fig. 2(b) shows the variation of dielectric loss with frequency at water content of 17.5 %, 21.4%, 25 %, 28.2 % and 31.2 % at temperature 25 ^{o}C. It is observed that at the lower frequency below 300 MHz, due to the ionic conduction dielectric loss for high water content is low for a particular temperature. As the frequency increases dielectric loss decreases for pure honey (water content 17.5 %) because polarization lags behind the applied electric field. The dielectric loss factor for honey samples with a water content of 31.2 % is low at lower frequencies due to ionic conduction, but increases with frequency and reaches its maximum at 5400 MHz, and a similar trend is observed for honey samples with a water content of 28.2 %. It was noticed that at lower frequency the dielectric loss for water content of 25 % increases with frequency and it shows resonance at 2100 MHz after that on the frequency of 2100 MHz onwards, there is decrease in dielectric loss at a very slow rate.

Figure. 2(c) illustrates how the dielectric loss factor of honey brands A, B, C & D varies with frequency. From the graph, it is evident that dielectric loss at low frequency is high and then it shows resonance at 2100 MHz, where loss approaches its maximum value for all brands. It has been observed that, for all honey brands, dielectric loss is found to decrease as frequency increases. This implies that water content in these samples (A, B, C & D) is not more than 25 %. It is observed that all the honey sample have different value of dielectric loss at a given frequency and temperature. The value of dielectric loss for honey sample A is minimum followed by C, D and B. This shows that there is some adulteration of water in all the honey samples except for sample C, where very minor adulteration is observed.

3.3 Electrical Conductivity

Figure. 3(a) depicts the fluctuation of honey's electrical conductivity with frequency at various temperatures, indicating that frequency and temperature have a significant impact on electrical conductivity. Honey's dielectric conductivity is observed to increase with frequency at a specific temperature, as expected, and this is consistent with already established results[30]. The change in electrical conductivity shows that as the temperature of the sample is increased from 25 ^{o}C to 55 ^{o}C at interval of 10 ^{o}C, the electrical conductivity increases significantly with temperature. At 915 MHz and temperatures of 25, 35, 45, and 55 ^{o}C, electrical conductivity of pure honey sample are 0.23, 0.28, 0.32, and 0.38 (S/m), respectively. The electrical conductivity

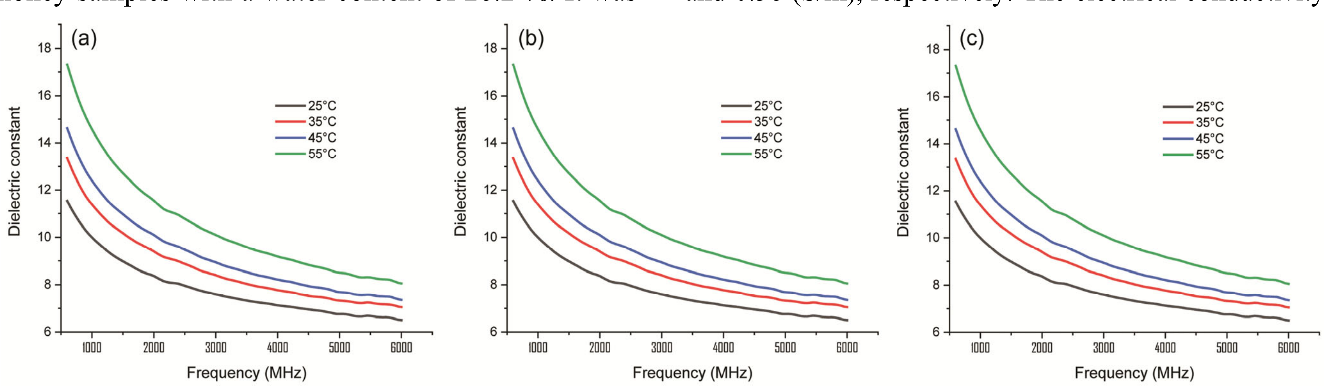

Fig. 2 — (a) Dielectric loss verses frequency at given temperature. (b) Dielectric loss verses frequency at different water content. (c) Dielectric loss factor verses frequency for different honey brands.

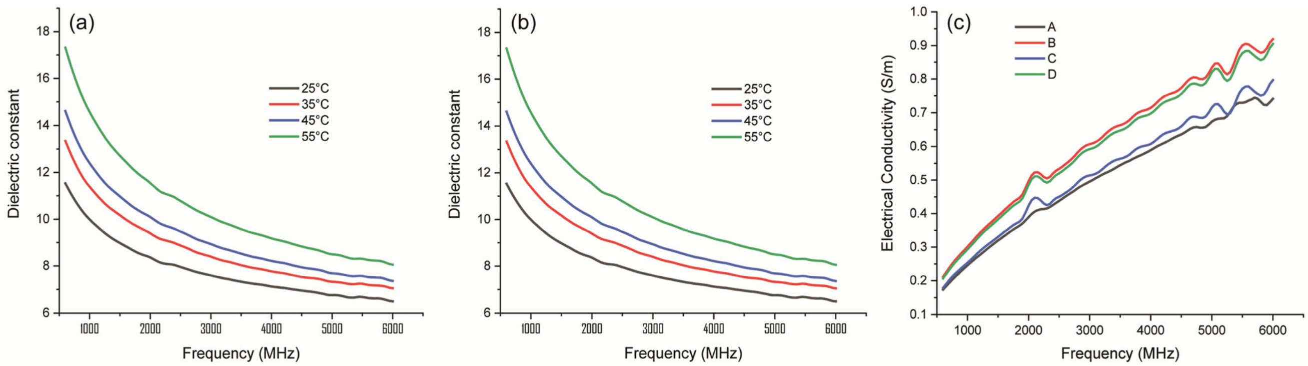

Fig. 3 — (a) Electrical conductivity verses frequency at given temperature. (b) Electrical conductivity verses frequency at different water content. (c) Electrical conductivity verses frequency for different honey brands

of a solution mainly depends upon the mobility of the ions present in it. As the temperature rises, the mobility of ions increases and the conductivity rises with it. At any given frequency value, electrical conductivity increases with rising temperature, as expected, and is consistent with the reported work[31]. Furthermore, over the whole frequency range of observation, electrical conductivity is lowest at 25 °C and highest at 55 °C.

