2.1 Introduction

The preservation and quality control of agricultural materials and food products have been an overriding concern for the human beings since time immemorial. As it has been the thorn of the industrialized world especially in agriculture and food sector, it is concomitance to find and niche for research and development in seeds and grains spheres. By the application of radio frequency and microwave heating the associated problem in seeds and grains can be dealt with research in this field. It has diverse orientation like: insect resistance problem, to improve seed quality, seed treatment with radio frequency and microwave energy and making use of dielectric properties of seeds and grains. Dielectric heating by radio frequency and microwave energies are the only remedy that can help us to tackle with infested seed and grains by insects. This can be done by raising the temperature of insects and germs without meeting the same treatment to host (grains/seeds). This is possible only by selective heating. Thus, the study of dielectric properties in both radio frequency and microwave region with various temperatures and in different moisture content would give fairly good idea as to what extent its effectiveness and efficiency can with stand for these applications.

When materials are exposed to radio frequency fields, including microwaves, energy is absorbed, and if the power of the source is high enough, the material heats up rapidly as the energy from the electromagnetic field is converted to heat energy. The rate of dielectric or microwave heating depends upon the dielectric loss of the material, the frequency and strength of the alternating electric fields. The dielectric constant also has some influence on the heating rate, because it generally affects the electric field strength in the materials.

2.2 Theories Related to Dielectric Relaxation of Agricultural and Food Products and Food Materials

The dielectric properties of above agricultural and food materials vary significantly with frequency over a wide enough frequency range. These variations even exceed and surmount the variations due to moisture content. The variation occurring over a wide
range of frequency is called ‘dispersion’, and mechanism responsible for such dispersion may result into ‘relaxation’. Much of the interest in dielectric properties of a material is concerned with the frequency region where dispersion occurs. In this region the permittivity falls off with rising frequency with consequent occurrence of absorption because the dipolar polarization fails to keep pace with the changing electric field. The dielectric relaxation or dispersion over wide frequency range is called **Dielectric Relaxation Spectrum (DRS)**. The DRS analysis is useful in studying the properties of water in food products and food constituents by elucidating the function of different dispersion and losses mechanism. This function has been used to study the hydration of food and food components (1) and can also be used to analyze the moisture and temperature response of dielectric properties (2).

### 2.2.1 Debye Theory

Dielectric properties are represented by the relative complex permittivity $\varepsilon'$. It is an intrinsic electrical property of material which describes the interaction of materials with an electric field. The dielectric loss factor $\varepsilon''$ is the imaginary part of the complex permittivity $\varepsilon'$. The complex permittivity is expressed as

$$
\varepsilon' = |\varepsilon'| e^{j\delta} = \varepsilon' - j\varepsilon''
$$

(2.1)

Where $\delta$ is the loss angle of the dielectric it can be given as

$$
\tan \delta = \frac{\varepsilon''}{\varepsilon'}
$$

(2.2)

Dielectric constant ($\varepsilon'$) is the real part of the complex permittivity which is a measure of the electromagnetic energy stored in material and the imaginary part of complex permittivity ($\varepsilon''$) is known as dielectric loss factor which describes the rate of energy dissipation in the material. The loss tangent (tangent of the loss angle of the dielectric) is also called as dissipation factor. The (ac) conductivity of dielectric is defined as-

$$
\sigma = \omega \varepsilon_0 \times \varepsilon''
$$

$$
\sigma = 55.63 \times 10^{-12} f \times \varepsilon''
$$

(2.3)

Where $\omega = 2 \pi f$ and $\varepsilon_0 = 8.85 \times 10^{-12}$ Farad
The unit of conductivity is siemen/meter, \( \Omega \) is angular frequency and \( f \) is in Hertz. The dielectric material dictates to a large extent, the behavior of the material, when subjected to radio frequency or microwave field for the purpose of heating or drying the materials. The power dissipation per unit volume in dielectric can be expressed by the following relation:

\[
p = E^2 \times \sigma = 55.63 \times f \times E^2 \times \varepsilon'' \times 10^{-12}
\]

