CHAPTER-1
Introduction

Microwaves are the electromagnetic waves whose frequencies lie in the frequency range of 300 MHz to 300 GHz and wavelength from 1 mm to 1m. Microwaves travel through space by the same process as followed by the light waves, i.e., in the form of oscillations of electric field $E$ and magnetic field $B$ in mutually perpendicular directions with a velocity $c \approx 3 \times 10^8$ m/s in vacuum through direct transmission in the line of sight and showing phenomena like reflection, refraction, diffraction, polarization etc., as shown by light. Microwaves can also travel in the form of guided waves through hollow metallic tubes, called waveguides or through strip lines etc.

Fig. 1.1 Electromagnetic frequency spectrum

When microwaves are made incident on a material sample, a part of them may be reflected, a part is absorbed by the sample and a part is transmitted through the sample. Reflection is more for metallic objects, while every dielectric sample absorbs some amount of microwaves. Microwaves are transmitted without significant absorption through materials like, air, gases and some other dielectric
materials. Water and food materials with high water contents and substances containing carbon etc. are good absorbers of microwaves, whereas ceramics and most of the thermoplastic materials only slightly absorb microwaves (Buffer, 1993; Ohlsson, 1993; Mullin, 1995; Hill, 1998).

Microwave radiation can interact with materials by penetrating them and dissipate energy in them in the form of heat. Because of this ability of microwaves the polymer and ceramic industries make use of microwaves for various purposes, such as, for joining, cutting, sintering, combustion, synthesis, and melting of metals and alloys, and epoxy curing; preheating, galvanizing and thermosetting of rubber; in medicine for thawing frozen tissues, warming blood cells and in tumor therapies; in textiles for drying fibres, yarns and clothes and in agriculture for estimating moisture level in crops and for saving fruits and nuts from insects by selective heating etc (Decareau, 1992 a). Microwaves are used in food industry for several food processing operations, including blanching, thawing, pasteurization, baking, roasting, sterilization, dehydration, etc. (Bengston and Ohlsson, 1974). Moreover, the microwave ovens working on the principle of heating by absorption of microwaves at 2.45 GHz is a breakthrough in the food industry, which is now most commonly used by consumers for domestic applications.

The use of microwaves for cooking has advantages, like, instant start-up, faster and homogeneous heating of the bulk of food material, improved color, flavor and texture of cooked food and nutrient retention. The major components of a microwave oven are: the source, the transmission lines, and the applicator. The electromagnetic energy generated by the microwave source (a high power magnetron) is delivered by the transmission lines to the applicator. In the applicator, most of the energy is absorbed by the material; a fraction of the incident energy may be reflected or transmitted through the material, which may be reflected back on the material by using reflectors to increase the efficiency of the oven. The theoretical analysis of the performance of microwave oven is governed by the Maxwell equations given below and appropriate boundary conditions.

\[ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}, \quad \nabla \cdot \mathbf{B} = 0 \]

\[ \nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{I}, \quad \nabla \cdot \mathbf{D} = \rho, \]
where $E =$ Electric field vector;
$H =$ Magnetic field vector;
$D =$ Displacement vector or the electric flux density;
$B =$ Magnetic flux density;
$I =$ Current density; and
$\rho =$ Charge density.

The Maxwell equations are the physical laws that govern the behaviour of electromagnetic fields that travel through space and vary sinusoidally with time. For design of a microwave oven one needs to procure all the needed components, such as, microwave sources, which are generally cavity magnetrons of 1 Kilo watt power output, the transmission lines, applicators, etc. One should have the ability to combine these elements into an efficient cooking system to process food materials, for which not only the knowledge of electromagnetic theory but a good understanding of interaction of microwaves with the materials is required.

1.1 The heating process by microwave

The electromagnetic fields generated inside the microwave oven, on being absorbed by the food, cause molecular and atomic excitations, resulting in to rotations and vibrational motion of the polar molecules and ions inside the food. Different types of molecular excitations, rotations and vibrations are opposed by the molecular friction and as a result of it microwave energy is in turn converted into heat energy. Excitation of ions of salts present in the food under the influence of the electromagnetic fields and their collisions with the food molecules may also produce heat in the food materials. The molecular friction is, therefore, responsible for generation of heat, which subsequently leads to rise in temperature of the food material placed inside the microwave oven. Therefore, interactions responsible for the generation of heat inside the food materials are dipolar and ionic interactions, the detailed mechanisms of which are given below.