Fig. 3(b) represents the variation of electrical conductivity with frequency for different level of water content at constant temperature of 25 °C. The water content is one of the factors which affect the electrical conductivity. It is found that the electrical conductivity of honey sample increases with the water content or dilution at a given temperature and frequency. The values found in the present study were compatible with the published data[32-33]. It is observed that the electrical conductivity of honey sample with water content of 17.5 % is minimum and maximum for water content of 31.2 %. As the honey, in its pure state, is concentrated, therefore, the mobility of the ions in the solution is lowest and the electrical conductivity is lowest. With increase in the level of dilution, electrical conductivity value increases as a result of increased mobility of ions in solution. It was studied that in the more diluted samples, electrical conductivity values increased as the result of increasing ion concentration up to a maximum value[34]. The present work on electrical conductivity corroborates the work done by researchers earlier.

Figure. 3(c) represents the variation of electrical conductivity of honey brands A, B, C and D with frequency at a particular temperature. It is found that behavior of sample C is consistent with pure standard honey sample A but the behavior of B and D sample is quite divergent from standard sample A. All these samples show similar behavior to frequencies as electrical conductivity of all samples increases with increasing frequency at a particular temperature. But electrical conductivities of honey sample B and D are higher than pure standard sample A at particular frequency and temperature. As the conductivity of honey depends upon the mobility of ion which is further dependent on water content, therefore, greater is the water content in honey, higher is the value of electrical conductivity. It is found that brands B and D have higher electrical conductivity than A which shows that moisture content in B and D is substantially higher than the pure honey sample and hence we can say that, there is some adulteration of water in the sample B and D.

3.4 Penetration Depth

Figure. 4 shows how change in temperature affects penetration depth of pure yellow honey computed on the frequency range from 600 to 6000 MHz. It was noticed that as the temperature of pure yellow honey (A) rises, the penetration depth at a particular frequency decreases. Figure also illustrates that for a given temperature when we increase the frequency penetration depth gets decrease and the penetration depth at 915 MHz is higher than that of frequency at 2450 MHz. In other terms, penetration strength of the applied field in the lower frequency is better than that of higher. To make the pasteurization process more effective with dielectric heating, the thickness of food materials should not exceed two or three times the penetration depth[25]. However, according to the computed value of penetration depth, dielectric heating at 915 MHz appears to have more benefits for large volume of materials. Moreover, besides the frequency and dielectric properties of food material, the distributions and magnitudes of electromagnetic waves inside food is also influenced by the shapes,

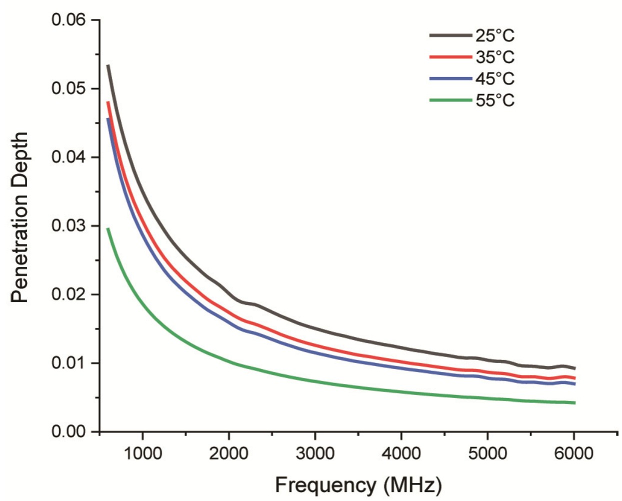

Fig.4 — Penetration depth verses frequency at given temperature

sizes *etc*., and making it difficult to assess the efficiency of dielectric heating. As a result, more research on the dielectric characteristics of food products is needed to successfully use dielectric heating to the food business.

4 Conclusions

Honey's dielectric characteristics evaluated over a given frequency range might be beneficial for recognizing honey adulteration. Because these parameters are simple to measure, techniques based on dielectric parameter determination can be simple and fast.

- The results implied that the dielectric constant and electrical conductivity of honey are significantly dependent on frequency at a given temperature, and the temperature also affects these parameters over the whole frequency range, implying that heating degrades honey quality.
- At a particular temperature and frequency, adulteration of water has a significant impact on the dielectric properties of honey, and conductivity is found to be higher than the value reported in the literature (Codex Alimentarius, 2001). The presented approaches might be a useful tool for determining the quality of honey and detecting water adulteration.
- The outcomes of this study indicated that water content affects dielectric loss, suggesting that honey contaminated with water having high loss tangent, altering the chemical properties of honey.
- With variations in frequency and temperature, the value of the penetration depth decreases with increase in temperature. High penetration depth for low frequency shows that the use of frequency signal at 915 MHz than 2450 MHz is more appropriate for sterilization of honey's dielectric heating.
- In comparative analysis of various honey brands, it was noticed that the dielectric constant and dielectric conductivity of brand C is compatible with the pure honey sample A and the value of dielectric constant of sample A and C at 25 ^{o}C and frequency of 915 MHz is found 10.2 and at 2450 MHz is 8, whereas the parameters for B and D are wildly different from that of sample A.

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