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Investigation of Dielectric Properties of Some Varieties of Wheat and their Correlation with Food Nutrients

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Abstract - A simplified method is proposed for determination of dielectric properties of the food grains in powder form by employing a specially designed dielectric cell and using two point methods. Dielectric constant (ε') and loss factor (ε") of five different varieties of wheat have been determined in powder form and their dependence on nutrients has been investigated. .Food nutrients . such as, percentage moisture content, carbohydrates, protein and fat are also estimated in the five varieties of wheat by using standard Bio-chemical methods. Graphical and mathematical correlations are established between the dielectric properties and nutrients of the wheat.

Index Terms—**Dielectric constant, food nutrients, Indian wheat, loss factor.**

I. INTRODUCTION

Dielectric properties of materials are important for predicting the behaviour of a material in an electric field or for knowing how the presence of the material may influence the field or an associated electrical circuit. These are the main parameters that provide information about how materials interact with electromagnetic energy. The dielectric properties of agricultural and food materials (and products) help in predicting heating rates describing the behaviour of materials when subjected to high frequency or microwave electric fields in dielectric heating applications [1]. The dielectric properties of food grains and seeds are used in many applications, such as moisture content determination, protection of stored grains from insects, dielectric heating, sorting, cleaning etc. [2]. So, for the development of microwave process control, it is important to know dielectric properties of the materials. Dielectric properties of food products depend on the frequency of the microwaves, temperature, composition, and density of the materials.

In the realm of food crops in the world, wheat occupies the number one position. Wheat is rich in carbohydrates and in dietary proteins and is the major food component for most of the people worldwide. India is one of the principal wheat producing and consuming countries in the world.. Wheat flour based products is part of the staple diet in most parts of India - particularly in northern India. Wheat products are used to prepare different food items, like breads, biscuits, cookies, cakes, breakfast-cereal, pasta, noodles, etc. In view of the above mentioned applications of wheat in our diet, its dielectric properties are very important. A little information on the dielectric properties of wheat, cultivated in India, is available in literature. Therefore, it was considered desirable to study the dielectric properties of wheat cultivated in India. The present paper reports dielectric properties of five varieties of wheat at room temperature (32° C) and frequency 9.34 GHz along with their nutrients.

Dielectric properties of agricultural products have been of interest for many years. Use of dielectric properties of food grains for moisture measurement has been the most prominent application in agriculture. The first quantitative data on the dielectric properties of food grains were reported by Nelson *et al.* [3] in 1953 for barley in the frequency range 1 to 50 MHz. Nelson [4] made extensive measurements on grains and crop seeds in the frequency range 1 to 50 MHz and the results were made available for use in electric moisture meter design and other applications. Trabelsi and Nelson [5] studied dependence of dielectric properties of wheat, soybeans and corn on their bulk densities and found that both the dielectric constant and loss factor vary appreciably with the bulk density of these species. Singh *et al.* [6] measured the dielectric constant, dielectric loss factor and conductivity of some oil seeds over the range of temperature 15º-45º C at varying frequencies from 5 KHz to 10 MHz the dielectric constant was found to increase with increase in moisture level and with increase in frequency. Dielectric properties of chickpea flour in compressed form were determined by Guo et al. [7] and it was observed that dielectric constant and loss factor of the sample decreased with increase in frequency at all

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temperatures and moisture levels. Water is the major constituent of most foods; its dielectric properties also determine, to a great extent, the dielectric properties of the food [8]. Water is the major absorber of microwave energy in foods, and consequently, the higher the moisture content, the better the heating. In its pure form, water is a classic example of a polar dielectric [9]. In general, higher moisture content results in higher dielectric constant and loss factor of the food [10]. Tabil [11] observed that dielectric properties of food products depend on their composition. Carbohydrate, Fat, Moisture, Proteins and salt contents are the major components of food materials. The physical changes that take place during processing, such as moisture loss and protein denaturation also have an effect on dielectric properties. Food components such as proteins have low dielectric activities at microwave frequencies [12]. Dielectric constant and loss factor of Raj-4120 variety of Indian wheat have been determined by Sharma et al. [13], in powder form of grain size 125 to 150 microns at room temperature by employing the technique proposed by Yadav and Gandhi [14] at three different frequencies lying in C-band, X-band and Ku-band .