1.1.1 Dipolar interaction

When microwaves interact with the food material, polar molecules present in it, such as water molecules, rotate and try to follow $E$ of the microwave field. The
water molecule behaves as a “dipole” with its one end positively charged and the other end being negatively charged. Similar to the action of magnet, these “dipoles” tend to align themselves parallel to the $E$ field when they are subjected to electromagnetic field. However, since $E$ field in electromagnetic wave oscillates and changes its direction rapidly, the dipole tries to follow the oscillations of $E$ field, though it lags behind $E$ because of its inertia and friction offered by the other molecules. This gives rise to what is called ‘dielectric relaxation’. The rotation of water molecules thus dissipates energy due to dielectric relaxation and generates heat, which is used for cooking in oven (Buffer, 1993; Ohlsson, 1993; Hill, 1998).

### 1.1.2 Ionic interaction

In addition to the dipolar water molecules, ionic compounds, such as dissolved salts present in the food, also get ionized in the aqueous medium provided by the food and the free ions get accelerated by the electromagnetic field (+ ve ions in the direction of electric field $E$, and the – ve ions in the direction opposite to field $E$) and during their movement when they collide with the molecules, they also produce heat. It is, therefore, the composition of the food, which decides that by which mechanism it will be heated up inside the microwave oven. As the water molecules are dipolar in nature, they respond fast to the electric field and produce heat through rotations and molecular frictions. As such water has got high dielectric permittivity. Food materials with higher moisture content are therefore heated up faster. As the concentration of ions, i.e., dissolved salts increases, the rate of heating further increases because of the interaction of ions present in the material with microwaves. Even though oil molecules are non-ionic, food products with high oil content have a faster heating rate as compared to non-oily foods because the specific heat of oil is much less than that of water (Singh and Heldman, 1993).

### 1.2 Advantages of microwave cooking

The use of microwave oven for cooking food materials has the additional advantage of reduced processing time and energy saving. In thermal processing of food, the energy is transferred from the source to the material through convection or conduction, or radiation of heat or more than one mechanism may be responsible for transfer of heat. In contrast, when the food is processed by microwave oven, the
energy is directly delivered to the material being cooked through interaction of its molecules with the electromagnetic field of microwaves. In conventional domestic method of cooking, the mechanism of heat transfer from source to food is mainly through conduction of heat, i.e., the energy transfer by motion of thermal gradients, or by way of diffusion of heat from hot surfaces, but in microwave heating, instead of transfer the transfer of energy heat is generated in food through conversion of electromagnetic energy in to thermal energy by way of molecular interaction. This difference in the mechanism of energy delivered to the food materials has several potential advantages of using microwaves for processing of food materials. Because microwaves can penetrate through materials and deliver energy by way of interaction with molecules, heat can be uniformly generated in the material, leading to rapid and uniform heating throughout the volume. In traditional cooking, the cycle time is often governed by heating rates that are chosen to be slow so as to minimize steep thermal gradients and save food from being burnt out; this results in the process that causes induced stresses. Moreover, in this process the cooking of interior parts is effected through diffusion of heat from the surface, resulting in lesser heat being available to the interior so that the interior is not properly cooked, whereas surface of the material is over cooked. In microwave processing, the transfer of energy to the food does not depend on diffusion of heat from hot surfaces, rather heat is directly generated in food through interaction of molecules with the electromagnetic fields, it is possible to achieve efficient, rapid and uniform heating of food throughout its volume; viz., a thick cake can be uniformly cooked by microwaves, whereas it is not possible by using any method of thermal processing.

