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MEASUREMENT OF DIELECTRIC PROPERTIES OF LOCAL CEREALS IN THE AUDIO FREQUENCY RANGE.

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ABSTRACT

This paper deals with the measurement of dielectric properties of some local cereals (corn, beans, rice) in the audio frequency range (0.3 – 20KHz) since dielectric properties of various agro-foods and biological materials are finding increasing applications, as fast and new technologies adapt/adopt these cereals for use in their respective industries and research laboratories.

A Marconi instrument, 0.1% universal impedance bridge together with a specially designed and constructed coaxial sample holder was used for the required measurements. The properties measured include the dielectric constant, the dielectric loss factor, the loss tangent (or dissipation factor) and the dielectric conductivity. The frequency dependence of these properties was explored in this research. The following characteristics were obtained:

(i) Dielectric constants for the cereals (corn, rice and beans) decreased with increase in frequency in the audio frequency range.

(ii) Dielectric conductivity increased with increase in frequency in the audio frequency range.

(iii) Dielectric loss factor and loss tangent values for the cereals decreased with increase in frequency in the audio frequency range.

(iv) The capacitance of the samples decreased with increase in frequency in the audio frequency range.

These electrical characteristics of the cereals are important for many potential applications viz the use of electric energy for moisture measurement, grain drying, seed conditioning, stored grain insect control and remote sensing for measurement or process control.

1.0 INTRODUCTION

Adequate storage and preservation of cereals is important to countries the world over. The earlier methods of storage and preservation of cereals required them being exposed to natural sunlight or being smoked and stored in bans or bags.

In order to reduce the quantity of wasted cereals, scientists delved into determining some of their useful properties, such as their dielectric properties. One such method uses the universal impedance bridge together with a specially designed and constructed sample holder. This same method was adopted for this research.

Dielectric properties are affected by moisture content, bulk density and frequency variations. This paper discus widely the frequency dependence of dielectric properties for dry cereals at room temperature in the audio frequency range. No attempts were made to investigate the dependence of such properties on bulk density and moisture content but from history, the trends will follow the same pattern to those showing the frequency dependence of the dielectric properties.

Electrical characteristics of cereals find great applications in areas including the use of electric energy for moisture measurement, grain drying, seed conditioning, stored grain insect control and remote Sensing for measurement and control. [1]

Dielectric properties can be used to understand the behavior of food materials during microwave processing. Dielectric properties influence the level of interaction between food and high frequency electromagnetic energy. Dielectric properties are, therefore, important in the design of foods intended for microwave preparation. [2]

The following are uses of dielectric properties measurements (not related to microwave heating of food) that can be of interest to agro-food researchers. Some of them are:

• An important use of the dielectric properties of grain and other agricultural products in their exploitation for rapid, nondestructive sensing of moisture in materials.

• Moisture content is often the most important characteristic of agricultural products, because it determines their suitability for harvest and for subsequent storage or processing. It often determines the selling price of the products for intended purposes.

• Dielectric properties have been utilized with properly designed electronic sensors with reasonable accuracy. Such moisture testing instruments, operating in the 1-50 MHz

range, have been developed and used for rapid determination of moisture in grains for many years.

• 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. In addition to moisture measurement, the dielectric properties measurements have been useful in several diagnostic tests as well as for the processing of materials (sectors such as: agro-foods, pharmaceuticals, biomedical, forestry, textile, metallurgy).[3]

1.1 AVAILABLE MEASUREMENTS TECHNIQUES

There various methods and techniques that can be used to measure dielectric properties .

[3]

- Permittivity measurement principles and techniques
- Perturbation techniques

- Transmission line techniques
- Open-ended probe techniques
- Free space transmission techniques

The task of the research lies in the design and construction of the coaxial sample holder. Over the years there has been a transition in the type of sample holder used in the investigation of dielectric properties of cereals.