II. MATERIAL

Grains of four different varieties of farm type wheat (viz LOK 1, UP 2382, RAJ 3765, RAJ 2384) required for the present studies were obtained from Durgapura Agriculture Research Station of Rajasthan Agriculture University, Bikaner and one sample of local variety of fresh crop (Sharbati) was included in the study for the sake of variety of samples .

A) Sample Preparation

It is difficult to measure the dielectric properties of the whole grains of wheat because of the irregular shape of the grains. The measurement errors are reduced by using a grinded sample of seeds [1], [5]. To determine dielectric properties of food grains accurately, powder of food grains or flour is therefore taken. Sample of particular grain size is then obtained with the help of sieves. Known weights of grinded flour are placed in the cell with the cross sectional area 1.00 cm x 2.28 cm and depth of 4.50 cms. In the present study, samples of four farm varieties of wheat viz LOK 1, UP 2382, RAJ 3765, RAJ 2384 and one sample of local variety of fresh crop were prepared by grinding and sieving the same, employing sieves of different hole sizes. For every variety samples of three different grain sizes (viz; 90 to 150 micrometers, 250 to 300 micrometers and 355 to 425 micrometers) were prepared for the study of dielectric properties.

B) Dielectric cell

For the present study a dielectric cell was fabricated by closing a X band wave guide piece of about 5 cm depth at one end by a short circuiting metallic plate and attaching wave guide flange at the other end so as to connect it to the slotted section by means of a E-plane bend. The powder of food grains can be compressed in the cell by means of a plunger of almost the same cross section as the wave guide, using a hydraulic press.

III. EXPERIMENTAL METHOD

Two point method [15]-[16] used in the present study is a technique involving measurement of reflection coefficient of a solid material placed in a wave guide, backed by a short circuiting conducting plate. In order to use this method for powders, the waveguide is bent through 90° by means of a E-plane bend and terminated by a dielectric cell in which powder sample is filled up. This method is suitable for low and medium loss dielectrics and can be adopted for measurement of dielectric properties of food stuff in powder form. Let for an empty short-circuited wave guide dielectric cell , a voltage minimum is obtained with the probe located at position D_R in the slotted section. The same waveguide dielectric cell containing the sample (powder of food grains in the present case) of length l_ε will have the probe located in the slotted section at a new position D for a voltage minima in this case. The transcendental equation obtained by impedance matching can be written as

$$\frac{\tan\beta(D_R - D + l_\epsilon)}{\beta l_\epsilon} = \frac{\tan\beta_\epsilon l_\epsilon}{\beta_\epsilon l_\epsilon} \qquad (1)$$

where the phase factor $\beta = (2\pi / \lambda_g)$, λ_g being the guide wavelength for the waveguide containing air; and the phase factor β_ε for the waveguide filled with the dielectric is given by

$$\beta_\varepsilon = (2\pi / \lambda_0)\ \{ \varepsilon_r\, \mu_r - (\lambda_0 / \lambda_c)^2\}^{1/2} \qquad (2)$$

Here λ_0 represents free space wavelength, λ_c is the cut off wavelength of the waveguide and for the non-magnetic materials $\mu_r = 1$.

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The phase difference φ in the waves traveling in the guide with and without dielectric material in the cell is given by

$$\varphi = 2\,\beta\,(\Delta x - l_\varepsilon) \qquad (3)$$

Where Δ x is the shift in minimum.

Voltage standing wave ratio is determined for the load (food powder in this case) and then magnitude of the reflection coefficient (|Γ|) is computed by employing the relation:

$$|\Gamma| = \frac{(S-1)}{(S+1)} \qquad (4)$$

where S is the VSWR for the sample in the waveguide.