(2.4)

Where, \( E \) is rms electric field intensity. The rate of change of temperature in \( ^\circ \text{C}/\text{sec} \) in the dielectric material in due to the conversion of energy from the electric field to heat in the material is given as-

\[
\frac{dT}{dt} = \frac{P}{c \rho}
\]

(2.5)

Where \( c \) is the specific heat of the material and \( \rho \) is the density of material. From equation (2.4) it is clear that the power dissipation depends upon the dielectric loss factor of material used and applied electric field intensity. Debye P described mathematically the nature of dielectric dispersion (variation of dielectric constant with frequency) and absorption for polar materials by a single relaxation time (3).

\[
\varepsilon^* = \varepsilon_\infty + \frac{(\varepsilon_s - \varepsilon_\infty)}{1 + j\omega\tau}
\]

(2.6)

Where \( \varepsilon_s \) is the static dielectric constant and \( \varepsilon_\infty \) is the permittivity at infinite frequency. Separating real and imaginary parts we can write

\[
\varepsilon' = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + \omega^2\tau^2}
\]

(2.7)

\[
\varepsilon'' = (\varepsilon_s - \varepsilon_\infty) \frac{\omega\tau}{1 + \omega^2\tau^2}
\]

(2.8)

Where \( \tau \) is the relaxation time. The relaxation time is the period associated with the time for dipoles to revert to random orientation. Equation (2.7) and (2.8) graphically represented as-
Fig. 2.1: Dispersion and absorption curves for a polar material following Debye Relaxation process.

Dispersion and absorption curves for a polar material which follow Debye relaxation process are shown in the above graph fig-2.1, the dielectric dispersion cover wide range of frequency and dielectric loss reaches its maximum $\varepsilon''_{\text{max}} = (\varepsilon_s - \varepsilon_\infty)/2$ at the frequency $\omega = 1/\tau$. The time scale and shape of decay are related to the structure of the material and polarization mechanism. The corresponding dielectric conductivity of the material with single time constant can also be mathematically expressed as:

$$\sigma = (\sigma_\infty - \sigma_s) \frac{\omega^2 \tau^2}{1 + \omega^2 \tau^2}$$

Where

$$(\sigma_\infty - \sigma_s) = \frac{\varepsilon_0 (\varepsilon_s - \varepsilon_\infty)}{\tau}$$  \hspace{1cm} (2.9)

2.2.2 Cole-Cole Theory

The dispersion of some pure liquids closely follow Debye equation (2.8) (Buckley and Maryoft) but in general it has a distribution of relaxation times in the material. Cole-Cole modified the Debye equation which describes the distribution equation satisfactorily. The plot for Debye relation between $\varepsilon'$ and $\varepsilon''$ in the complex plane shown in following graph (2.2) results a semi circle.
Equations (2.6) and (2.7) are parametric equation of a circle and when we combine above two equations by eliminating $\omega \tau$, Cole-Cole relation is obtained.

$$\left( \varepsilon' - \frac{\varepsilon_\infty' + \varepsilon'_\infty}{2} \right)^2 + (\varepsilon'')^2 = \left( \frac{\varepsilon'_\infty - \varepsilon'_\infty}{2} \right)^2$$  \hspace{1cm} (2.10)

This describes a circle of radius $\left( \frac{\varepsilon'_\infty - \varepsilon'_\infty}{2} \right)$ with centre lies on the $\varepsilon'$ axis at $\left( \frac{\varepsilon'_\infty + \varepsilon'_\infty}{2}, 0 \right)$.

The modified equation presented by Cole-Cole. This is shown in the above fig. 2.3.

The modified equation presented by Cole-Cole is as -

$$\varepsilon = \varepsilon'_\infty + \frac{\varepsilon'_\infty - \varepsilon'_\infty}{1 + (j\omega\tau)^{-\alpha}}$$  \hspace{1cm} (2.11)

The empirical relaxation time distribution parameter $\alpha$ has values in between zero to one and $\alpha$ is an index of the spread in the relaxation time.

