Study of Dielectric Properties of Fruit Juices at Different Frequencies

Ruchi Kulhar[1], Mukesh Kumar Alaria[2], Nidhi Bhargava[1] and Ritu Jain[1]

1. Department of Physics, IIS (Deemed to be University), Gurukul Marg, SFS Manasarovar, Jaipur-302020, Rajasthan, India.s
2. Microwave Tubes Area, CSIR-Central Electronics Engineering Research Institute (CEERI), Pilani-333031, Rajasthan, India.

Abstract: This research paper contributes to the understanding of the dielectric properties of fruit juices at different frequencies. Understanding the dielectric properties of food materials, particularly fruit juices, is essential for optimizing microwave processing techniques and ensuring product safety and quality. In this research, various fruit juices, such as pomegranate, sweet lime, and lemon, were selected as representative samples. The dielectric measurements were conducted at discrete frequencies, using Vector Network Analyzer with an 85070E dielectric probe. The collected data were then analyzed to investigate the frequency-dependent behavior of the dielectric properties. The results revealed that the dielectric constant (ε′) of the fruit juices decreased with increasing frequency, while the dielectric loss factor (ε″) increased with frequency at room temperature (24^0C). This result finding may be due to the molecular structure and polarization of the materials.

Keywords: Dielectric properties, Sweet lime, Lemon, Pomegranate

Introduction:

Sweet lime, also known as mosambi, belongs to the citrus family. Sweet lime, lemon, and pomegranate are good sources of vitamin C, which boosts the immune system and promotes collagen production. They also provide potassium, which helps supports heart health and regulate blood pressure. Sweet lime and lemon both contain calcium, which contributes to bone health, and vitamin A, which is important for vision and skin health. Lemon acts as a natural detoxifier and helps cleanse the body. It contains antioxidants that protect against free radicals and reduce oxidative stress Pomegranates have a unique sweet and tangy taste and are packed with juicy seeds called arils. Pomegranate is a good source of Vitamin C, Vitamin K, Iron, Potassium, and several other nutrients. Pomegranate helps to prevent coronary heart diseases, cancer (breast, skin), inflammation, hyperlipidemia, cardiac disorders, aging, diabetes, brain disorders, hypoxia, and AIDS (Shishodia et al. 2006).

The interaction between electromagnetic radiation and matter is characterized by fundamental parameters known as dielectric properties. These properties play a crucial role in determining and developing applications of materials based on their electrical characteristics. By studying the dielectric data of materials, valuable insights can be gained to effectively understand their capacitive properties, energy storage capabilities, and energy losses resulting from their interaction with electromagnetic fields.

The dielectric permittivity of materials at microwave frequencies can be represented by a complex number, $\varepsilon^* = \varepsilon' - j\varepsilon''$, where ε' is the real part, which is known as the dielectric constant, and ε" is the imaginary part, referred to as the dielectric loss factor [1]. Dielectric constant (ε') is defined as the ratio of the electrical permittivity of the material to the permittivity of free space. The dielectric constant characterizes the material's ability to store electromagnetic energy and is a molecular property that is dependent on temperature and frequency and it also depends on the material's internal structure. The dielectric constant's value is essential in determining how electromagnetic energy is reflected and transmitted when it encounters the interface between material and air. In the case of a vacuum, the dielectric constant is simply equal to one ($\varepsilon'=1$).

The dielectric loss factor (ε") is a measure of how well a material can convert electromagnetic energy into heat, and it depends on both the frequency and the specific dielectric material. This factor can be divided into two components: ε''_d, which relates to dipole rotation, and ε''_σ, which relates to ionic conduction. The ionic conductivity, σ, is measured in Siemens per meter (S m^{-1}), while ω represents the angular frequency of the waves in hertz, and ε_0 represents the permittivity of free space or vacuum.

The measurement of dielectric permittivity in fruit juices at microwave frequencies is a specialized approach that explores the dielectric properties of these juices. It offers valuable insights into how they respond when exposed to microwave radiation. This analysis provides crucial information regarding the behavior of fruit juices in microwave environments. Such knowledge is significant in understanding their interaction with electromagnetic waves and can aid in various applications, including food processing, quality assessment, and product development.

Materials and Measurement Method:

To perform the experimental investigation, freshly obtained samples of Sweet lime, Lemon, and Pomegranate were acquired from a nearby local supermarket and subsequently subjected to juice extraction using a high-quality juicer, followed by meticulous filtration utilizing fine-grain filter paper with appropriate pore size. This methodology ensured the removal of any particulate matter, and impurities, maintaining the purity of the sample.