Earlier experiments utilized a parallel plate sample holder made out of aluminum. Due to the difficulty to fill this holder and edge effects due to fringing fields at the corners of the holder, this form of sample holder was discarded. This lead to the birth of the coaxial sample holder made out of brass due to cost and availability of materials, aluminum and perspex were used to construct the coaxial sample holder used for this research work. [4]

1.2 ANALYSIS, DESIGN & CONSTRUCTION

1.2.1 DESIGN & CONSTRUCTION OF THE SAMPLE HOLDER

A dielectric sample holder was designed with appropriate specification and required dimensions.

When the paper work was set out, a model was made out of cardboard paper to visualize the size of the holder for feasibility. This was then replaced by a model carved out of sheet metal slightly above the desired specification. The inner cylinder had a conical finish. Both the inner and outer cylinders were furnished with electrodes.

A special mould was formed using clay-like soil into which the models were inserted. The soil was guarded by a rectangular wooden mould. When the wooden mould was filled with soil, two vents were provided to serve as a filler route for pouring the molten aluminum and as an outlet indicating that the carved models in the mould were completely filled up. The aluminum lump was then placed in a steel container and put into an oven regulated to a temperature slightly above the melting point of the aluminum so as to melt the aluminum. The molten aluminum was then poured into the mould and allowed to solidify. The soil was disposed of from the wooden mould and the respective models for the sample holder were allowed to cool. After cooling the sheet metal were discarded and the moulded cylinder were now machined to specification.

To fix the electrodes to the cylinders, they were drilled at the base and the pencil shaped electrodes were hammered into the drilled holes. The cylinders were then bonded by a carved cylindrical piece of wood which also served as a stand for the completed holder. A doorway was created at the lower end of the wood to expose the electrode attached to the inner cylinder. [4]

1.2.2 ANALYSIS OF THE SAMPLE HOLDER

At any given frequency, a dielectric material may be represented by a parallel equivalent circuit consisting of a capacitance and a resistance.

The electrical equivalent circuit of the coaxial sample holder is as shown in Fig.1.

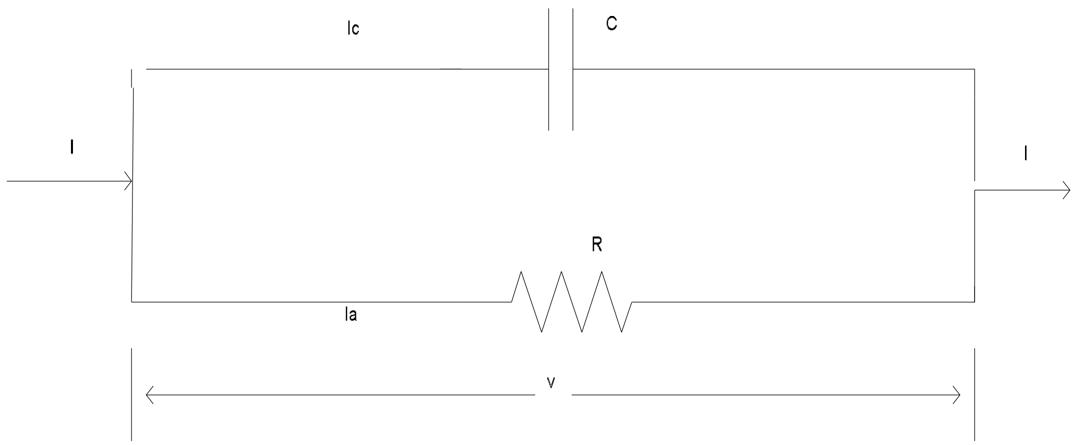

FIG 1: PARALLEL CIRCUIT OF THE SAMPLE HOLDER.

Fig. 1 serves for both empty and filled sample holder; the only difference is the additional resistance and capacitance introduced by the sample in the holder.

For any dielectric material, the complex relative permittivity can be represented thus:

$\varepsilon = \varepsilon_1 - j\,\varepsilon_2$……………………. (1)

Equation one specifies the behaviour of any dielectric material.