### 2.2.3 Cole-Davidson Theory

To explain the behavior of certain types of materials many other models have been developed, one known as Cole Davidson representation which result in a skewed arc when plotted (fig. 2.4), rather than the symmetrical Cole-Cole circular arc (4).

Mathematically Cole-Davidson defined the relation as-

$$\varepsilon = \varepsilon'_\infty + \frac{\varepsilon'_\infty - \varepsilon'_\infty}{1 + (j\omega\tau)^{b}}$$  \hspace{1cm} (2.12)
Fig. 2.4: The Cole-Davidson skewed arc.

Where $\beta$ is restricted to values between 0 and 1. For $\beta = 1$, the arc is Debye semi circle, but for values of $\beta < 1$ the arc is skewed to the right. That is the value of loss factor peaks shift to the right of the centre line for the Cole-Cole arc. The Cole-Dividson representation is useful for materials exhibiting a non-symmetrical distribution of relaxation time with polarization process and decreasing importance extending into the higher frequency region. The frequency dependence of some biological substances may be described reasonably well by Cole-Cole relation is reported by Schwan and Grant (5, 6).

2.2.4 Maxwell Wagner Absorption

Maxwell Wagner absorption, which results from polarization at interfacial boundaries, which occurs in non homogeneous materials and also in biological materials has been sorted by Davis and Shchwan (7,8). Frequency dependence of the Maxwell-Wagner absorption and Debye dipolar absorption are similar in nature but Maxwell-Wagner absorption occurs at lower frequencies. Dielectric properties of materials also depend on temperature. For polar materials Debye equation reveals that the relaxation time and dielectric constant decrease if temperature of material increases but in absence of dielectric loss, the dielectric constant for such materials decreases with increase in temperature (9).

2.3 Polarization

When two opposite charges having same magnitudes are separated by a small distance, they constitute an electric dipole. Those molecules having non-zero permanent electric dipole moment are called polar molecules. The non polar molecules are those molecules
in which the centre of positive charge coincides with the centre of negatively charge particle, as a result the dipole moment of non-polar molecule is zero. If non polar molecule is placed in an external field the distortion of their electronic distributions occurs. As a result a dipole is formed in non polar molecules. The relative permittivity is the measure of the polarizing effect due to external field which show how easily the medium is polarized. The polarization (P) can be described by the following relation:

\[ P = \varepsilon_0 (\varepsilon - 1) E \]  

(2.13)

There are three types of polarization, electronic, atomic, and orientation polarization. Another important mechanism at microwave frequencies is ion conductivity (ionic loss or polarization), where hydrated ions seek to move in the direction of the electrical field and transfer energy by this movement. This is strongly temperature dependent. Electronic polarization is the displacement of centre of negatively charged electron cloud with respect to the positive nucleus of an atom due to external electric field. Electronic polarization occurs in all substances but in case of atomic polarization, atoms move in crystals or molecules. Atomic polarization brings to begin in the infrared band, while electronic polarization is found in the optical band. Electronic and atomic polarization is practically independent on temperature (10).

The orientation polarization is characteristics of polar dielectrics of polar dielectrics which consist of molecules having permanent dipole moment. In absence of external field, the orientation of dipole is random. When this type of molecules is placed in an external field, the molecular dipoles rotate about their axis of symmetry in the field direction. Water molecule is an example of polar molecule, which is a major component of biological materials.

The orientation polarization is strongly temperature dependent. As temperature increase, thermal agitation becomes more vigorous and fewer dipoles are oriented. The orientation polarization occurs at microwave frequency due to inertial force (11). The loss mechanism due to orientation polarization is most significant in microwave heating application at frequencies above 1GHz. But orientation polarization does influence the lower frequency bands as well, and ionic loss typically predominates at frequencies
below 1GHz (12). The origin of different types of losses can be seen in following figure (2.5). With rising temperature all the phenomena are found at higher frequencies.

