

Comparison of Dielectric Constant & Loss Factor for Preliminary, Oven Dried and Saturated Grains Using Ku Band Microwave Frequency

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Abstract: *The paper speaks to the investigation of dielectric constants alongside their loss factor for different sorts of grains which characterize their reactions against electromagnetic energy at various microwave frequencies by absorbing, radiates, reflect, and disperse a segment of electromagnetic energy. Estimation of dielectric constant and loss factor have made for different specimens of grains, for example, Rice, Wheat, Split Red Gram (Arhar), Bengal Gram (Chana), Green Gram (Moong) for three unique states as preliminary, oven dried and saturated at various gravimetric moisture content in scope of X Band at two different frequency values (5.30 and 6.60 GHz) and furthermore in the scope of Ku Band at frequency of 10.65 GHz by utilizing waveguide cell (short-circuited lines or double minima or two point) technique. The general lab measurements are similarly critical in recognizing the grains and relatively increase the characterized crop productivity by using microwave remote sensing applications. The analytical study of various grains and pulses at microwave frequencies may give data about the vegetation field and furthermore distinguishes their behavioral properties. The examination of a capacity of cereals and pulses to absorbing emits, disperse, and reflect a part of an electromagnetic field is found by determining dielectric constant and fluctuation with the real factors. Accordingly, estimation of dielectric constant are made for different specimens of grains, for example, Rice, Wheat, Bengal Gram (Chana), Green Gram (Moong), Split Red Gram (Arhar) for three particular stages named as preliminary, oven dried and saturated at various gravimetric moisture content for Ku Band at 12.8 GHz. By utilizing waveguide cell (short-circuited lines or double minima) technique estimations have been made, includes focusing of microwaves over the specimen in a rectangular waveguide cell and fundamental standards engaged with it. The general research center measurements are assuming indispensable part to identify the grains and enhancing crop yield by utilizing microwave remote detecting applications. This paper introduces the data with respect to the impact on the essential variables influencing the dielectric properties of the agricultural products, and for detecting the quality characteristics of the agricultural products.*

Keywords: Dielectric constant, Gravimetric moisture content, Waveguide cell, Preliminary, Oven dried, saturated, Microwave remote sensing, X Band, vegetation

1. Introduction

The interest in dielectric properties of materials has historically been associated with the design of electrical equipment, where various dielectrics are used for insulating conductors and other components of electrical equipment. [1] Briggs found a logarithmic increase in electrical resistance as the moisture content of grain decreased. This indicated that moisture content can be determined by an electrical measurement. Briggs (1908) also found a nonlinear increase in electrical resistance as temperature decreased. [2]

Dielectric properties are the intrinsic properties of a material and depend on its chemical and molecular structure. The area of dielectric properties is a broad field even when limited to grains, because it depends not only on the nature of the material but also on other environmental related parameters such as frequency, temperature, moisture content and density. [3]

During the study of cereals and pulses by the microwave remote sensing, the significance of dielectric constant is much sense due to the dependence of emissivity and scattering coefficient parameters of cereals and pulses. The dielectric constant of a material under given conditions reflects the extent to which it concentrate electrostatic lines of flux.

Dielectric constant is dimensionless number that is in general complex. The imaginary portion of the dielectric constant corresponds to a phase shift of the polarization P relative to E and leads to the attenuation of electromagnetic waves passing through the medium.

Generally, both the dielectric constant and loss factor show monotonic decreases in value as frequency increases. The dielectric constant increased with temperature at lower frequencies but decreased with temperature at higher frequencies. Loss factor generally increased with increasing temperature. [4]

The objective of this research was to investigate the feasibility for measuring dielectric properties of grain samples using double minima setup. Dielectric properties are highly correlated with moisture content because the permittivity of water greatly exceeds that of the dry matter of the agricultural product. [5] In this context, the dielectric properties of the grains are quantitatively and qualitatively analyzed graphically to study their dependence over applied radio-frequency, density, temperature, quality, moisture content and its highly variable dielectric nature with respect to moisture content present in it.