In the two point method, the complex dielectric constant is given by

$$C\angle -\psi = \frac{1}{j\beta l_\epsilon}\,\frac{1-|\Gamma|e^{j\varphi}}{1+|\Gamma|e^{j\varphi}} = \frac{\tan X\angle\theta}{X\angle\theta} \qquad (5)$$

Where C and Ψ represent respectively the magnitude and phase of the complex quantity in the middle of Eq. (5) and X ∠ θ represents the solution of this transcendental equation . This equation provides several solutions for X ∠ θ, which can be found by employing graphs and tables provided for solution of such equations by Hippel [17] alternatively the problem can be solved by using a computer based mathematical tool like MATLAB/ Mathematical. The experiment is performed for two different heights of powder sample and the common root obtained from solutions for the two cases, is used for evaluation of the admittance of the material of the sample. Alternatively, we may perform the experiment for a given height of the sample at two different frequencies to obtain the correct root X ∠ θ.

The admittance (Y_ε) of the material of the sample is given by

$$Y_\epsilon = \left(\frac{X}{\beta l_\epsilon}\right)^2 \angle 2(\theta - 90°) = G_\epsilon + jS_\epsilon \qquad (6)$$

where G_ε and S_ε are respectively the conductance and susceptance of the sample.

The values of G_ε and S_ε are obtained by separating Eq. (6) in to real and imaginary parts, which provide the values of ε' and ε" in the following form:

$$\epsilon' = \frac{G_\epsilon + (\lambda_g/2a)^2}{1+(\lambda_g/2a)^2} \qquad (7)$$

$$\epsilon'' = \frac{-S_\epsilon}{1+(\lambda_g/2a)^2} \qquad (8)$$

In the present study ,a computer program in MATLAB was written to solve the transcendental equation and obtain the values of dielectric constant (ε') and loss factor (ε")

IV. RESULT AND DISCUSSION

The nutrient values of different varieties of wheat were estimated by employing Micro Kjheldal method for protein determination, Ether extraction method for fats, Oven drying method for moisture content, and calculation method for carbohydrates. The same are assembled in Table 1. The dependence of ε' and ε" on % moisture content is displayed in Fig 1. It may be observed from Fig. 1(a) that ε' first increases slowly and then rapidly with % moisture content for grain sizes 250 – 300 µm and 90 -150 µm, whereas for grain size 355-425 µm we obtain somewhat different behavior. The dependence of loss factor on % moisture content is shown in Fig. 1(b), from which it is apparent that for the grain size 90 – 150 µm, ε" first increases and then decreases with the % moisture content, showing almost inverted parabolic behavior. For grain size 250 – 300 µm ,the variation of ε" with moisture is almost linear, whereas for grain size 355-425 µm , we obtain a curve with its curvature upside. This clearly shows that losses due to moisture content depend on the grain size. The smaller value of ε' for smaller moisture content (8.73 %) may be attributed to strong bound water state (monolayer), where distance between the water molecule and cell wall is very small and force of attraction is very large. As moisture increases beyond 8 %, ε' increases, which may be attributed to change of bound water state from first (monolayer) to second (multilayer) type. The variation of ε' and ε" with % carbohydrate content for different varieties of wheat is shown in Fig. 2 for the three grain sizes. It may be observed from Fig. 2 that the values of ε' are higher for the grain size 355-425 micrometers as compared to the smaller grain sizes. The value of ε' first increases and then decreases as the % of carbohydrates is increased, it being highest at about 66 % of carbohydrate value for all the grain sizes. The loss factor on the other hand first decreases and then increases, showing lowest value at about 66% of the carbohydrates. The dependence of ε' and ε" on protein and fat content for three grain sizes has been shown in Fig.3 and Fig. 4 respectively, where no definite trends are observed for variation of ε' and ε" with these nutrients.

In food materials, the dielectric constant and loss factor are affected by the presence of water, surface charges, electrolytes and non electrolytes and hydrogen bonding also plays a role in the dielectric behavior of a substance. As the dielectric properties of a typical food material depend on a number of factors and since interactions are complex, the present approach provides a simple method to correlate the electrical properties of food materials with their nutrients. For more realistic relationships, other factors like temperature, frequency etc .should also is involved in the simulation.