When the dielectric materials are placed in an electric field at high temperature, the electric charge get accumulated at the interface due to sudden change in conductivity. The space charge polarization is not significant in most of the dielectrics.

![Fig.2.5: Origin of different types of losses in heterogeneous mixtures containing water; for water containing ions (38).](image)

2.4 Permittivity Measurement Principle and Techniques

There are numerous techniques available for the measurement of permittivity of materials depending on their advantages and limitations. The Study of dielectric properties are performed by various methods employing different size and shapes of material (13). Thus the fact that different kinds of techniques can be used, measuring techniques which provide reliable determinations of the required dielectric properties involving the unknown material in the frequency range of interest can be considered (14). In dielectric heating at frequency below 200 MHz, impedance bridges and resonant circuit have usually been used to determine the characteristics of capacitive sample holders with and without dielectric sample from which the dielectric properties are calculated. At frequencies above 200 MHz and into the microwave region, transmission line and resonant techniques have been useful.
2.4.1 Wave-Guide and Co-axial Transmission Technique

For the study of dielectric constant and dielectric loss factor of materials wave guide and co-axial transmission techniques were developed at the Massachusetts institute of technology (15, 16). The dielectric constant and dielectric loss were derived form transmission line theory. The dielectric properties could be determined by measuring the phase and amplitude of reflected microwave signal from a sample of material placed against the end of short-circuited transmission line such as wave-guide and coaxial line. For a waveguide structure, rectangular sample that fit into the dimension of the wave-guide at the frequency being measured are required. For coaxial line, an annular sample is needed (17).

2.4.2 Free Space Transmission Line Technique

Free-space transmission techniques are also grouped under non-destructive and contactless measuring methods. This method does not require preparing special sample. So, they are particularly suitable for materials at high temperature and for inhomogeneous dielectrics. In addition, this method may be easily implemented in industrial applications for continuous monitoring and quality control of the agricultural materials and food products. This method is also used for the measurement of density and moisture content in materials (18, 19). In this technique, material is placed between a transmitting antenna and a receiving antenna, and the attenuation and phase shift of the signal are measured. Perfect measurement of the permittivity over a wide range of frequencies can be achieved by free space techniques. The accuracy of dielectric constant and dielectric loss determined depends mainly on the performance of the measuring system. In this technique a uniform plane wave is normally incident on the flat surface of a homogenous material, and that the planar sample has infinite extent laterally so that diffraction effects can be neglected at the edges of the sample. Multiple reflections, mismatches, and diffraction effects at the edges of the sample are generally considered the main sources of errors (20). To enhance the accuracy in measurement, particular attention must be paid to the choice of the radiating elements and in the design of the sample holder, sample geometry and location between the two radiating elements (17).
2.4.3 Transmission Line Technique
This technique is cumbersome because the sample must be made into a slab or annular geometry (21). At 2450 MHz, the sample size is quite large, mostly for fats and oils. Generally existing waveguide test equipment for 2450 MHz designed is WR-284. For measurement at 915 MHz, only the coaxial technique is practically used for which large size of the waveguide is required. This method is used for liquids and viscous-fluid type foods by using a sample holder at the end of a vertical transmission line. The dielectric properties can be easily obtained by the transmission line technique, particularly if one utilizes a slotted line and standing-wave indicator (22).