2. Dielectric Definition and Principles

A dielectric is a material that is a poor conductor of

electricity which supports an electric field. The dielectric constant can be defined as the ratio of the permittivity of a substance to the permittivity of free space.

Dielectric constant is typically denoted as $\epsilon_r(\omega)$ and is defined as:

$$\epsilon_r(\omega) = \frac{\epsilon(\omega)}{\epsilon_0} \quad (1)$$

Here,

$\epsilon_r(\omega)$ is the complex frequency-dependent absolute permittivity of the material, and ϵ_0 is the vacuum permittivity.

It is an expression of the extent to which a material concentrates electric flux, and is the electrical equivalent of relative magnetic permeability. As the dielectric constant increases, the electric flux density increases i.e. increase in the holding capacity of charge.

$$C = \epsilon \frac{(a)}{(d)} \quad (2)$$

Where,

- C - Capacitance of the capacitor (F)
- ϵ - Permittivity of the dielectric medium (F/m)
- a - area of the parallel plates (m^2)
- d - Distance between the parallel plates (m)

Permittivity is the fundamental electrical property which describes the interactions of electromagnetic properties of material [2].

3. Basic Microwave Material Interaction Aspects

When microwaves are directed towards a material, part of the energy is reflected, part is transmitted through the surface and of this latter quantity, and part of it is absorbed. The proportions of energy, which fall into these three categories, have been defined in terms of the dielectric properties. The fundamental electrical property through which the interactions are described is the complex relative permittivity of the material. [6]

Dielectric constant for the lossy medium can be formulated as:

$$\epsilon_r = \epsilon'_r + \frac{(\sigma)}{(j\omega\epsilon_0)} \quad (3)$$

Here,

$\sigma = \omega\epsilon_0\epsilon'' =$ Dielectric conductivity in Siemens per meter (sums overall dissipative effects of the grains)

$\epsilon'_r =$ real valued permittivity = Dielectric Storage Factor

$\omega = 2\pi c/\lambda = 2\pi f =$ angular frequency (f in Hz)

$\epsilon_0 = 1/(\mu_0 c^2) = 8.854 \times 10^{-12}$ F/M permittivity of free space

It reduces to:

$$\epsilon_r = \epsilon'_r - j\sigma\lambda\kappa \quad (4)$$

Here,

$\kappa = \mu_0 c/2\pi$

$j = \sqrt{-1}$

$\sigma\lambda\kappa = \epsilon''_r =$ Dielectric Loss Factor

So,

$$\epsilon_r = \epsilon'_r - j\epsilon''_r = |\epsilon'|e^{-j\delta} \quad (5)$$

δ - Loss angle of dielectric i.e. $\tan \delta = \epsilon''/\epsilon'$ is the tangent loss or dissipative factor.

r - it is the subscript used for simplification in the remainder of this article. [7]

The real part ϵ' is an ability of the material to store energy in the form of electric field in itself, and imaginary part ϵ'' is an ability of the material to absorb or dissipate energy means to convert electrical energy into heat energy. [8]

Dielectric properties are very important parameters for developing RF and MW treatments and may be used to estimate heating uniformity and penetration depth. [9]

One possible nonchemical alternative is the use of radio frequency (RF) energy to volumetrically heat product. [10] RF heating is very rapid, significantly reducing treatment times when compared with conventional heating methods. [11] In RF treatments, electromagnetic energy interacts directly with commodities containing polar molecules and charged ions to generate heat. The way in which any material interacts with electromagnetic energy may be described by their dielectric properties. The knowledge of the dielectric properties of both pest insects and products is useful in developing RF treatment protocols. Dielectric properties have been reported for different frequency ranges, temperatures and moisture contents for a variety of dry products. [12]-[13]-[14]-[15]-[16]-[17]-[18]-[19]-[20]-[21]

4. Sample Grains: Cereals and Pulses

4.1 Wheat

The grain of any cereal grass of the genus Triticum, especially T. aestivum, with moist dry weather condition, grown in clay and loamy soil used for culinary and nutritional purposes.