V. CONCLUSION

The simplified method proposed in this work for the determination of Dielectric properties of the food grains in powder form provides values of dielectric parameters with greater ease and increased accuracy. The dielectric parameters of food grains are found to depend on the food nutrients, like moisture content, carbohydrates, fat, proteins etc. The studies have further potential to involve temperature and frequency dependence of the dielectric parameters and to develop mathematical modeling for the same along with the food nutrients.

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Table 1.Values of different nutrients obtained by proximate analysis and values of dielectric constant ε' and dielectric loss factor ε'' for the five varieties of wheat in three grain sizes

Variety	Moisture (%)	Protein (%)	Fat (%)	Carbohydrate (%)	ε'			ε''		
					355-425 μm	250-300 μm	90-150 μm	355-425 μm	250-300 μm	90-150 μm
LOK-1	10.66	14.87	2.00	66.14	4.95	4.55	3.98	0.15	0.15	0.10
UP 2382	9.06	14.50	2.90	63.44	3.66	3.62	3.39	0.18	0.18	0.14
RAJ 3765	8.73	12.41	1.39	75.40	3.60	3.58	3.51	0.19	0.15	0.11
RAJ 2384	9.39	12.76	1.57	74.80	4.62	3.65	3.59	0.17	0.15	0.15
Sharbati	10.20	12.10	1.70	69.40	4.74	4.28	3.43	0.16	0.16	0.14

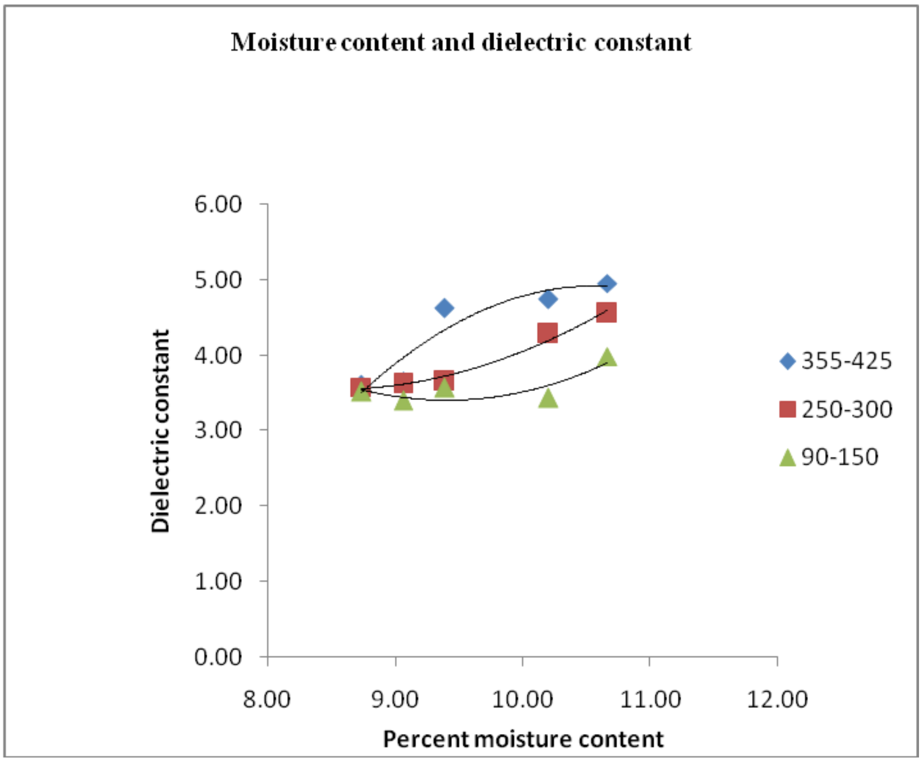

Fig. 1(a)