2.4.4 Open Ended Coaxial Probe Technique
The coaxial probe is a convenient and broad band technique it is commonly used for lossy liquids and solids (23, 24). It is non destructive and in this method little or no sample preparation is required for liquids or semisolids. In the case of solid material under test, the material face must be machined at least as flat as a probe face, as any air gap can be significant source of error. It operates at frequencies between 1 Hz to 20 GHz. The technique assumes that the material under test is non-magnetic and uniform throughout. It should be noted that the accuracy in coaxial probe measurement is dependent on both frequency and relative permittivity with the best attainable accuracy being 5 % in the real part of permittivity and ± 0.05 in loss tangent. Therefore, this dielectric measurement system allows measurement of dielectric properties of materials with relatively high dielectric loss values, over the frequency range 30 MHz to 45 GHz, including two microwave frequencies of 915 MHz and 2450 MHz that are allowed by the U.S. Federal Communication Commission (FCC) for industrial, scientific, medical and domestic (I S M D) heating applications.

2.5 Drying Systems
Drying is a preserving technology for the safety and quality of food. It has greatly extended the consumer acceptable shelf life of food materials commodities from a few days to weeks and few weeks to few months and years. The lower storage and transportation costs associated with the reduction of weight and volume due to the water
removal have provided additional economic incentives for wide spread application of drying process. The expanding varieties of commercial dehydrated food available today have stimulated unprecedented competitions to maximize their quality. This is attributed to improved mechanization, automation, packaging and distribution techniques. Different drying systems applicable for drying agricultural materials and edible products are discussed in this section.

2.5.1 Hot Air Drying
The most common drying method of agriculture edible product to date is that of the process of hot air drying (25). However, there are some disadvantages of this method. Among these are low energy efficiency and lengthy drying time during the falling rate period. This is mainly caused by rapid reduction of surface moisture and consequent shrinkage, which often result in reduced moisture transfer and sometimes reduced heat transfer (26, 27).

Several investigations on drying have been reported that hot air drying, which have prolonged exposure to elevated drying temperatures, resulted in substantial degradation in quality attributes, such as color, nutrients, flavor, texture, severe shrinkage, reduction in bulk density and dehydration capacity, damage to sensory characteristics and solutes migration from the interior of the food to the surface (28, 29).

2.5.2 Cabinet Drying
Cabinet dryers are small-scale dryers used in the laboratory and pilot plants for the experimental drying of fruits and vegetables. These consist of an insulated chamber with trays located one above the other on which the fruits and vegetables are loaded and a fan that forces air from heater and allows it to pass through the material by cross flow or through flow.

2.5.3 Tunnel Drying
Tunnel dryers are basically a group of truck and tray dryer widely used due to the flexibility for the large scale commercial drying of various types of fruits and vegetables. In these dryers trays of wet material stacked on trolleys are introduced at one end of
tunnel dry (a long cabinet), while the material is discharged from the other end. The drying characteristic of these dryers depends on the moment of air flow relative to the moment of trucks, which may move parallel to each other either concurrently or counter currently, each resulting in its own drying pattern and product properties.

2.5.4 Radio Frequency Drying

During radio frequency heating, many material properties affect the heating performance. The most significant are the electromagnetic properties especially the dielectric properties of agricultural materials and edible products. In addition to these properties, geometry, packaging and the type of oven itself also affects the heating. Increased international commerce in agricultural production, enhancing demands on regulatory agencies to prevent the introduction of unwanted product and furthermore environmental and health concerns, are restricting the post harvest use of chemicals. A new approach is to use radio frequency heating energy to disinfect these products. Radio frequency heating is defined as the heating of substances by electromagnetic energy distinguished by long wavelength and ultra rapid oscillation. There are many advantages of radio frequency heating over conventional heating approaches. As in other industries, units can be inserted into commercial operation including packing line. The best advantage of radio frequency heating is that the heating is much faster than conduction methods. Radio frequency application is not simple and many variables need to be addressed before a practical treatment is developed. Some of these variables are interrelated so that adjusting one requires adjusting others. These variables are size and shape of electrodes, gap of electrode, dielectric properties of the material treated, initial temperature and mobility of the treated material. The important dielectric properties of agricultural materials and edible products are the dielectric constant, loss factor, loss tangent and ac conductivity.