ε_1 is the dielectric constant and is ε_2 the dielectric loss factor known as loss factor hereafter. The loss tangent or the dissipation factor, D, is the loss angle, δ and is expressed as shown in equation 2:

$D = \tan\delta = \varepsilon_2 / \varepsilon_1$ ……………………..(2)

The dielectric conductivity, σ is expressed as shown in equation 3

$\sigma = w\varepsilon_0\varepsilon_2$ ……………………………… (3)

and $w = 2\pi f$ ………………………………… (4)

With ε_0 as the permittivity of free space $\varepsilon_0 = 8.854 \times 10^{-12}$F/m.

This research investigates the parameters defined by equation (1) to (4). Analysis of Fig. 1 leads to the derivation of these formulas as related to the work.

1.3 TESTS AND RESULTS

1.3.1 TESTS

Series and parallel tests were carried out respectively, the meters were mechanically zeroed and the mains lead connected to the power supply. With the supply switch on, as indicated by the pilot lamp, the L C R switch was set to C, the D- Q switch set to D and the 1 kHz – 10kHz switch set to the desired frequency. The loss balance, fine D ad fine and coarse balance controls were set midway. The sensitivity control was set to give a meter deflection of half scale and the range switch adjusted to give the lowest meter reading. The coarse balance control was adjusted for a minimum meter reading. When the approximate balance position was found, the loss balance control was adjusted for a sharp null, by advancing the sensitivity control as required.

Finally as near as possible a zero meter reading was obtained by adjusting the fine balance control together with the loss balance control. The values for the capacitance and dissipation factor were then read off the meters. This procedure was repeated for 0.3, 0.5, 1, 2, 3, 5, 10 and 20 kHz frequency values respectively for both the series and parallel measurement.

1.3.2 RESULTS

The results obtain were as shown in Table 1.

1.3.2.1 Results with Empty Sample Holder

Table 1: Series Tests

Frequency (f) (kHz)	Series Capacitance C_{s0} (pF)	Dissipation Factor D_{so}

0.3	28050	0.9524
0.5	27050	0.8000
1.0	19050	0.6667
2.0	16050	0.5000
3.0	15050	0.4167
5.0	14050	0.3333
10.0	12050	0.2500
20.0	1150	0.2000

Table 2: Parallel Test

Frequency (f) (kH)	Series Capacitance C_{po} (pF)	Dissipation Factor D_{po}
0.3	28050	0.9600
0.5	27050	0.8000
1.0	19050	0.6600
2.0	16050	0.5000
3.0	15050	0.4200
5.0	14050	0.3100
10.0	12050	0.2900
20.0	1150	0.2000

1.3.2 (b) Tests with full sample holder

Table 3: Series and Parallel Tests using Rice

Frequency (f)	**C_s (pF)**	**C_p (pF)**	**D_s**	**D_p**

(kHz)				
0.3	56050	56050	0.6061	0.6000
0.5	53050	53050	0.4651	0.4500
1.0	46050	46050	0.3704	0.3600
2.0	41050	41050	0.3333	0.3200
3.0	37050	37050	0.3030	0.3000
5.0	34050	34050	0.2500	0.2400
10.0	30050	30050	0.2500	0.2700
20.0	28050	28050	0.1667	0.1600

Table 4: Series and Parallel Tests using Corn

Frequency (f) (kHz)	**C_s (pF)**	**C_p (pF)**	**D_s**	**D_p**
0.3	49050	49050	0.6410	0.6200
0.5	44050	44050	0.5405	0.5300
1.0	36050	36050	0.4546	0.4400
2.0	29050	29050	0.4167	0.4000
3.0	27050	27050	0.3704	0.3600
5.0	25050	25050	0.2857	0.2600
10.0	10950	10950	0.1100	0.1000
20.0	10950	10950	0.2300	0.2000

Table 5: Series and Parallel Tests using Beans

Frequency (f) (kHz)	**C_s (pF)**	**C_p (pF)**	**D_s**	**D_p**
0.3	40050	40050	0.6667	0.6600
0.5	37050	37050	0.5714	0.5500
1.0	29050	29050	0.5000	0.5000
2.0	250505	250505	0.3846	0.3800
3.0	23050	23050	0.3333	0.3100
5.0	10950	10950	0.3241	0.3000
10.0	20050	20050	0.2000	0.2500
20.0	10950	10950	0.2000	0.2500

Where:

C_{so} is the series capacitance of the empty holder.