In microwave cooking, in addition to uniform volumetric heating, the energy transfer takes place at the molecular level, hence it can have some additional advantages, viz., the microwaves, based on different values of dielectric parameters, can be utilized for selective heating of materials. The transfer of energy by microwaves through molecular interaction depends on the ability of the microwaves to interact with the materials and molecular structure of the material. When several materials having different dielectric properties are kept in contact with each other, microwaves selectively couple with the higher loss material. The phenomenon of
selective heating by microwaves can be used for a number of specific applications such as, killing of insects in dry fruits. Considerable time and energy is wasted in joining of ceramics or plastics by conventional methods in which heating of interface to desired temperatures is achieved by conduction through substrates. With microwaves, on the other hand, the joint or interface can be heated in-situ by incorporating a higher loss material at the interface (Siores and Dorego, 1995).

1.3 Efficiency of cooking and poorer consumption

Because microwaves heat the food from the inside out (rather than outside-in, as in the case of thermal processing), energy wastage is minimum in cooking of food by using microwave ovens and hence they have a better cooking efficiency (the % of energy that is utilized for heating the food during the cooking cycle) as compared to electric or gas convection ovens. The efficiency of different techniques of cooking are compared below in table 1.1.

<table>
<thead>
<tr>
<th>OVEN TYPE</th>
<th>EFFICIENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microwave</td>
<td>57%</td>
</tr>
<tr>
<td>Electric convection oven</td>
<td>17%</td>
</tr>
<tr>
<td>Gas convection oven</td>
<td>9%</td>
</tr>
</tbody>
</table>

Microwaves also use less electrical power as compared to other types of electric ovens, as apparent from Table 1.2, given below:

<table>
<thead>
<tr>
<th>OVEN TYPE</th>
<th>WATTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microwave oven</td>
<td>750-1100</td>
</tr>
<tr>
<td>Toaster oven</td>
<td>1200-1700</td>
</tr>
<tr>
<td>Electric oven</td>
<td>3000-8000</td>
</tr>
</tbody>
</table>

1.4 Nutrient Retention

It is now the common knowledge that the nutrients are leached out from food during any form of cooking, especially when the food contains large amount of water is cooked and for a longer period of time. For example, boiling of carrots in
water might strip their nutrients much more drastically than on microwaving them, because the carrots’ nutrients might get washed away by the boiling water. The microwave oven usually does not destroy food nutrients because the energy of microwaves is not sufficient to produce any chemical changes in the food or to change the molecular structure of the food. However, proteins have been reported to be degraded on heating. The degradation rates of proteins depend on the heating time and temperature. The nutritive values of proteins in food treated by conventional thermal heating and microwave heating have been found to be almost comparable (Hill, 1998; Petrucelli, 1994). Several studies have been made to examine the retention of vitamins in different types of food in particular meat and vegetables cooked by conventional methods and on microwaving them. It has been observed that water soluble vitamins, such as, vitamin B and C are depleted by heat treatment and depletion of vitamins in cooked food depends on factors like, the size and shape of the food, cooking time and cooking temperature, etc. As such, for retention of vitamins in cooked food these parameters should be optimized. Decareau (1992 b) and Hill (1998) have shown that microwaved foods have better vitamin retention than conventionally cooked foods because the heating time is comparatively shorter for microwave cooking. Hill (1998) has reported that the minerals are generally not depleted in cooking by conventional methods or by microwaving them. However, they might be lost due to being dissolved in cooking water or meat drippings. A comparison of microwaved and conventionally braised beef showed that significantly more phosphorus and potassium are retained in the microwaved beef.

Therefore, it may be concluded that the nutritional values of food cooked by microwaves are comparatively better than those for food cooked by conventional methods. Even if the nutrient retention of microwaved food is considered equivalent to that of conventional cooking, microwave cooking has additional advantage of fast and uniform cooking throughout the volume of the food material. As such, it is desirable to further investigate the interaction of electromagnetic waves with foods through determination of its dielectric properties and to establish their correlation with food nutrients, if such a relationship can be possible.
1.5 Microwave – material interaction

In microwaving of food, energy is delivered to the food by interaction of its molecules and ions in the food with the electromagnetic fields. The dielectric properties of food in a way measure the interaction of the radio waves with the food materials (Ahmed et al., 2007). Therefore in microwave processing of foods, the physics of the interaction of microwaves with materials is of fundamental importance.