The dielectric constant (ε′) and dielectric loss factor (ε″) of the fresh Sweet lime, Lemon, and Pomegranate samples cleaned after cleaning the fruit extract juices then measured using a high-frequency vector network analyzer, model Agilent E8364C, in the frequency range of 4 GHz to 20 GHz at room temperature (24^0C). In the study, a test probe used that consisted of an open-ended coaxial probe system, specifically the Agilent 85070E. This probe system allowed the assessment of dielectric properties by examining the phase and amplitude of the signal reflected at the interface between the open-ended coaxial line and the sample being tested. By conducting measurements of the reflection and transmission coefficients at different frequencies and analyzing the physical dimensions of a material, one can obtain a thorough understanding of its permittivity and permeability [2]. This approach enables a comprehensive characterization of the electromagnetic properties of the material. These VNAs automatically display changes in frequency and width of resonant maxima, which can be used to compute the values of the dielectric constant (ε') and dielectric loss factor (ε") (Engelder and Buffler, 1991).

In order to ensure the accuracy of the measurement, the instrument was calibrated using three different loads. These loads were chosen to cover a range of dielectric properties, namely air, a short circuit with metal contacts, and pure water at room temperature. Calibration is a process that helps to make sure that the measurements we take are accurate and reliable. After calibration place the juice sample in a container which is a clean and flat bottom. Insert the open-ended coaxial probe into the juice so that the probe tip is just below the surface of the juice and measure the S-parameters of the juice samples using the open-ended coaxial probe method with the help of VNA over a frequency range 4GHz to 20GHz. The S-parameters can provide valuable insights into the reflection and transmission coefficients of the samples under the study. The open-ended coaxial probe method is a widely accepted and established technique for determining the dielectric properties of liquids or semisolids. Using the S-parameters, it is possible to determine the dielectric properties of the samples, including the dielectric constant and dielectric loss. This can be done using software that is aligned with the Vector Network Analyzer.

The Vector Network Analyzer (VNA) is an accurate and reliable tool for measuring the scattering parameters that are mandatory for calculating the complex permittivity, which includes the dielectric constant and dielectric loss. This technique is highly reliable in determining the dielectric properties of semisolids or liquids, as it provides accurate measurements of the scattering parameters required for the calculations. The complex permittivity is an important aspect in understanding the behavior of dielectric materials, and hence it is important to have a precise and dependable tool like VNA for accurate measurements.

The fundamental components of a VNA consist of a signal source, a receiver, and a display unit. The signal source sends a signal at a single frequency through a coaxial probe to the material under examination. The receiver measures the transmitted and reflected signals of that frequency with the incident energy as the reference. The VNA produces the relevant magnitude and phase data at that frequency. The source is then stepped to deliver a signal of another frequency, and the measurements are repeated. The frequency variation and measurements on the VNA are rapidly performed, displaying the phase and magnitude data for the reflected and transmitted signals as a function of frequency on the detector screen (Agilent, 2006).

Fig.1 Vector Network Analyzer with 85070E dielectric probe kit

Results and Discussion:

In the present work, the values of dielectric constant (ε′) and dielectric loss (ε″) of Sweet lime, Lemon, and Pomegranate juices were measured at different frequencies respectively are listed in table1, 2, and 3. As seen in the data, the values of the dielectric constant and dielectric loss varied with frequency at room temperature(24^0C). The obtained results provide useful insights into the dielectric properties of Sweet lime, Lemon, and Pomegranate.

Table 1. Experimental values of Dielectric properties of Sweet lime Juice at different frequencies at room temperature (24^0C):

Frequency (GHz)	ε′	ε″
4	81.0381	4.5648
6	77.2202	10.2306
8	71.8978	14.9434
10	65.7508	19.0548
12	59.9755	22.3214
14	54.1326	24.3808
16	48. 9816	26.1517
18	44.0745	26.7269
20	39.9676	27.5726