C_{po} is the parallel capacitance of the empty holder

D_{so} is the series dissipation factor for the empty holder

C_s is the series capacitance of the filled holder

C_p is the parallel capacitance of the filled holder

D_s is the series dissipation factor of the filled holder

D_p is the parallel dissipation factor of the filled holder.

The results show that dissipation factor and capacitance **drop off** with increasing frequency in the audio frequency range.

1.4 CALCULATION OF DIELECTRIC PROPERTIES,

The working formulae include the following

1. $D_O = D_{SO}$

2. $C_{PO} = C_{SO}$

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$1 + D_O^2$

3. $D_M = \frac{1}{2}(D_S + D_P)$

4. $C_{PM} = \frac{1}{2}(C_P + {}^{CS}/_1 - Dm^2)$

5. $D = \dfrac{CpmDm - C_{po} D_o}{C_{pm} - C_{po}}$

6. $\varepsilon_1 = 0.0062 (Cpm - Cpo) + 1$

7. $\varepsilon_2 = \varepsilon_1 D$

8. $\sigma = 0.556 f\varepsilon_2$

All the parameters were as defined during the course of the work and the formulae were as derived.

NOTE: For simplicity the calculations were done in tabular form and the results obtained were used to produce the graphs below.

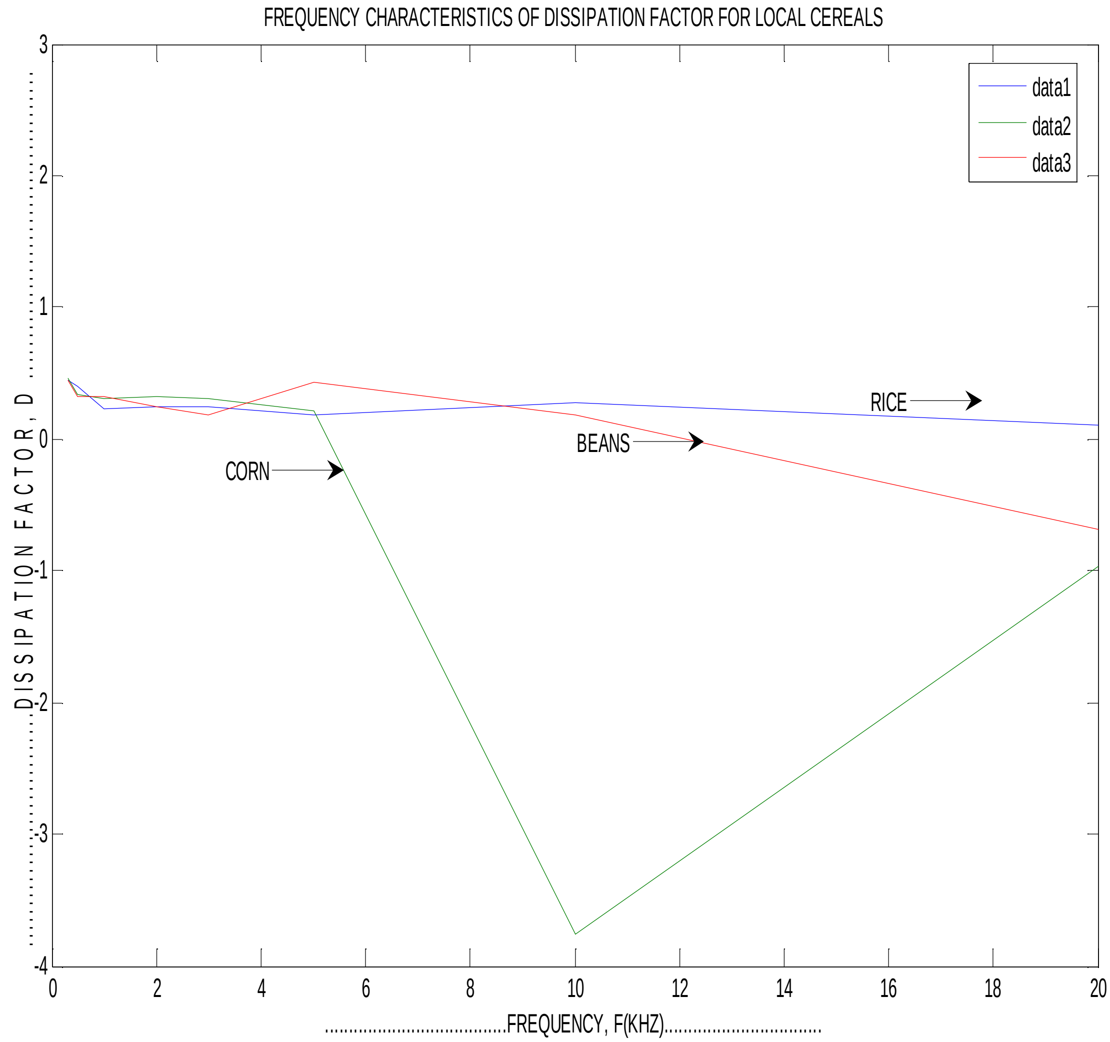

FIG 2 : Frequency characteristics of dissipation factor for local cereals.

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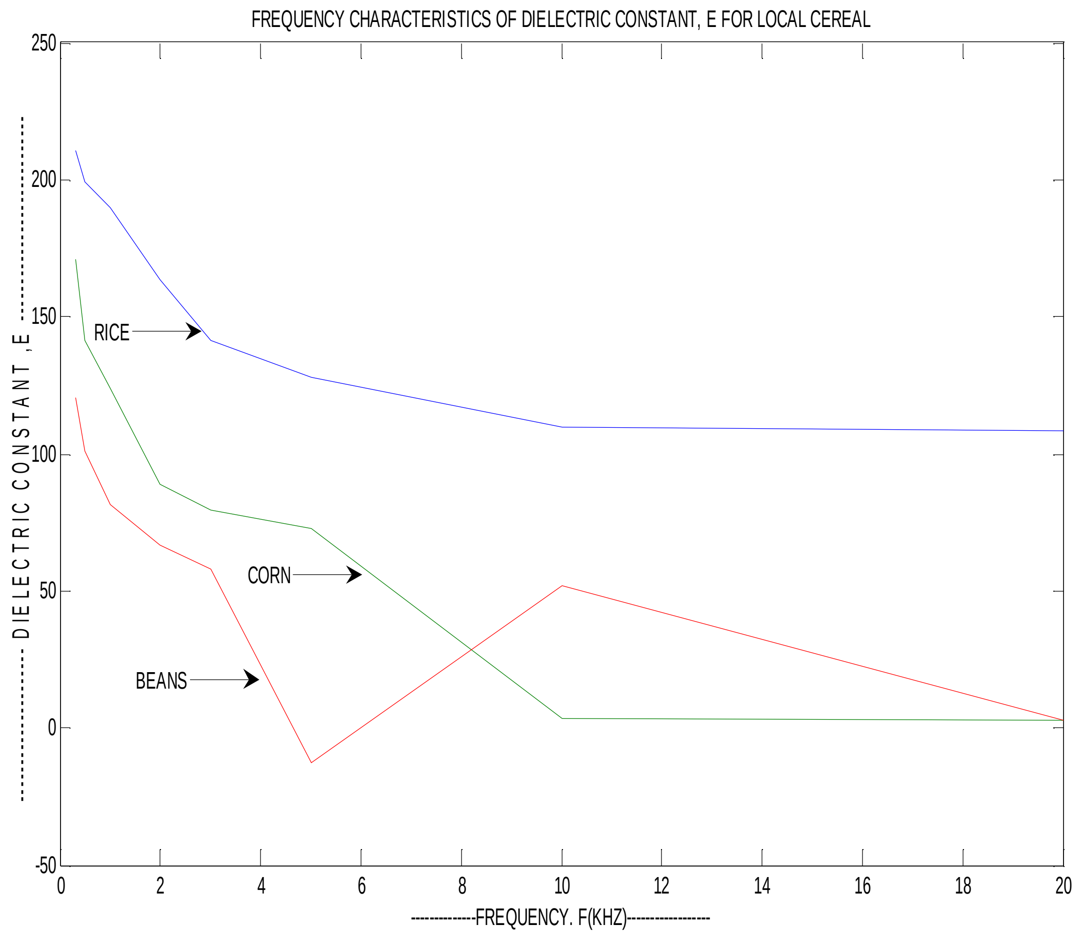

FIG 3: Frequency characteristics of dielectric constant, E for local cereals.