1.5.1 Mechanisms of microwave heating

The permittivity of food materials has been found by Ryynanen (1995) to depend on the chemical composition and physical structure of food and also depends on the interaction parameters, such as frequency, temperature, and moisture content. The absolute permittivity of vacuum \((\varepsilon_0)\) is related to the speed of light \((c)\) and the magnetic permeability of free space \((\mu_0)\), through the relation

\[
e^2\mu_0\varepsilon_0 = 1
\]

The numerical value of \(\varepsilon_0\) is about \(8.854 \times 10^{-12} \text{ F/m}\) and that of \(\mu_0\) is \(1.26 \mu\text{Hm}^{-1}\). In any other medium (solid, liquid and gaseous), the absolute permittivity \((\varepsilon_{abs})\) has values higher than \(\varepsilon_0\) and it is usually expressed in terms of relative permittivity \((\varepsilon_r)\), i.e., permittivity of the medium relative to the permittivity of vacuum (Nyfors and Vainikainen 1989):

\[
\varepsilon_{abs} = \varepsilon_r \varepsilon_0 \quad \text{or} \quad \varepsilon_r = \frac{\varepsilon_{abs}}{\varepsilon_0}.
\]

Nyfors and Vainikainen (1989) have advised the use of complete notation to express the time dependance of the high frequency radiowave or microwave fields as they are sinusoidal time dependent (time-harmonic) in nature. The interactions of electromagnetic fields with materials are described through the fundamental electrical property i.e., relative permittivity of the material. The relative permittivity \((\varepsilon^*)\) is also a complex quantity with real and imaginary components given by Risman (1991).

\[
\varepsilon^* = \varepsilon' - j\varepsilon''
\]

where, \(\varepsilon'\) is the real component of \(\varepsilon^*\) (called as dielectric constant) and \(\varepsilon'' = \) imaginary component of \(\varepsilon^*\) (called as dielectric loss factor), and \(j\) appearing in
equation 1.2 is a imaginary unit \((= \sqrt{-1})\). The real component of the permittivity (i.e., dielectric constant \(-\epsilon'\)) represents the effective capacitance of a substance and serves as a measure of the ability of the substance to store electrical energy. The imaginary component, (i.e., the dielectric loss factor \(-\epsilon''\)) is related to various mechanisms of energy absorption, responsible for energy dissipation in the material and is always positive and usually much smaller in magnitude than dielectric constant. The substance is lossless if dielectric loss factor \(\epsilon'' = 0\) (Mudgett 1986; Nyfors and Vainikainen 1989). The loss tangent \((\tan \delta)\) is defined as the ratio of dielectric loss factor and dielectric constant. Also called as dissipation factor, it is a dielectric parameter, used as a measure of losses of electromagnetic energy in the material, also used as an index to measure the ability of the to convert electromagnetic energy into heat (Mudgett 1986).

\[
\tan \delta = \frac{\epsilon''}{\epsilon'}
\]  

(1.3)

The conductivity of the dielectric material \(\sigma\) is related to the dielectric loss factor, and is given by

\[
\sigma = \omega \epsilon_0 \epsilon''
\]  

(1.4)

where \(\sigma\) is expressed in Siemen/m, and \(\omega = 2\pi f\) is the angular frequency in radians, \(f\) being the frequency expressed in Hertz.

The thermal energy generated as a result of interaction of radio frequency or microwaves in a lossy material is given by (Goldblith, 1967)

\[
P_v = 5.56 \times 10^{11} \times f \epsilon'' E^2
\]  

(1.5)

where \(P_v\) - the thermal power generated per unit volume \((W/m^3)\)

\(f\) - frequency (Hz)

\(\epsilon''\) - relative dielectric loss factor

\(E\) - electric field of radio frequency or microwaves \((V/m)\)

Various mechanisms that contribute to dielectric losses in materials are related to dipole, electronic, atomic and Maxwell-Wagner polarization and electrical conduction through dielectrics (Kuang and Nelson, 1998; Metaxas and Meredith, 1993). But for food applications the dominant mechanisms in the radio and
microwave frequency range of practical importance are through ionic conduction and dipole rotations (Fig. 1.2).