In prevailing techniques and methods, complex dielectric permittivity has been measured at certain discrete frequencies of frequency domain of interest by putting sample in a sample holder. The real and imaginary part of complex dielectric permittivity is inter dependent. This means that if either part is determined over a substantial range of frequency, the other can be calculated. From a practical point of view it may not be
possible to cover a sufficient range; therefore measurement of both dielectric constant and loss factor is desirable. It has however not been possible to device a single measurement technique which would cover the whole frequency range of measurement. Therefore, various techniques suitable to different frequency range are employed.

2.5.5 Microwave Drying
About thirty years ago, industrial engineers began developing microwave drying techniques that avoided some limitations of conventional heating. When microwave which is a form of electromagnetic wave, passes through the material, the molecules in the material act like miniature magnets attempting to align themselves with the electric field. Under the influence of this high frequency alternating electric field the particle oscillates about their axis creating the molecular friction, which manifests itself as heat.

2.5.6 Infra Red Heat Drying
Infra red energy has the ability to penetrate an object apart from conversion of electromagnetic energy into heat. The depth of penetrating of infrared is a function of its wavelength. In general shorter the wavelength greater is its penetration power. Infra red increases surface temperature, this in turn increases surface evaporation.

2.5.7 Microwave Hot Air Combination Drying
In recent years, microwave drying offered an alternative way to improve the quality of dehydrated products. Usually drying is not induced by dielectric heating alone, but most microwave drying system combine microwave and conventional heating. Microwave drying, like conventional drying, is caused by water vapour pressure difference between interior and surface regions, which provides a driving force for moisture transfer. It is most effective to the product of moisture level below 20% (30). Microwave has been used in drying of diced apples, herbs, potato, radish, apple and mushroom, carrots, banana and oilseed (25, 31, 32, and 33).
2.5.8 Microwave Vacuum Drying
Low boiling points are developed due to the low pressure during microwave vacuum dehydration, where the thermal damage causes are practically non-existent as reported by Erle et al., (34). As long as there is enough water in the tissue, these boiling points can only be exceeded minimally due to dissolved substances.

2.5.9 Freeze Drying
Vacuum freeze drying is the best method of water removal with final products of highest qualities compared to other methods in food drying (35). Freeze drying is based on the dehydration by sublimation of a frozen product. Due to the absence of liquid water and low temperature requirement for the process, rate of the deterioration and microbiological reactions would be very low, which can give a final product of excellent quality (36). A longer shelf-life, product diversity and substantial volume reduction are the reasons for popularity of dried fruits and vegetables, and this could be expanded further with improvement in product quality and process applications. These improvements in process selection could increase the current degree of acceptance of dehydrated foods in the market.

2.6 Sample Holder
The sample holder designed for specific material is an important aspect of measurement techniques. The choice of sample holder design depends upon the dielectric material to be measured and the frequency range of interest. In the present study coaxial cylindrical sample holder has been fabricated for use with the impedance gain/phase analyser for measurement of dielectric permittivity. The parallel equivalent circuit representation of the empty sample holder is given in figure-2.7 and the important dimensions of the cell are given in figure-2.8. Dimensions of sample holder should be large enough to avoid diffraction effects at the edges of sample. It was also found that larger plate area was necessary to provide better sensitivity in the measurement of dielectric loss. The important dimensions of the coaxial cylindrical sample holder, made of brass with effective geometrical capacitance 2.085 pF, are given in figure-2.8. Spacing between the electrodes was maintained by annular base plate made from ½ inch Teflon plate to hold
the two electrodes in coaxial position. The brass tubing sections were cemented to the Teflon base ring using a commix Teflon bonding kit obtained from chemical rubber company. Teflon provides the required electrical insulation and permitted the use of benzene or other active solvent for calibration purposes. The height of the liquid sample has been calculated from the measured volume of the sample. A mounting block was constructed to support the sample holder and facilitate electrical connection to the impedance bridge. All the conducting parts of sample holder were silver plated to reduce conduction loss. The sample holder, therefore, may be considered loss less since dielectric loss of Teflon is very low. An open circuit termination for the sample holder was provided in the form of threaded brass cap which screws onto the top of outer conductor. This termination confines the electric field, prevents radiation from an open end also eliminates effects due to the field fringing.