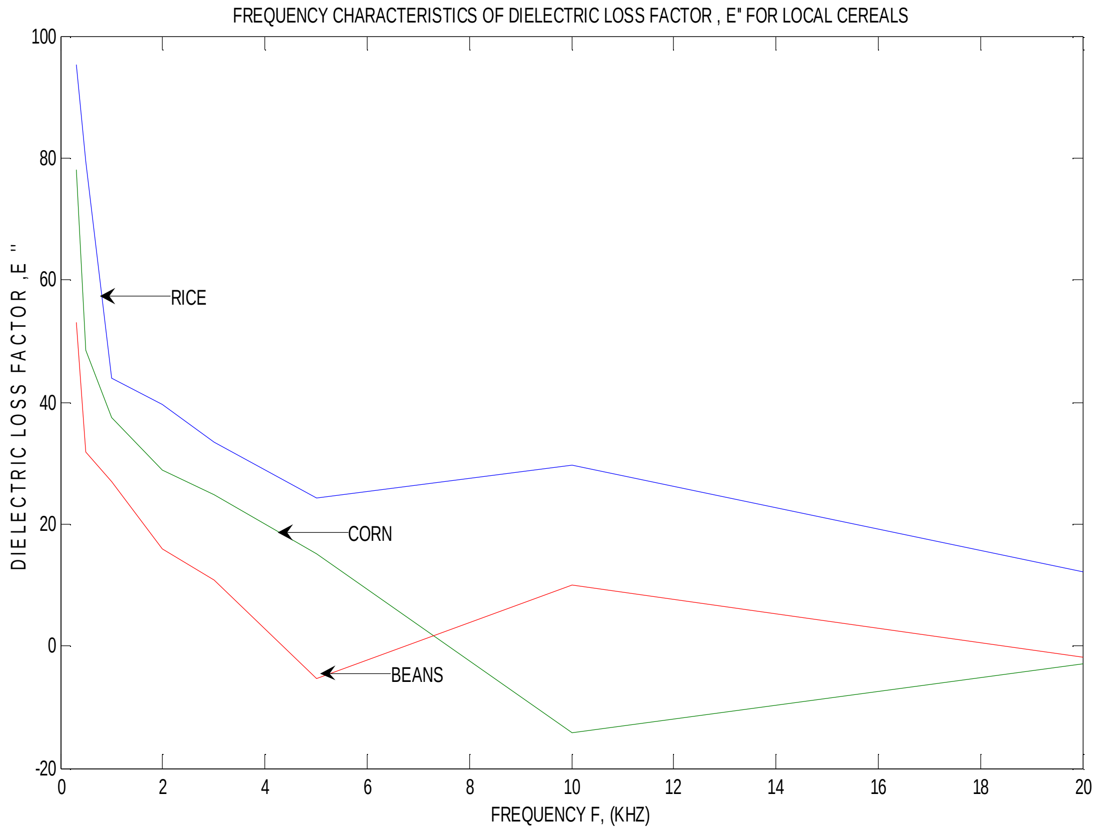

FIG 4: Frequency Characteristics of Dielectric Loss Factor, E'' For Local Cereals.