We therefore write

$$
\varepsilon'' = \varepsilon''_d + \varepsilon''_\sigma = \varepsilon''_d + \frac{\sigma}{\varepsilon_0 \omega}
$$

(1.6)

where subscripts “$d$” and “$\sigma$” represent dipole rotations and ionic conductivity, respectively; $\omega$ represents angular frequency of the microwaves, and $\varepsilon_0$ is the of free space permittivity (8.85 x 10^{-12} F/m). In the frequency range between 1 KHz to 100 MHz, a very important role is played by Maxwell-Wagner polarization mechanism, but it is generally not considered to be of any significance in microwave heating.

![Diagram showing the mechanisms contributing to the loss factor of moist materials in different frequency regions and effect of temperature](image)

**Fig. 1.2** The mechanisms contributing to the loss factor of moist materials in different frequency regions and effect of temperature (Ref. - Kuang and Nelson, 1998; Metaxas and Meredith, 1993; Harvey and Hoekstra, 1972; Roebuck et al., 1972).

The dielectric properties of materials other than extremely low loss materials, which absorb practically no energy from high frequency electromagnetic fields, vary considerably with the frequency of the applied electric field (Nelson and Datta, 2001; Nelson, 1991; Nelson, 1973). The alignment of dielectric molecules
having permanent dipole moments parallel to the imposed electric field is called polarization and the magnetic moment per unit volume of the so aligned molecular dipoles is called polarization vector $\mathbf{P}$. The polarization $\mathbf{P}$ changes direction under the influence of varying electric fields and if the frequency of applied electric field is high the polarization $\mathbf{P}$ lags behind the electric field $\mathbf{E}$. This behaviour of the polarization vector $\mathbf{P}$ is responsible for frequency dependence of the dielectric properties of materials. The mathematical formulation developed by Debye to describe the frequency dependence of the permittivity of polar materials (Debye, 1929) can be expressed by

$$\varepsilon = \varepsilon_{\infty} + \frac{\Delta \varepsilon_i}{1 + j\omega \tau_i} \quad (1.7)$$

where $\omega = 2\pi f$ is the angular frequency of electromagnetic field of frequency $f$, $\varepsilon_{\infty}$ represents the permittivity at frequencies so high that the molecules do not find sufficient time to contribute to the polarization, and $\tau$ is the relaxation time in seconds, which is defined as the time period in which the polarization vector $\mathbf{P}$ is reduced to $1/e$ of its original value when the applied electric field is removed. During this time the dipoles tend to revert back to random orientations. The relevant expressions for $\varepsilon'$ and $\varepsilon''$ of a material are given by

$$\varepsilon' = \varepsilon_{\infty} + \frac{\varepsilon_s - \varepsilon_{\infty}}{1 + \omega^2 \tau^2} \quad (1.8)$$

and

$$\varepsilon'' = (\varepsilon_s - \varepsilon_{\infty}) \frac{\omega \tau}{1 + \omega^2 \tau^2} \quad (1.9)$$

Here $\varepsilon_s$ represent the static permittivity, i.e., the d.c. value of the relative permittivity. The frequency dependence of $\varepsilon'$ and $\varepsilon''$ is illustrated graphically in Fig. 1.3. From this diagram it is apparent that at very low and very high frequencies as compared to molecular relaxation frequency, dielectric constant ($\varepsilon'$) acquires constant values $\varepsilon_s$ and $\varepsilon_{\infty}$ respectively, whereas the loss factor ($\varepsilon''$) becomes zero at these frequencies. At intermediate frequencies, the dielectric constant ($\varepsilon'$) undergoes a dispersion whereas the loss factor ($\varepsilon''$) shows a maxima, with its peak value at the relaxation frequency, $\omega = 1/\tau$. The Debye equations are represented graphically in the complex $\varepsilon'$ vs. $\varepsilon''$ plane as a semicircle with locus of points ranging from $(\varepsilon' = \varepsilon_s, \varepsilon'' = 0)$ in the low-frequency limit to $(\varepsilon' = \varepsilon_{\infty}, \varepsilon'' = 0)$ in the high-frequency limit.
and centre of semicircle at \( (\varepsilon_s + \varepsilon_x / 2) \) (Fig. 1.4). Such a representation of dielectric properties is known as the Cole-Cole diagram (Cole and Cole, 1941).