4.2 Rice

A cereal grass (Oryza sativa) that is cultivated extensively in warm climates in the areas having heavy rainfall for its edible grain.

4.3 Green Gram

A well-known as Moong is a Kharif crop grown in moistened summer season.

4.4 Split Red Gram

It is grown in summer season cultivated during warm tropical

and subtropical climate, requires fertile soil.

4.5 Bengal Gram

It requires irrigation, and grown in less heavy soil texture having drain and rainy conditions in winter season.

5. Measurement of Permittivity: Principles and Techniques

The measurement methods relevant for any desired application depend on the nature of the dielectric material to be measured, both physically and electrically, the frequency of interest, and the degree of accuracy required. Despite the fact that different kinds of instruments can be used; measuring instruments that provide reliable determinations of the required electrical properties involving the unknown material in the frequency range of interest can be considered. [22]

The challenge in making accurate permittivity or dielectric property measurements is in designing of the material sample holder for those measurements (RF and MW frequency ranges) and adequately modeling the circuit for reliable calculation of the permittivity from the electrical measurements. If one can estimate the RF circuit parameters appropriately, the impedance or admittance for example, the dielectric properties of that material at that particular frequency can be determined from equations that properly relate the way in which the permittivity of the material affects those circuit parameters.

Techniques for nondestructive determination of quality and related characteristics of agricultural products are helpful to producers, handlers and processors, those marketing the produce, and consumers. [23]

The dielectric constant ϵ' influences the electric field distribution and the phase of waves travelling through the material, while, the energy absorption and consequent attenuation is influenced principally by the loss factor ϵ'' . In general, the behavior of dielectric constant is more regular than that of loss factor with respect to changes in moisture content and the frequency of the applied fields. [24]

Since, bulk grain is a mixture of grain particles and air, measurement of the dielectric properties is more difficult than if it were a homogeneous substance consisting of grain only. There is a need for better understanding of the usefulness and measurement techniques of dielectric properties of grains to develop new sensing devices for the automation of moisture content measurements and design of drying methods.

Therefore, the short-circuited line technique is used to measure the dielectric constant of the various samples.

6. Materials and Methods

4.1 Sample Preparation

- 1) Preliminary sample
- 2) Oven dried sample



Figure 1: Heater for oven-dried sample (at 110°C)

- 3) Saturated sample

During sample preparation, same sample only, of different varieties of grains undergo from all the three different physical states (i.e. of preliminary, oven-dried, and saturated states) successively.

4.2 Method Used

At microwave frequencies, generally about 1GHz and higher, there are basically four different methods available for the measurement of dielectric constant are Resonant cavity method, Waveguide cell (short circuited line) method, Free space method (Open Structure) and Reflection or Transmission line method.

The estimation of dielectric constant has been made using the measure values of dielectric constant using waveguide cell in frequency range of Ku-band.

Closed structure method includes short circuited waveguide reflection measurements.



Figure 2: Setup for Measurement of dielectric constant at Ku Band (12.4 GHz-18.0 GHz)

The Design of dielectric sample holder for the cereals, pulses in an important aspect of the measurement technique. The Roberts and von Hippel [25] short circuited line technique for dielectric properties measurements provides a short section of rectangular waveguide with a shorting plate or other short-circuit termination at the end of a line against which the sample rests. This is convenient for particulate samples, because the sample holder, and also for the slotted line or slotted section to which the sample holder is connected can be mounted in a vertical orientation so the top surface of the sample can be maintained perpendicular to the axis of the wave propagation as required for the measurement. The vertical orientation of the sample holder is also convenient for the saturated samples containing distilled water into it.