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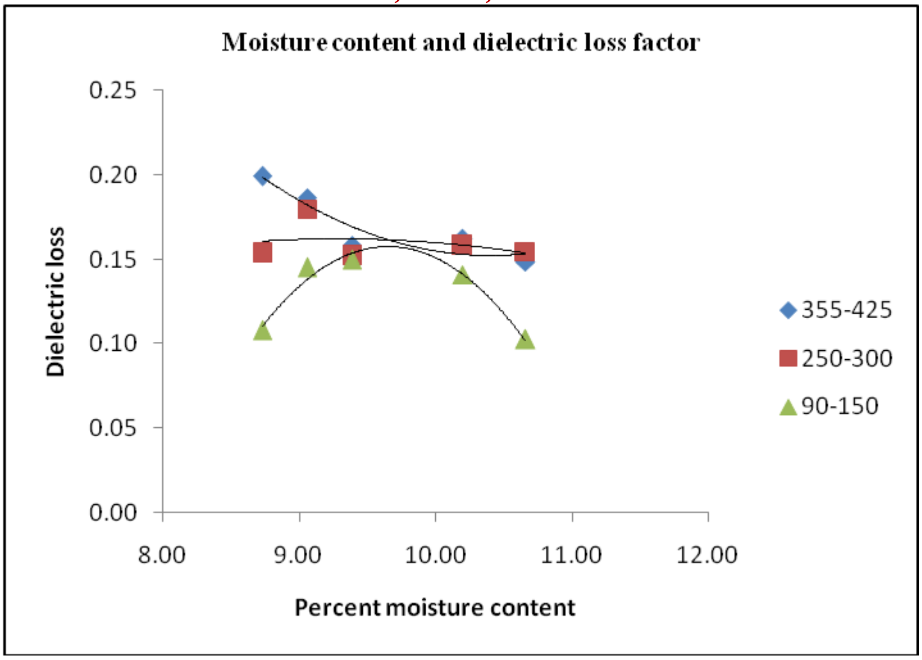

Fig. 1(b)

Fig.1. Dependence of ε' and ε'' on % moisture content for the three grain sizes

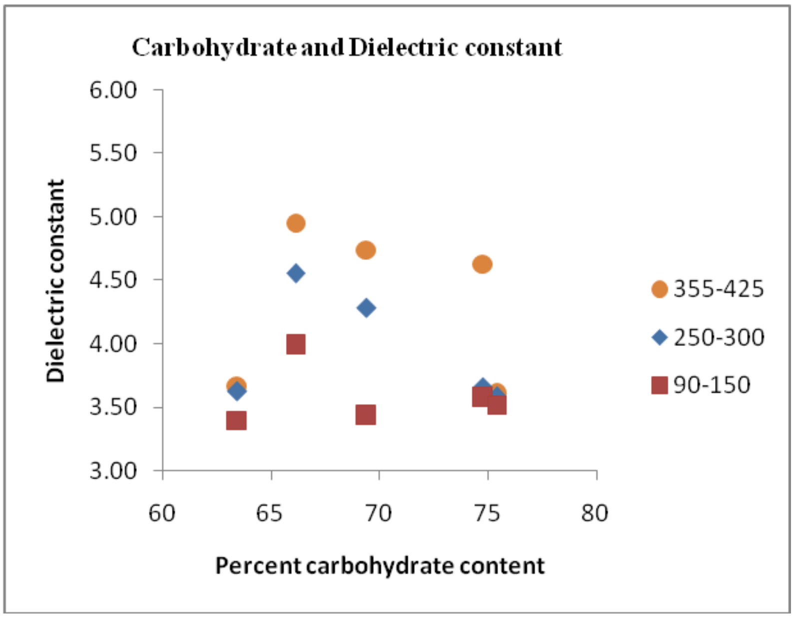

Fig. 2(a)