Only a few materials, which consist of polar molecules, have a single relaxation time, whereas others show more than one relaxation time, corresponding to different relaxation processes present in them. Several attempts have been made to analyze such relaxation processes and develop equations to describe the frequency-dependent behaviour of materials with more than one relaxation times or with a distribution of relaxation times (Bottcher and Bordewijk, 1978; Cole and Cole, 1941; Davidson and Cole, 1951; Havriliak and Negami, 1967; Nigmatullin et al., 2006; Nigmatullin and Nelson, 2006; Nigmatullin et al., 2008).

For materials with multiple relaxation times, the relative complex permittivity can be written as

\[
\varepsilon = \varepsilon_\infty + \frac{\Delta \varepsilon_i}{1 + j\omega \tau_i}
\]  

(1.10)

where \( \tau_i \) is the relaxation time of the \( i \)th dielectric dispersion, and \( \Delta \varepsilon_i = \varepsilon_{si} - \varepsilon_{x,i} \) is the dielectric increment for the \( i \)th dielectric relaxation. For closely distributed relaxation times, which are commonly encountered in biological materials in a defined frequency range, equation (1.10) can be replaced by the integral

\[
\varepsilon = \varepsilon_\infty + (\varepsilon_s - \varepsilon_x) \int_0^\infty \frac{f(\tau)}{1 + j\omega \tau} d\tau
\]  

(1.11)
where $F(\tau)$ represents the distribution function for the relaxation time $\tau$. The general approach in interpreting experimental data is to infer the forms of $F(\tau)$ and identify the underlying physical mechanisms corresponding to different values of $\tau$. Such an attempt involves modeling of physical processes and is usually very complicated (Foster and Schwan, 1989).

Another approach, which is purely empirical in the sense that it serves to parameterize the data without going into details of the underlying mechanism, is due to Bottcher and Bordewijk (1978). The empirical equations used by them is

$$\varepsilon = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + (j\omega\tau)^{1-\alpha}}$$

(1.12)

where $0 \leq \alpha \leq 1$ is an adjustable parameter, indicating the relaxation time distribution. In general, multiple time relaxations have a very complicated behavior. As equation (1.10) indicates, it is composed of many single time relaxations. Some single-time relaxations may overlap and act like a single dispersion. The Cole-Cole plot for multiple relaxations becomes more flattened as compared to a single-time relaxation. Pure single-time relaxation behavior is rare in practice, except for some pure polar compounds.

The dielectric properties of food materials depend on a number of factors. Nelson and Datta (2001) have reported that the dielectric properties of food materials not only depend on the frequency of the applied radio frequency field, but also depend on the temperature, composition, density and structure of the material. The dominant component of almost all the food materials is water and as such the food materials are hygroscopic in nature. The dielectric properties of food materials are also affected by the presence of mobile ions (which are produced due to the presence of salts and other such ingredients) and the water molecules, which behave as permanent dipoles.

### 1.6 Application of microwave dielectric measurement techniques

#### 1.6.1 In Agriculture

The dielectric properties of crops and agricultural products are of great importance not only to the farmers but also to the warehouse keepers and
processors, and in marketing of crops, as they provide information about moisture level of the crops. By knowing the moisture level, it can be decided whether the crop is safe for storage. If the moisture level of the crop is high, it is more likely to be spoiled by insects, fungi etc. For agricultural products such as fruits and vegetables, dielectric properties are highly correlated with the amount of water present in them, therefore these properties can be used for rapid measurement of their moisture content and for their quality assessment (Jha et al., 2011). Dielectric properties of food materials at radio and microwave frequencies also provide information about their behaviour in electromagnetic fields (Ryynanen, 1995). Microwaves are also used to kill the insects that may spoil the stored grain by selective dielectric heating (Nelson, 2006; Nelson et al., 2006). Therefore, the dielectric properties of food materials provide us useful information, which helps in designing of radio frequency and microwave processing equipments and in the design of improved techniques for microwave processing of foods (Mudgett, 1985). The process of selective dielectric heating is also used in fruits and dry fruits so as to kill the insects. The state of ripeness of fruits can also be ascertained by measurement of their dielectric properties (Nelson and Whitney, 1960; Nelson 1996). Treatment of seeds by microwaves saves them from being spoiled by insects and also helps in improved germination (Nelson, 1965). Engelder and Buffler (1991) observed that by measuring dielectric properties of different materials it is possible to estimate density and water activity in them.