Figure 3: Sample Holder (Ku-Band from 12.4-18.0 GHz)

For purposes of research, it is customary to artificially add water to grain and seed to investigate variations of their dielectric properties with frequency, temperature, moisture content and bulk density. [26]-[27]-[28]

Distilled water is usually used to be the material standard because of its known complex permittivity. [29]

The Roberts and von Hippel method requires measurement to determine the standing wave-ratios (SWR's) in the line with and without the sample inserted. From the shift of the standing-wave node and changes in node widths related to SWR's, sample length, and waveguide dimensions, etc. ϵ' and ϵ'' can be calculated with suitable computer programs. [30]-[31] The technique is subject to errors if there are significant density variations in the material or if there are air gaps or air bubbles between the samples.

It is a simple method measurement of dielectric constant of a solid material like pulses. The dielectric constant obtained by using the shift in minima of standing wave pattern inside a slotted section of rectangular waveguide. This shift takes place due to the change in guide wavelength, when dielectric material is introduced in waveguide slotted section by the help of waveguide short circuited cell.



Figure 4: Calibrated sample weighing machine

Here, the measurement of guide wavelength is carried out at microwave frequency.

Table 1: Analyzed Frequency Band

Band	Frequency (GHz)
Ku-Band	12.8

The relevant equations used for determining the dielectric constant in the given frequencies are as follows:-

$$k = \frac{2\pi}{\lambda_g} \quad (6)$$

Here,
 k = Propagation constant
 λ_g = Guide wavelength

$$\varphi = 2k(D - D_r - l_\epsilon) \quad (7)$$

Here,
 φ = Phase angle
 D = First voltage minima of sample
 D_r = First voltage minima when waveguide is short-circuited.
 l_ϵ = length of sample

Table 2: Units and Corresponding Symbols

Band	Length of the Sample (cm)
Ku-Band	0.476

$$|\Gamma| = (r - 1)/(r + 1) \quad (6)$$

Here,
 $|\Gamma|$ = reflection coefficient
 r = voltage standing wave ratio (VSWR)
 Complex transcendental equations

$$A = (|\Gamma|^2 - 1)/(k l_\epsilon (1 + |\Gamma|^2 + 2|\Gamma| \cos \varphi)) \quad (7)$$

$$K = (-2|\Gamma| \sin \varphi)/(k l_\epsilon (1 + |\Gamma|^2 + 2|\Gamma| \cos \varphi)) \quad (8)$$

(10) Now, solve for X in the real transcendental equation, using

the two sets of data to determine X'

$$R = \frac{(AX'^2)}{(\tan X' - X'(1 + \tan^2 X'))} \quad (9)$$

$$K' = \frac{(R \cdot \tanh R(1 + \tan^2 X') + X' \tan X'(1 - \tan^2 hR))}{((R^2 + X'^2)(1 + \tan^2 R \cdot \tan^2 X'))} \quad (10)$$

If K and K' are almost identical, the values of X' and R calculated are acceptable; if not, this method of solution does not apply.

$$T = \sqrt{R^2 + X'^2} \quad (11)$$

$$\tau = \tan^{-1}(X'/R) \quad (12)$$

Here,
 $\{45^\circ < \tau < 90^\circ\}$

$$\gamma_e = (T/(kl_e))^2 < (2 * (\tau - 90^\circ)) \quad (13)$$

$$\gamma_e = G_e - jB_e \quad (14)$$

Here,
 γ_e = admittance
 Ge = conductance
 Be = susceptance

$$\epsilon' = ((G_e + (\lambda_g/2a)^2)/(1 + (\lambda_g/2a)^2)) \quad (15) \quad (16)$$

$$\epsilon'' = (-B_e/(1 + (\lambda_g/2a)^2)) \quad (16)$$

$$\epsilon_r = \epsilon' - j\epsilon'' \quad (17)$$

Here,
 ϵ' = storage factor
 ϵ'' = loss factor
 ϵ_r = dielectric constant

7. Procedure

Different physical states (i.e. preliminary, oven-dried, and saturated) weighed samples (i.e. Rice, Wheat, Red Split Gram, Green Gram, Bengal Gram) for measurements are taken into the sample holder and try to make it homogenous so that no air gap is present in it, therefore the unwanted losses can be avoided and also determine the depth of the sample in the short circuited cell.