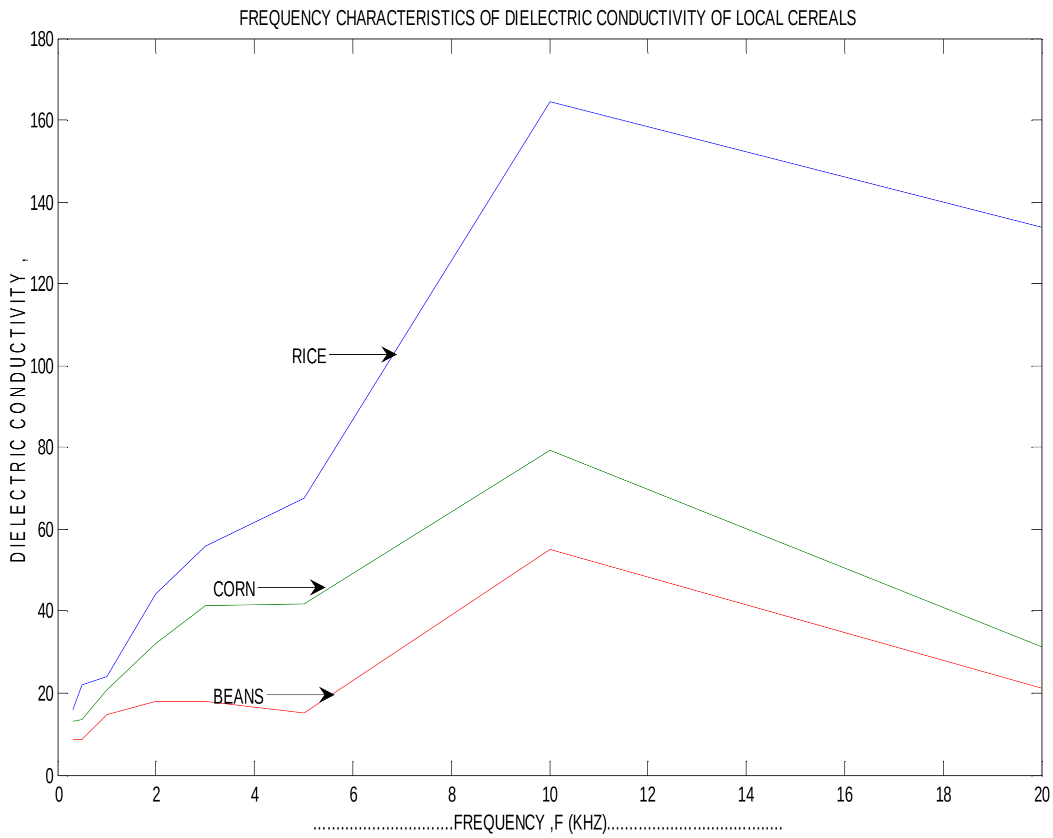

FIG 5: frequency characteristics of dielectric conductivity, σ of local cereals.