Dielectric properties of agricultural materials are important as they are utilized for a number of applications in different areas of human activities (Nelson, 2006). Techniques for non-destructive determination of quality of fruits and related characteristics of crops and agricultural products are useful for industrial applications and prove to be helpful to producers, handlers and processors (Nelson et al., 2006), viz., the information on moisture helps in their safe storage of crops. Dielectric properties can be used to understand behavior of food materials in radio frequency and microwave range and to develop controlling mechanism during microwave processing of materials (Ryynanen, 1995). For agricultural products such as fruits and vegetables, dielectric properties are highly correlated with the
amount of water, therefore these properties can be used for rapid measurement of their moisture content. These properties influence the level of interaction between the food material and high frequency electromagnetic radiation. Therefore, these are of primary importance in the design of radio frequency and microwave processing equipments and in the design of techniques for processing of foods and meals by microwaves (Mudget, 1985). The possible selective dielectric heating can be used for control of insects that infest stored grains (Nelson, 1996; Nelson, 1965; Nelson and Whitney, 1960) suggested that dielectric properties are also important in seed treatment by microwaves so as to improve germination. Engelder and Buffler (1991) reported that dielectric measurements can also be used to measure density and water activity in a given sample.

1.6.2 In food Industry

The dielectric investigation of materials at radio and microwave frequencies and determination of their moisture contents serves as a useful technique for quality control and improved performance in several areas, like agriculture, cement industry, soil preservation, wood industry, food science and industry, and in quality evaluation of food products, such as, beef, mutton, fruits, tea leaves, coffee seeds etc (Hlavacova 2003; Venkatesh and Raghavan, 2004). Toyoda (2003) reported that dielectric spectroscopy of materials is a simple, rapid and non-destructive, which provides knowledge about their response to varying frequency electromagnetic fields. This is an advantageous technique for examining food quality and for detecting moisture content in foods. With the knowledge of frequency dependence of dielectric properties an ideal frequency range can be determined in which the material has the desired dielectric characteristics for applications of interest, i.e., for developing heating processes or grading of materials (Nelson and Payne, 1982; Nelson, 2005; Wang et al., 2001 and 2006). Ohlsson (1989) has reported that the dielectric investigation of materials provides useful information about suitability of a particular material in the design of microwave heating equipments and cooking utensils, and such information is also useful in the selection of proper packaging materials for different types of items. Nelson (1992) reported that the knowledge of moisture-dependence of dielectric properties of materials in specific frequency range has been of great help in the development of online moisture meters. Berbert et al.
(2002) observed that the online moisture meters are useful in drying processes but they can also be used with advantage in other unit operations in the food industry. Penetration depth of electromagnetic energy in food materials can also be determined from the knowledge of their dielectric properties, which is a useful parameter in deciding design of microwave oven for bulk cooking and in characterizing physical properties of certain kinds of food and biomaterials.

Microwave heating was used by Zuercher et al. (1990); Mellgren et al. (1988); Kent (1987), and for developing baking processes. Kim et al. (1998) investigated the dielectric properties of cooked bread and flour at microwave frequencies so as to find out effect of cooking on dielectric properties. It was observed that the frequency 27 MHz is significant for baking industry operations as the absorption of electromagnetic energy is maximum at this frequency.

In the determination of the quality of frying oils and fats, dielectric properties play an important role. It is necessary to check and effectively monitor the quality of frying oils and fats because consumption of oils and fats is very much related to our health. Cataldo et al. (2010); Inoue et al. (2002); Paul and Mittal (1996); El-Shaml et al. (1992) have investigated the dielectric properties of frying fats and oils and reported that in commercially deep fat frying operations, dielectric constant of the frying oil is the most significant indicator for monitoring its quality. Venkatesh and Raghavan (2004) have suggested that more research is required for developing efficient utilization of dielectric properties in food storage, food making, oil storage and oil processing. Lizhi et al. (2008) measured the dielectric properties of ten edible oils and six fatty acids over the frequency range 100 Hz–1 MHz. Their results may be helpful in quality evaluation, quality monitoring and oil identification during oil processing and storage.