Now, the sample holder carefully tightened with the help of nuts and screws to the slotted section of the rectangular waveguide and makes it vertically aligned. Apply the Gunn Power supply and determine the two minima shifts with the help of SWR meter and slotted section; determine the guided wavelength ' λ_g ' and then VSWR with the help of related formulas and then determine the dielectric constant with the help of computer programs.

8. Influencing Factors

The dielectric properties of most materials vary with several influencing factors. [32]

Grain types whose shapes were more nearly spherical showed

much smaller differences among loading methods. The differences in dielectric constant and predicted moisture were shown to be highly correlated to kernel shape. [33]

Knowledge of dielectric properties is important in radio-frequency and microwave heating applications [34], remote sensing [35], and non-destructive sensing of physical properties of materials such as bulk density and moisture content of granular materials. [36]-[37]-[38]-[39]-[40]

8.1 Frequency Dependence

The frequency varies inversely with respect to dielectric constant for the different physical states and loss factor may decrease or increase with the frequency depending on the influence of dielectric relaxations.

8.2 Temperature Dependence

As the temperature rises the dielectric relaxation decreases which results into the increase in dielectric constant and the loss factor may increase or decrease depends on operating frequency is higher or lower than relaxation frequency.

8.3 Density Dependence

As the bulk density of the cereals and pulses increases the dielectric constant increases and loss factor decreases and may vary differently on the basis other features of the materials.

8.4 Moisture Dependence

Generally, the dielectric constant and loss factor both increase with increasing moisture content, especially in lower moisture materials such as cereal grains.

9. Merits of Dielectric Properties

- Helps in accurate measurement of moisture content and maintaining the optimum moisture content of grains are important operations in grain storage.
- They can be used to design dielectric heating applications for grain drying, control of insects and seed treatment to improve germination. [41]
- Dielectric properties also help to sense the quality factors other than moisture state. [42]
- Since water is easy to stimulate and most of the food products contains water, microwave heating is highly suitable for cooking. Thus microwave penetrates food easily and heats the food from inside out which includes the geometry of the cavity in which proper heating takes place (to prevent food poisoning due to micro-organisms) and the geometry and size of the object and its electromagnetic and thermal parameters.[43] Dielectric properties are one of these parameters that are specially considered here. [44]
- Permittivity helps to know the interaction of the material with electric field.
- Extension of dielectric properties sensing to the monitoring of moisture content in moving grain [45]-[46]-[47] promise

applications important to improving yield determination on combines and other harvesters for precision farming operations.

- These techniques are also applicable to control of grain dryers and other grain processing equipment for improving energy use efficiency and improvement of product quality.
- Some of the techniques developed [48]-[49]-[50] have been crucial in the design of moisture sensors on modern grain combines for continuous monitoring of grain moisture content as grain is harvested.
- More recently, techniques have been studied for sensing the moisture content of single grain kernels, seeds, nuts, and fruits so that instruments for measuring the moisture content of individual objects can be developed.

10. Future Directions

The importance of understanding the interaction of material subjected to electro-magnetic fields is addressed. The rapid advancement in the instrumentation and electronic component selection has necessitated the development of a permittivity analyser that is independent of vector network analyzer. This will be helpful for dielectric properties measurement and analyses on-line (e.g., moisture sensing in a conveying grain application) as they are portable and inexpensive. Continued research and development of such techniques are aimed at providing tools for better management of factors important in sensing, preserving, processing, and maintaining the quality of agricultural and food materials for ever growing consumer expectations.