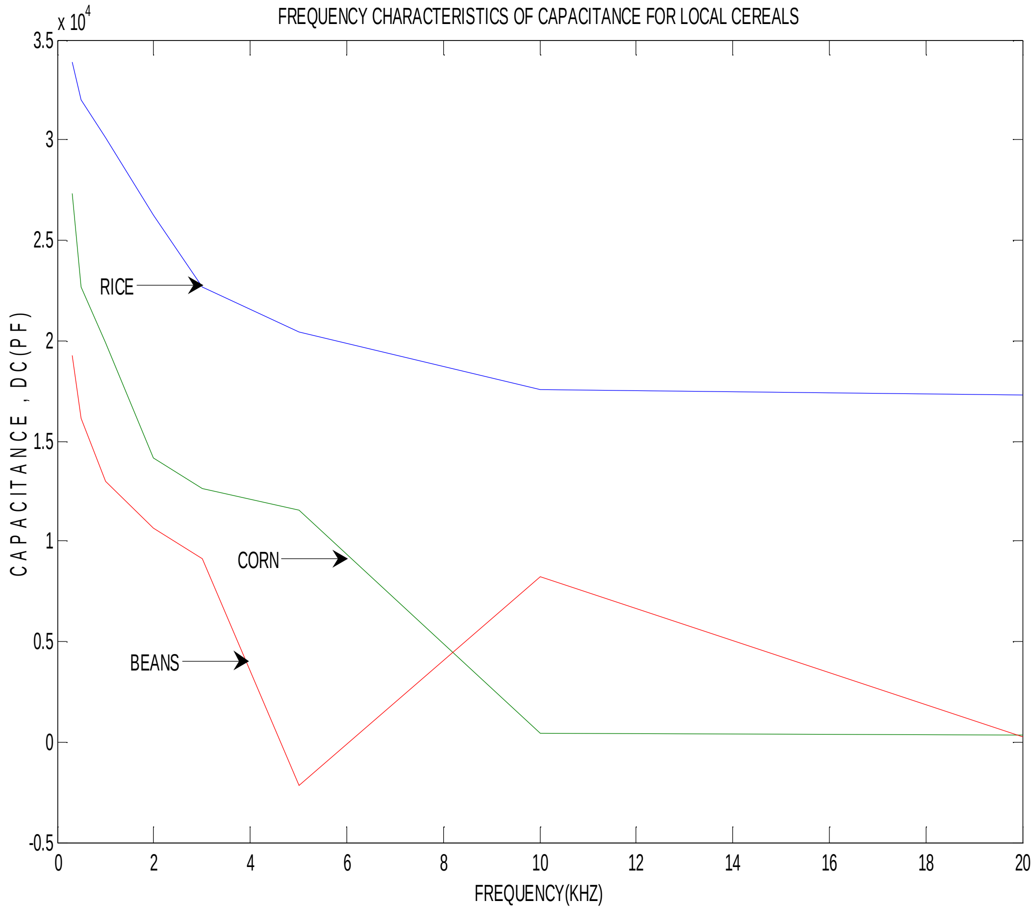

FIG 6: frequency characteristics of dielectric conductivity, σ of local cereals.

1.5 DISCUSSION, CONCLUSION & RECOMMENDATION

1.5.1 DISCUSSION

From table (1) & (2) (measurements made with empty holder), it can be seen that values for the series and parallel capacitance and dissipation factor decreased with increase in frequency from 0.1 to 20kHz. Though the same trend is maintained as can been in tables 3, 4 and (measurements made with the filled holder) the values of the capacitance have increased much more (almost double) the values in tables 1 and 2.

Never-the-less, though there was a decrease in dissipation factor with increase in frequency for the filled holder, the value had decreased to about a third of the value measured using the empty holder. The increased capacitance introduced by the sample in the holder in parallel with the capacitance of the empty holder.

From figures 2, 3, 4 and 5 there was a general decrease in the dissipation factor, dielectric constant and dielectric loss factor with increase in frequency for rice, corn and beans while for the same samples, the dielectric conductivity increased with increase in frequency.

Some irregularities exist due mainly to the electrical properties of the material used in the design and construction of the same holder. The irregularities might have as well been caused by slight variations in bulk density and moisture content.

1.5.2 CONLUSION AND RECOMMENDATION

Dielectric properties were measured at various frequencies for different cereals. The properties measured include the dielectric constant,ε_1, the dielectric loss factor,ε_2, the dielectric loss tangent, D and the dielectric conductivity, σ.

The following conclusions were reached showing their frequency of dependence:

1. Real permittivity (dielectric constant) values for grains and seeds in the audio frequency range drop off with increase in frequency (Fig. 3).

2. For accurate values of grains and seeds dielectric property measurements on individual seed lots were essential, but the data presented provide a basis for reasonable estimates of dielectric properties for several kinds of grains and seeds in the audio frequency range.
3. Dielectric loss factor and dielectric loss tangent values for grains and seeds drop off with increase in frequency in the audio frequency range. (Fig.2 &4).
4. Dielectric conductivity increases with increase in frequency in the audio frequency ranges (fig 5).

Thus dielectric properties information is essential in effectively selecting frequency or moisture ranges which may be useful for any particular sensing applications such as electric energy for moisture measurement, grain drying, seed conditioning, stored grain insect control and remote sensing for measurements or process control.

Since dielectric properties for grains and seeds vary with moisture content and bulk density and since this project only dealt with the frequency dependence of such properties, further works should investigate the dependence and bulk density. Also, the sample holder should be bonded in due course with epoxy or resin whose electrical properties are known. This should replace the wood used in bonding the concentric aluminum cylinders; due to cost the department can construct a sample holder using brass.

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