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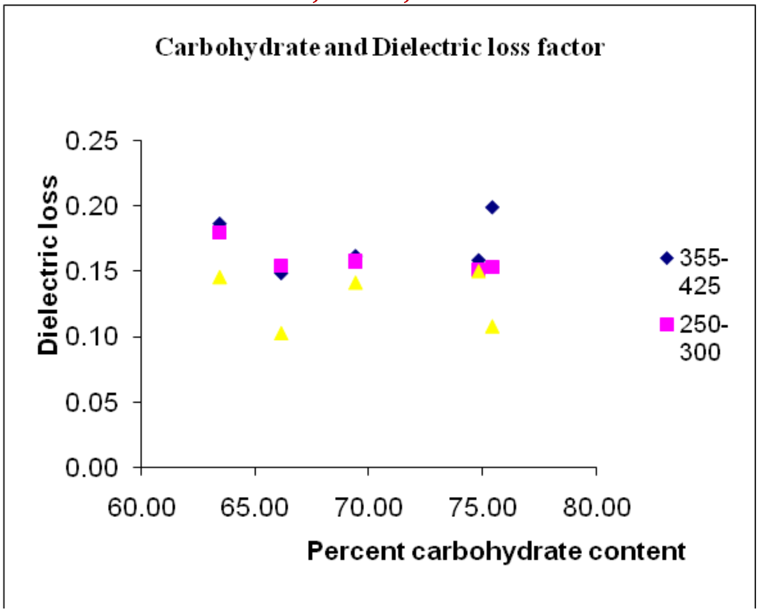

Fig. 2(b)

. Fig. 2. Dependence of ε' and ε' 'on % carbohydrate for the three grain sizes

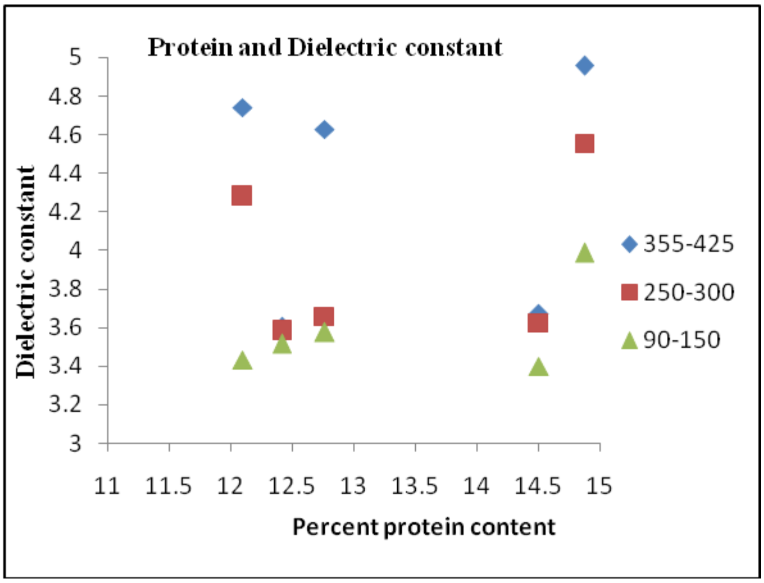

Fig.3 (a)

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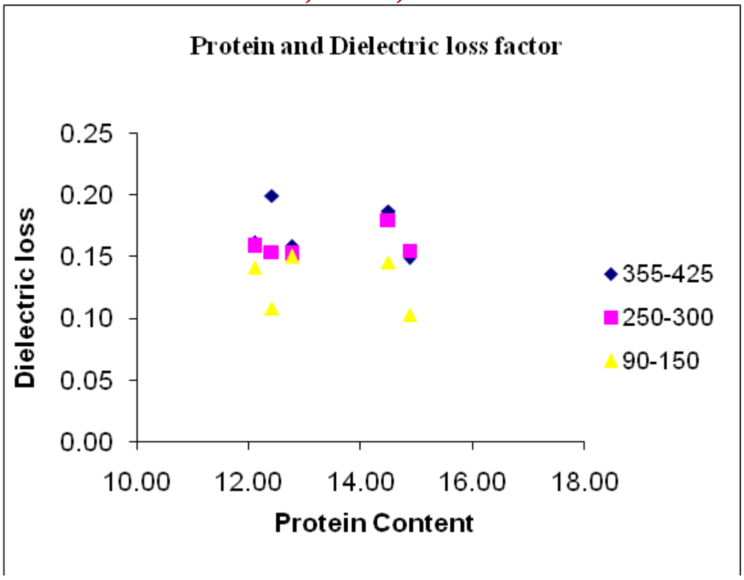