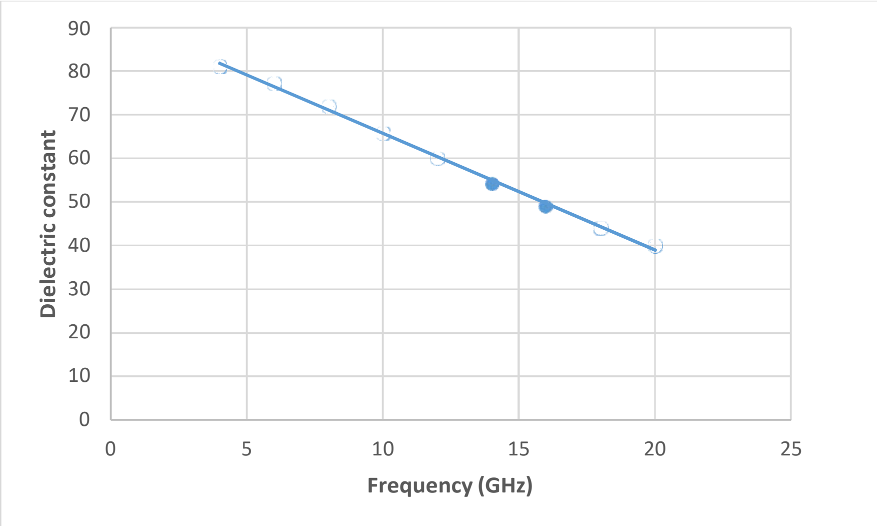

Fig.2 Frequency dependence of Dielectric constant of Sweet lime at room temperature (24^0C)

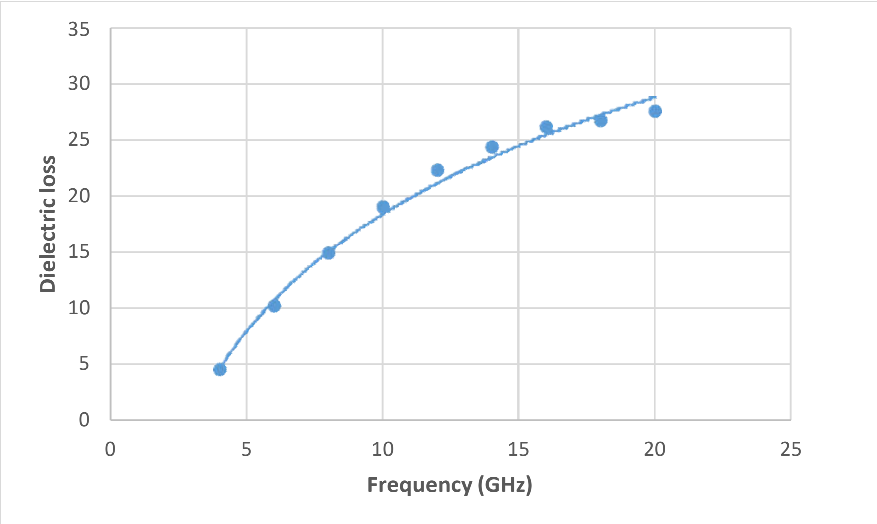

Fig.3 Frequency dependence of dielectric loss of Sweet lime at room temperature (24^0C)

figures 2 and 3 depict the graphical portrayal of the frequency-dependent characteristics of the dielectric constant (ε′) and dielectric loss (ε′′) of sweet lime juice at standard room temperatures. The data exhibits a discernible downward trend in the dielectric constant values as the frequency increases, whereas the dielectric loss values exhibit an upward trend with increasing frequency.

The decrease in the values of the dielectric constant of sweet lime at frequencies ranging from 4 GHz to 20 GHz at room temperature can be attributed to several factors like molecular structure and polarization of the material and electrical conductivity may also be responsible for this. The increasing order of dielectric loss of juice can be attributed due to the Ionic conduction, the presence of ions in the juice can lead to increased electrical conductivity, particularly at higher frequencies. As the frequency increases, the ions in the sweet lime juice are less able to respond to the alternating electric field, resulting in reduced polarization and increased dielectric loss.

Table 2. Experimental values of Dielectric properties of Lemon Juice at different frequencies at room temperature (24^{0}C):

Frequency (GHz)	ε′	ε′′
4	84.5754	2.2621
6	83.0897	10.0594
8	78.0005	14.2447
10	68.5706	18.1221
12	65.9014	22.3005
14	59.0799	25.1606
16	52.5612	26.3206
18	49.9431	27.0188
20	43.531	28.8752