![Image](image.png)

**Fig. 2.6:** Parallel equivalent electric representation of biomaterials.

![Image](image.png)

**Fig. 2.7:** Parallel equivalent circuit representation of

(a) Grain/seed sample

(b) Empty sample holder

(c) Sample holder filled with dielectric
2.7 Equipments Used in Present Study

Various equipments have been used to investigate the dielectric and optical properties of solid (seeds) and liquid (oils) samples. Details of these equipments along with the determination of different parameters and data description are given below-

2.7.1 Determination of Dielectric Properties

Dielectric properties are important as they provide useful information about the static and dynamic properties of agricultural material. Dielectric studies provide one of the few techniques for finding the nature of molecular reorientation and molecular dynamics of these important materials. Dielectric spectroscopy is specially sensitive to intermolecular interaction and capable of monitoring cooperative process, while molecular spectroscopy provides a link between the investigation of the properties of individual constituents of complex material and the characterisation of its bulk properties. In present work dielectric studies have been carried out on a computer controlled impedance / gain phase analyser model HP 4194A in frequency range 100 Hz to 40 MHz figure-2.9. Any particular frequency can be applied across the sample by simple operations as provided on the key pad. Various parameter values can be recorded in the tabular form and also can be seen in the form of the graph on monitor. Generally impedance can be measured within an accuracy of ± 0.17%. The values of capacitance and dissipation factor for with and without sample are recorded from the screen of the impedance gain phase analyser. The real part of dielectric permittivity of the sample is obtained from the change in
capacitance value of the sample holder due to presence of sample material using following equation:

\[
\varepsilon' = \frac{\Delta C \ln(b/a)}{0.556h} + 1 
\]  
(2.14)

Where \(a\) is the outside diameter of the inner conductor and \(b\) is inside diameter of the outer conductor, \(h\) is the height of the sample in the sample holder, \(\Delta C\) is the change in capacitance of the sample holder and is equal to

\[
\Delta C = C_M - C_o 
\]  
(2.15)

Where \(C_M\) is the capacitance of the sample holder with sample and \(C_o\) is the capacitance of empty sample holder.

The loss tangent or dissipation factor \(D\), for the sample material was derived from the dissipation factor and the capacitance measured for the sample holder with and without sample. The dissipation factor at a given frequency is given by

\[
D_0 = \frac{1}{\omega R_o C_o} 
\]  
(2.16)

Where the subscript 0 denotes the condition with sample holder empty. When some quantity of sample is placed in the sample holder, additional resistance and capacitance are added in parallel as shown in figure-2.6. The dissipation factor for the sample holder and material combination is

\[
D_e = \frac{R_o + R}{\omega(C_o + C)R_o R} 
\]  
(2.17)

Quantities measured using the impedance analyser were \(D_0, C_0, D_p\) and \(C_0 + C = C_M\). The dissipation factor for the material only is given by

\[
D = \frac{1}{\omega CR} 
\]  
(2.18)

Substituting an expression for \(R_o\) from equation (2.16) into equation (2.17) yields an expression for \(R\), which when substituted in equation (2.18) results in the following expression for \(D\) in terms of measured quantities.
\[ \tan \delta = D = \frac{C_M D_M - C_0 D_0}{C_M - C_0} \]  
(2.19)

Where \( D_M \) is the dissipation factor of the sample holder with sample and \( D_0 \) is the dissipation factor of empty sample holder.

Loss factor and conductivity were evaluated using following equations

\[ \varepsilon'' = \varepsilon' \tan \delta \]  
(2.20)

\[ \sigma = 0.556 f \varepsilon'' \quad (f \text{ in MHz}) \]  
(2.21)

Fig.2.9: Computer interfaced Impedance/gain phase analyzer equipped with Julabo, temperature controller for measurement of dielectric parameters

### 2.7.2 Absorption Measurement

Colorimetry is concerned with determination of the concentration of a substance by measurement of relative absorption of light with respect to known concentration of the substance. In Colorimetry, white light is generally used as light source and determination are usually made with photoelectric cell.