Fig. 3(b)

Fig.3.Dependence of ε' and ε' 'on % protein for the three grain sizes

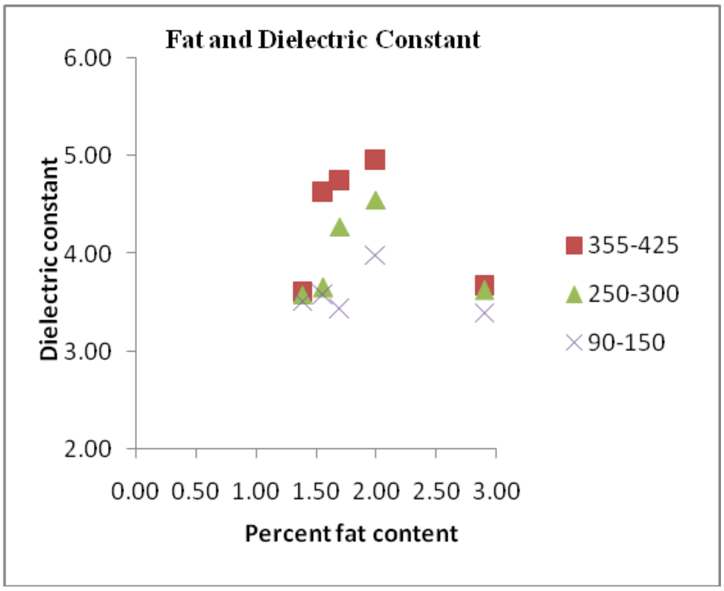

Fig 4(a)

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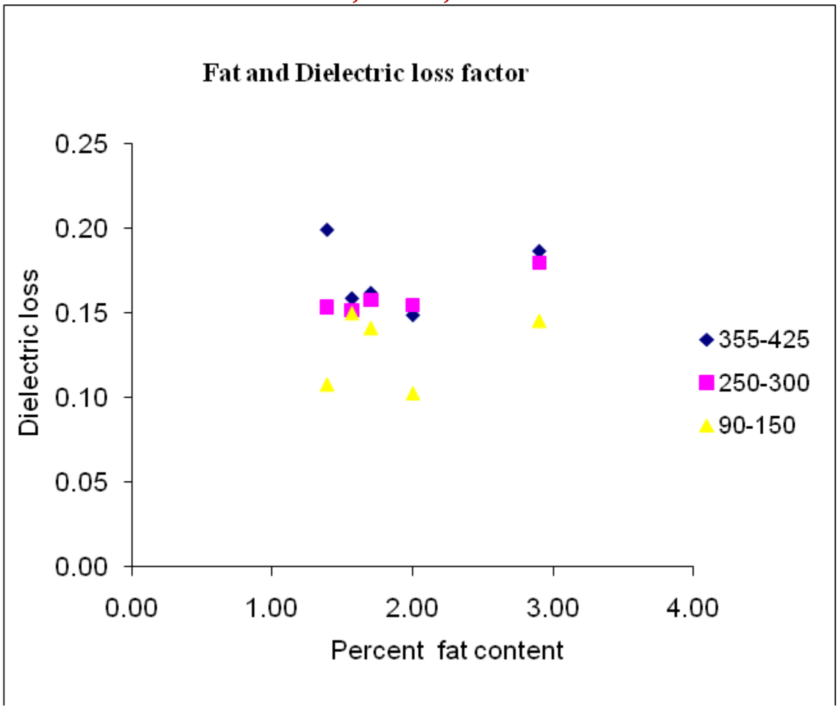

Fig.4 (b)

Fig. 4 Dependence of ε' and ε' 'on fat content for the three grain sizes