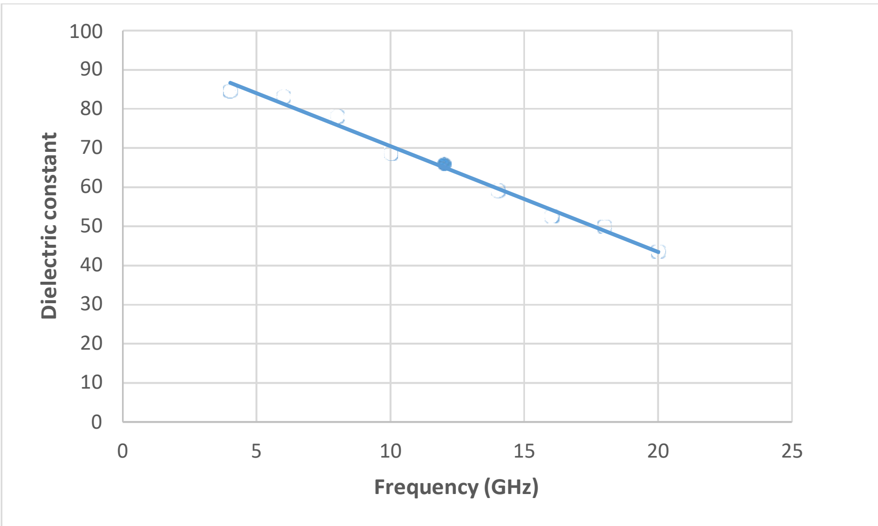

Fig.4 Frequency dependence of dielectric constant of Lemon at room temperature (24^{0}C)

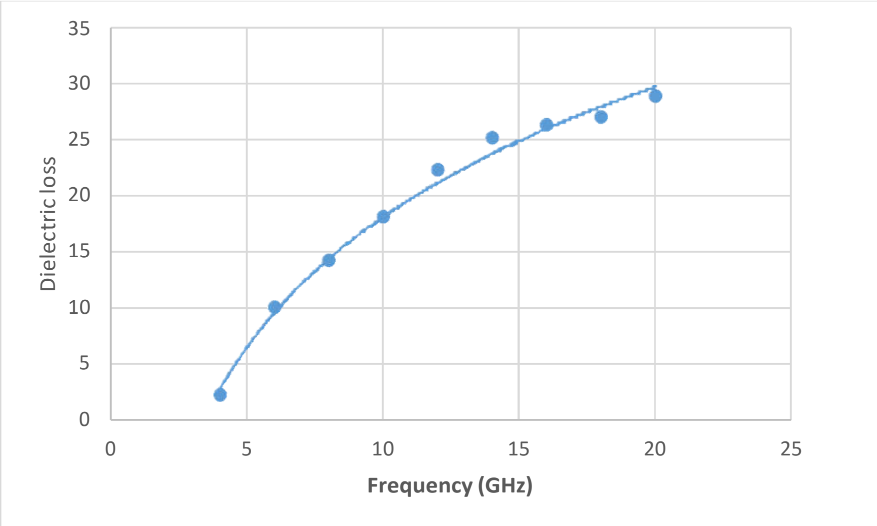

Fig.5 Frequency dependence of dielectric loss of Lemon at room temperature (24^0C)

Figures 4 and 5 present graphical representations of the frequency-dependent behavior of the dielectric constant (ε´) and dielectric loss (ε´´) of lemon juice at room temperature. The data showcases a clear inverse relationship between the dielectric constant and frequency, indicating a decline in values as the frequency increases. Conversely, the dielectric loss values demonstrate a positive correlation with frequency, exhibiting an upward trend.

The decrease in the dielectric constant of lemon juice as the frequency increases from 4 GHz to 20 GHz at room temperature can be explained by the molecular polarization and relaxation processes within the juice. The behavior of dielectric loss can be attributed to the overall, combination of molecular dipole orientation, interfacial polarization, and conductive losses.

Table 3. Experimental values of Dielectric properties of Pomegranate Juice at different frequencies at room temperature (24^0C):

Frequency (GHz)	ε′	ε″
4	77.7682	0.0921
6	75.2764	3.1962
8	70.4909	8.8027
10	65.2406	13.4076
12	60.0461	17.7089
14	54.9106	20.544
16	50.1471	22.7455
18	45.8121	24.0508