11. Results & Discussions

For frequencies 12.80 GHz measurements taken for different form of cereals which includes dielectric constant and loss factor (i.e. ϵ' and ϵ'') are given as follows-

Table 3: Dielectric Constant and loss factor of grains for Ku-Band (12.80 GHz)

Samples	Dielectric Constant	LOSS FACTOR
Preliminary		
Wheat	5.050	0.3142
Rice	4.3615	0.9154
Arhar	4.6513	0.5693
Chana	5.5360	0.2726
Moong	4.3890	0.7328
Oven Dried		
Wheat	3.5176	0.2190
Rice	2.5694	0.2138
Arhar	3.5117	0.2918
Chana	2.2031	0.0916
Moong	2.1937	0.2288
Saturated		
Wheat	7.2561	3.5667
Rice	7.3702	3.2357
Arhar	6.6176	2.5803
Chana	7.1975	3.5192
Moong	6.7615	2.6507

6.1 Combinational Study of Cereals and Pulses

In order to determine the variability of dielectric constant with frequency, the measurements were made at different frequencies. The measurements have been made at frequency in the range 12.4 to 18 GHz. The values are calculated of dielectric constant and loss factor for different samples in preliminary; oven dried and saturated states respectively.

It is observed that dielectric constant and loss factor of five samples are different due to the difference in their physical properties. The data have been obtained by taking ten sets of readings for each sample and each set comprising of three values of the shift in minima obtained throughout the length of the slotted waveguide. The process is repeated in order to check the accuracy and precision of microwave system used.

6.2 Resultant variation in Dielectric Constant and Loss factor with different moisture content

The variability in dielectric constant and loss factor can be attributed to the presence of moisture in the samples, which they absorb when kept exposed to the atmosphere and also get evaporated up to certain due to variable environmental temperature conditions.

We observed that the value of ϵ' & ϵ'' increases with the increase in moisture content. This is due to the presence of free water molecules in the sample. The dielectric constant of water is 80 at around 1 GHz and it decreases with increase in frequency and also the dielectric constant changes when impurities are present in the water. For moisture content, just add distilled water in the samples. The loss factor increases with increase in frequency.

The dielectric constant and loss factor of the samples were measured after determining the weight of the sample before the measurement. Some measurements were also made before the settlement and just after adding water to cereals at the saturated limit of water-cereals mixture.

In the present study, the measurements were made for the preliminary samples, oven dried sample and sample having moisture content 2%, 5%, 10%, 20%, 30%. The results of measurements of moisture content of 2% to 30.00% have been tabulated in this properly.

Dielectric constant and loss factor changes with humidity or water with water content, so that special arrangements have to be made to hold humidity constant and to determine its value or we can do it naturally just by drying it in air.

Grain moisture content is expressed as a percentage of moisture based on wet weight (wet basis) or dry matter (dry basis). Wet basis moisture content is generally used. Dry basis is used primarily in research.

$$Mw (\text{wet basis}) = \frac{w - d}{w} * (100) \quad (18)$$

$$Md \text{ (dry basis)} = \frac{w - d}{d} * (100) \quad (19)$$

Here,

w = wet weight

d = dry weight

M = moisture content on a percent basis.

A representative sample must be obtained to provide a useful moisture content evaluation. Also, the moisture content of the product must be maintained from the time the sample is obtained until the determination is made by storing in a sealed container.

The moisture content can be determined by an oven method, which is a direct method. The grain is weighed and dried, then weighed again according to standardized procedures. The moisture content is calculated using the moisture content equations. Most moisture meters measure the electrical properties of grain, which change with the moisture content. This is considered an indirect method and must be calibrated by a direct method. It is important to follow moisture meter directions carefully to achieve an accurate moisture test. A moisture meter should be periodically checked to see if it is accurate. One method of checking the meter is to compare it to at least two other meters.