In Colorimeters, light content with in a comparatively narrow range of wavelengths furnished by passing white light through filters of colored glass, gelatin etc, is employed, transmitting only limited spectral region. Colorimeters are also called filter photometers. In spectrophotometry source radiation used, extends into ultra violet region of the spectrum, from which definite wavelengths of radiation are chosen possessing a bandwidth of less than 1nm. In an optical spectrometer, measurements can be made of the quantity of transmitted radiation.
In the present study we have used double beam UV visible spectrophotometer [Model No. SL 164 figure-2.10].

![UV Visible Spectrophotometer](image)

**Fig. 2.10: UV Visible Spectrophotometer**

Specifications of the apparatus are

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>190 to 1100 nm</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>2 nm</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±0.5 nm</td>
</tr>
<tr>
<td>Readability</td>
<td>0.1 nm</td>
</tr>
<tr>
<td>Repeatability</td>
<td>± 0.2 nm</td>
</tr>
</tbody>
</table>

**2.7.3 Temperature Measurement**

The effect of radiofrequency heating on flavour of food material varies with temperature; in some cases the flavour is perceived as stronger or better while sometimes the radio frequency heated foods are described as flavourless. Because flavour can be encapsulated to ensure a controlled release during the heating period, as flavours are susceptible to steam distillation during heating. Due to this reason controlling of temperature is very important factor for agricultural and food materials. In the present case, temperature of the sample holder is controlled by a temperature controller of Julabo model F-25HD. Temperature range of the Julabo [Model No. F-25HD, figure-2.11] is from -20°C to
200°C with accuracy better than ± 0.1°C. Two types of oils have been used as circulator. First one is ethanol for temperature range -20°C to 200°C and other is silicon oil for the higher temperature range of -50°C to 200°C. The temperature of sample and oil in the bath can be measured with the help of external and internal pt 100 type temperature sensors.

Fig. 2.11: Temperature controller Julabo

2.8 Determination of Moisture Content

Moisture content is one of the most important factors determining quality of products during harvesting, storage, trading and processing. Since excessive moisture levels will cause product spoilage, drying of agriculture products is a common practice. High moisture content promote spoilage in stored grain and seeds. In an earlier review (37) the standard method given for grain moisture determination is that of the oven drying for long periods. Alternatively in general, the moisture content of cereal grains and seeds has been measured using an electrical moisture meter.

Radio frequency moisture meters are commonly used with static samples to measure moisture content of food materials. Measuring the moisture content of flowing material is usually difficult and expensive, because the variation in the bulk density, as the material flows through a sensor cause errors in moisture predictions. The reason is that density affects moisture content measurement. The moisture content of a material M expressed in percentage-wet basis is defined as (37).

\[ M = \frac{m_w}{m_w + m_d} \times 100 \]  
(2.22)
Where $m_w$ is the mass of water, and $m_d$ is the mass of dry materials.

In agriculture materials, physical properties of grains and seeds such as bulk density and moisture content for their optimum processing, safe storage and in trade. The bulk density is defined as where $\rho$ is the bulk density of sample, $V$ is is volume of material

$$\rho = \frac{m_w + m_d}{V}$$  \hspace{1cm} (2.23)

Thus moisture content is also defined as mass of water per unit volume divided by density. Knowing the sample weight and volume reduced after dehydration, the prediction of moisture content an estimation of the mass of water within the sample. Since dielectric constant of free water is much larger than that of agriculture product. Use of electrical properties of agriculture material and food product for moisture measurement has been the most prominent agriculture application for dielectric data. The need of quantitative values of dielectric properties arose from research on application of RF dielectric heating to agricultural problems.

2.9 References