20	41.6803	24.8384

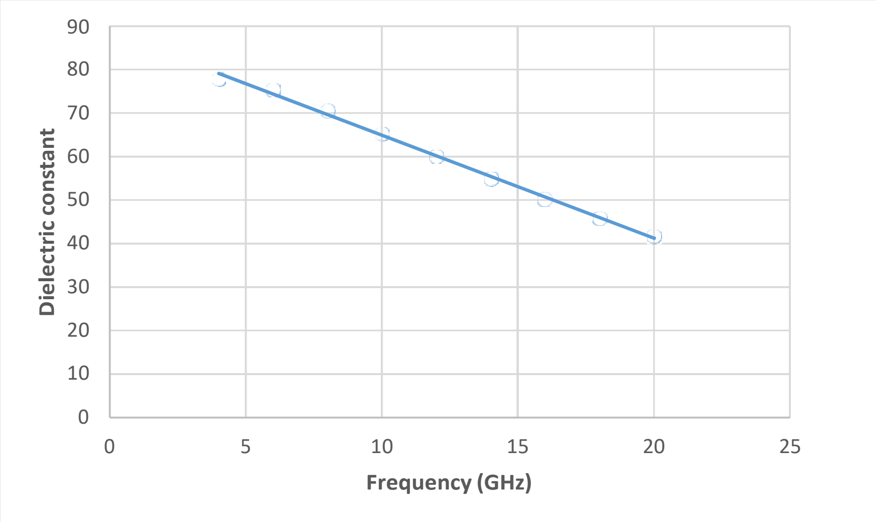

Fig.6 Frequency dependence dielectric constant of Pomegranate at room temperature (24^0C)

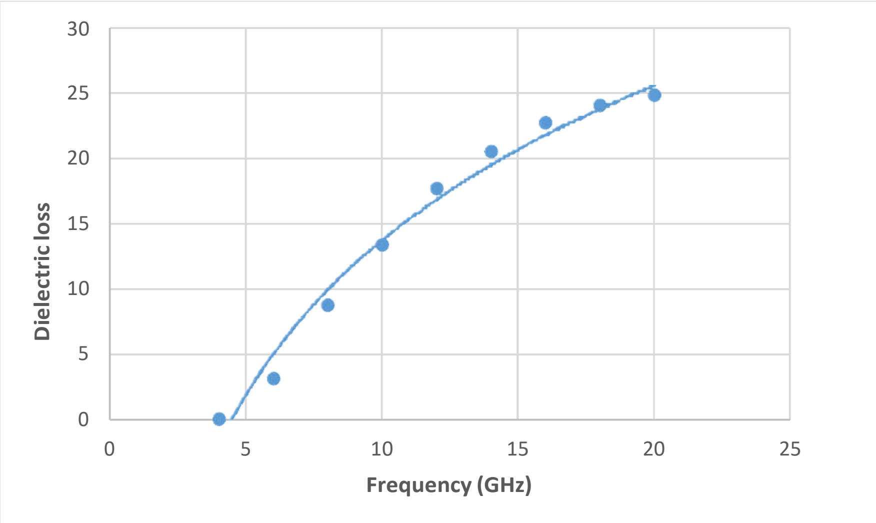

Fig.7 Frequency dependence of dielectric loss of Pomegranate at room temperature (24^0C)

Figures 6 and 7 show graphs that explain how the dielectric constant (ε´) and dielectric loss (ε´´) of pomegranate juice change with frequency at room temperature. The data reveals that the dielectric constant decreases as the frequency increases. On the other hand, the dielectric loss increases as the frequency goes up.

The data shows that the dielectric constant of pomegranate juice decrease with frequency, this behavior can be attributed to molecular relaxation processes, at lower frequencies, molecules have sufficient time to rotate and reorient themselves, contributing to higher dielectric constant values. However, at higher frequencies, molecular relaxation becomes limited, leading to a decrease in the dielectric constant. The increase in dielectric loss of pomegranate juice with frequency at room temperature may be due to the presence of charged particles and ions in the juice. These charged particles respond differently to alternating electric fields at different frequencies, leading to increased energy dissipation and higher dielectric loss.

Conclusion:

The purpose of this research was to examine the dielectric properties of citrus fruit juices, focusing on the dielectric constant and dielectric loss at various frequencies between 4 GHz and 20 GHz at room temperature (24°C). To carry out the measurements, a Vector Network Analyzer (VNA) was employed. The observed trend of a decrease in the dielectric constant values and an increase in the dielectric loss values of sweet lime, lemon, and pomegranate juices with higher frequencies can be attributed to the behavior of molecules within the dielectric substance. It is important to consider that the unique features of each fruit, like its molecules, water content, and cellular structure, can affect its dielectric properties and how they change with frequency. Things like sugars, acids, and other substances dissolved in the fruit can also influence the behavior of dielectric loss and also this may help in gaining a deeper understanding of their electrical characteristics. Further studies can explore the correlation between dielectric properties and other physicochemical parameters of fruit juices to facilitate improved quality control and product development in the food industry.

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