Table 4: Dielectric Constant and loss factor of grains for Ku-Band (12.8 GHz)

Moisture Content in %	Dielectric Constant (12.8GHz)				
	Wheat	Rice	Arhar	Chana	Moong
2	4.3452	4.2327	4.1554	4.9501	4.1776
5	5.0153	4.6984	4.6984	5.7283	4.2045
10	5.1925	5.3315	4.8143	6.3750	4.7763
20	6.9765	6.1957	5.4727	6.8513	5.6026
30	7.2560	7.3701	6.5926	7.1972	6.7612
Moisture Content in %	Loss Factor (12.8GHz)				
	Wheat	Rice	Arhar	Chana	Moong
2	1.1496	1.6133	1.3812	1.7593	0.9334
5	1.6042	1.7413	1.3825	2.5233	1.9878
10	2.5910	2.2794	2.0372	2.5635	2.0884
20	3.1165	3.0412	2.2096	2.8705	2.5486
30	3.5660	3.2350	2.5800	3.5190	2.6500

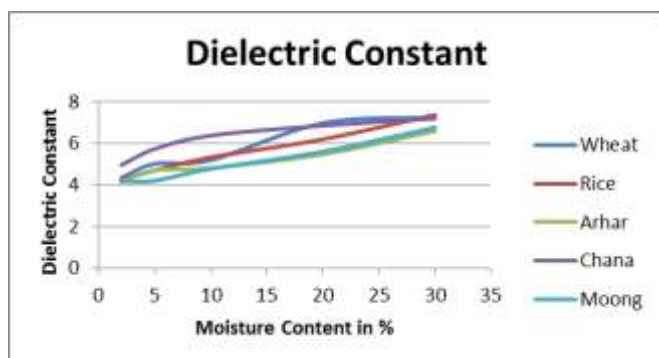


Figure 1: Variation in dielectric constant for Rice, Wheat, Arhar, Chana and Moong samples at different moisture levels

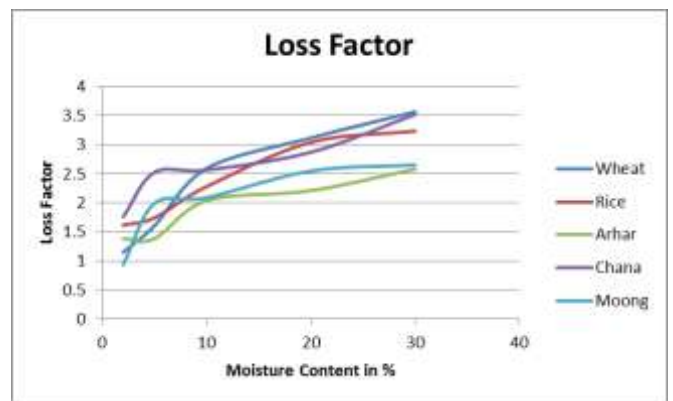


Figure 2: Variation in Loss Factor for Rice, Wheat, Arhar, Chana and Moong samples at different moisture levels

12. Conclusion

In this paper, the direction in which the research has moved has been indicated where we estimated the dielectric constant and loss factor of various cereals and pulses using the theoretical models and then compare it with the practical values of dielectric constants of same cereals obtained through the radiometer.

This paper also shows the behavior of dielectric constant of cereals and pulses (Wheat, Rice, Arhar, Chana, Moong) using theoretical model of two point method (wave guide method).

The dielectric constant is dependent of frequency and stays constant only over relatively small portions of the frequency spectrum. But, the variation of ϵ' with frequency is sufficiently gradual that it can be considered to be constant over a fairly wide frequency band for most common microwave applications. The percentage variation in ϵ'' is almost always greater than that of ϵ' , so that ϵ'' should be measured near the frequency or frequencies of interest. In some cases, ϵ' is affected by temperature, so that the temperature should be held constant. The ϵ' and ϵ'' is directly proportional to the moisture content present in the sample.

The method for the complex permittivity of cereals has been developed, by maintaining relationships of theoretical and physical significance. The estimated permittivity's and loss factor of Rice, Wheat, Moong dal, Chana dal, Arhar dal with average accuracies of 5 % to 10 % over the frequency 12.80 GHz and moisture content range from 2% to 30 %, wet basis. The research took place on analog instruments so accuracy may vary to negligible values under small tolerance limit.

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