1.6.3 In civil works and cement industry

The dielectric properties play an important role in improving the rate of strength development of concrete, when subjected to a microwave electric field.

Waston, (1965) used microwave absorption measurements to determine the evaporable moisture content (free water) in building materials. Hasted and Shah
(1964) used the Robert and Von Hippel method to study the standing wave in a guide and found that the dielectric properties of cement paste depend on the water present in the paste, which is responsible for the low frequency losses.

1.6.4 In soil Industry

Dielectric measurements are nondestructive, so these measurements have potential usefulness for the physical characterization of soil. Dielectric permittivity, direct current (DC), electrical conductivity and magnetic permeability are the characteristic properties of soil, which are combinely called the electromagnetic properties of soil. But since most of the soils are non ferromagnetic, the electromagnetic properties of soil usually include their dielectric permittivity and DC electrical conductivity. The dielectric constant of four varieties of soil (viz., sand, silt and two clays) was studied by Hoekstra and Delaney (1974) over the frequency range from $0.1 \times 10^9$ Hz to $26 \times 10^9$ Hz, the moisture content of the soils was varied from 0.0 g H$_2$O/g soil to 0.15 g H$_2$O/g soil and the temperature was varied from 20°C to 24°C. The results suggest that the relationship between the dielectric constant and volumetric moisture content does not depend soil type.

1.6.5 In textile Industry

Researches have been studying for a long time the dielectric behavior of fibers and textile materials as they provide useful information about strength of the fiber and its quality. Multidimensional researches on the dielectric properties of fibers and textile materials have been carried out by Bal and Kothari (2008). Chand (1979) studied the relaxation phenomenon to know the molecular structure of fiber polymers. The dielectric properties have also drawn attention of fiber Engineers as moisture contents of fibers can be estimated from their dielectric properties. The dielectric properties of yarns can also be used to estimate their linear density, to detect impurities within fibrous mass and in many such other applications.

1.6.7 In glass Industry

Glass is a important material to be used as a medium to separate two plates of the capacitor or as a substrate in integrated circuits. For any of the applications dielectric properties of glass may be required to be evaluated. For use as dielectric in a capacitor, its dielectric constant should be high, whereas for substrate its dielectric
constant should be low enough to allow high signal speeds. In general, the dielectric constant of glass increases with concentration of NWM ions. Vitreous silica has lowest values of dielectric constants; hence it can be used for IC substrates. Soda-lime-silicates on the other hand have high dielectric constants, which make them suitable for being used as dielectric material for capacitors. Rosidah (2013) determined the dielectric parameters \( (\varepsilon' \text{ and } \varepsilon'') \) of glass ceramic system in the frequency range 10 KHz to 10 MHz at room temperatures. It was observed that the dielectric constant of glass decreases with increase in frequency, a normal dielectric behaviour observed experimentally by Chenari et al. (2011). A glass ceramic system is therefore considered as a heterogeneous material that can experience interfacial polarization, as predicted by Maxwell and Wagner.

The current trends in clean energy parallel with a more sustainable development and more environmental friendly processes microwave energy is becoming a more popular energy source for heating and drying in various industrial applications.

1.7 Hazards of Microwaves

Several studies have shown that the use of microwave ovens for cooking purposes has adverse effect on human health for following reasons: firstly the person cooking the food may get exposed to microwaves and secondly the food cooked in microwave oven may loose its nutrients. The taste of human breast milk when heated in microwave oven is changed and not only its vitamin contents are depleted but some of the amino acids contained by it also become biologically inactive and sometimes they have poisonous effect on the nervous system and kidneys. The food cooked in microwave oven also looses its nutrients. It has been reported by manufactures that the microwaves do leak out of the oven which can be detected up to a distance of 5 inches, however the intensity of the leaked out radiation diminishes rapidly with distance and reduces to almost nil at a distance of 20 inches. Therefore, it is safe to stand in the back of the oven while using it for cooking purposes (Stossel, 2013).