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A Study of Comparative Performances of Different Models for the Variation of Dielectric Parameters of Shelled Yellow–dent Field Corn with Moisture Content at 2.45 GHz.

Hariniwas Singh and Ashutosh Prasad

University Department of Physics,
Tilkamanjhi Bhagalpur University, Bhagalpur – 812007, INDIA.

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ABSTRACT

In the present work two models namely, quadratic and cubic, for the variation of relative permittivity and dielectric loss factor of shelled yellow-dent field corn, ***Zea mays L.*** with decimal moisture content at a microwave frequency of 2.45 GHz have been proposed by the authors. The data of results for relative permittivity and loss factor have been derived from the works of S.O. Nelson and the models chosen for comparison with the present models are also due to S.O. Nelson. The evaluation of constants for the models has been done using the method of Least-Squares-Fit for nonlinear regression analysis. With the values of coefficients of determination (r^2) too close to unity ($\approx$ 0.99), except for cubic model for loss factor ($r^2 \approx 0.89$), and lower average percentage errors, excepting the cubic model for loss factor having average errors $\approx$ 19.49 %, both the present models and both dielectric parameters compare the present models favorably with the established models.

Keywords: Relative Permittivity, Dielectric loss factor, Nonlinear regression, Microwave frequency. Corn.

1. INTRODUCTION

The use of electrical properties of grains for moisture measurement has been the most prominent agricultural application for dielectric properties data. The dielectric properties offer a potential means in making devices for sensing moisture content of grains which help in preventing the spoilage of large blended lots stored in elevators, ships or mills[1-2]. It is why; several efforts to model the dielectric properties of grains have been made[3-4].

The purpose of the present paper is to consider a more general approach towards modeling the dielectric properties of Shelled Yellow-dent field corn (*Zea mays L.)* using the data of results for them at a fixed frequency of 2.45 GHz at 240C to present empirical expressions which allow predictions of permittivity and loss factor. The data of results for relative permittivity have been taken from Table 5 of Nelson's Paper5 and the data of approximate values of dielectric loss factor at the same frequency and temperature have been derived from the graphical representation of the data points as contained in Fig.12 (b) of Nelson's another paper[1]. The values of bulk density at the six moisture contents from 10.3 % to 33.4 % were derived from the bulk density – moisture relationship for corn as presented by equation (4) of Nelson's Paper[6]. Data for dielectric properties have been chosen at microwave frequency keeping in view the fact that hazardous ionic conductivities and bound-water relaxation effects disappear almost completely in this range of frequency. Thus microwaves offer a nondestructive, sensitive and feasible method for determining the water content of grain samples.

2. EXISTING MODELS, DEVELOPMENT OF PRESENT MODELS AND EVALUATION OF CONSTANTS

The general quadratic and cubic models connecting dielectric constant, moisture content and frequency of operation were used for their comparison with the corresponding new models proposed in the present study.

General form of the equations is

$\varepsilon' = [1+\{A_2 - B_2 \log f + (C_2 - D_2 \log f)M\} x\rho]^2$ (1)

and $\varepsilon'' = [1+\{A_3 - B_3 \log f + (C_3 - D_3 \log f)M\} x\rho]^3$ (2)

The only one equation for the dielectric loss factor available for comparison is of the form:

$\varepsilon'' = 0.146\,\rho^2 + 0.004615\,M^2 \rho^2\,[0.32 \log f + 1.743/\log f - 1]$ (3)

Where $\rho \equiv \rho b$ = bulk density of the material in gram x cm-3

M =100m = % moisture content, wet basis

f = frequency of operation in MHz.

m = decimal moisture content.

The values of constant viz., A_2, B_2, C_2, D_2 or A_3, B_3, C_3, and D_3 of equations (1) and (2) for Shelled Yellow-dent field corn were taken from Table 6 of Nelson's paper[2].

Based on the observations of almost linear plots obtained from the dependence of relative permittivity of grains and cereals with moisture content, especially in the microwave range, it was proposed to give quadratic as well as cubic models for such variations.

The proposed models are:

(1) Quadratic

$\varepsilon' = am^2 + bm + K_1$ 4(a)

and $\varepsilon'' = cm^2 + dm + K_2$ 4(b)

(2) Cubic

$\varepsilon' = am^3 + bm^2 + cm + K_1$ 5(a) and $\varepsilon'' = dm^3 + em^2 + fm + K_2$ 5(b)

The value of the constant K_1 was taken as the average of the values of relative permittivity derived from equations (1) and (2) by putting M=0. The value of bulk density corresponding to M=0 (ρ0) as taken from equation (4) of Nelson's Paper[6], is equal to 0.6829. The value of K_2 was equal to the value of loss factor corresponding to M=0, which is given by equation (3) in the form

$K_2 = (\varepsilon'')$ M=0 = 0.146 ρ02 = 0.146 x (0.6829)2 =0.06808 (6)

The average value of K_1 was found to be equal to 1.4456 from the data of results for relative permittivity at different decimal moisture contents. The constants for the first part of each of the two sets of models as envisaged in equations 4(a) and 5(a) were evaluated, using the method of least-squares- fit for nonlinear regression. The same method was adopted for the second part of each of the two models given by equations 4(b) and 5(b), using the data of results for dielectric loss factor derived from the works of S.O. Nelson[1], as referred to earlier in the text.

Table 1- Data of results for relative permittivity, loss factor and bulk density of Shelled Yellow-dent field corn, *Zea mays L.* measured at 2.45 GHz and 240C at six moisture contents, wet basis.

Moisture Content %, wet basis	Bulk density in g x cm3	Relative permittivity ε´	Dielectric loss factor ε´´
10.3	0.74	2.47	0.30
12.2	0.74	2.59	0.37
17.7	0.71	3.2	0.63
19.5	0.70	3.59	0.69
22.9	0.68	3.98	0.80
33.4	0.64	5.25	0.85

Table 2- Data of evaluated constants for the different models for complex permittivity of corn, (ZeaMays. *L.*) corresponding to 24^0C and 2.45GHz .

Models for relative permittivity		**Models for dielectric loss factor**	
Quadratic Model(Q.M)	Cubic Model(C.M)	Quadratic Model(Q.M)	Cubic Model(C.M)
a= 7.2307 b=9.3904 K_1=1.4456	a= -36.5222 b=24.7005 c=7.2757 K_1=1.4456;	c=7.90057 d=1.08605 K_2=0.06808	d= -71.91018 e=31.96729 f=0.29947 K_2=0.0680

Table 3(a)--Comparative Performances of different models for the variation of relative Permittivity with moisture content of Corn(Zea Mays L) at 24^0C and 2.45 GHz

Nelson's Model				Present Model			
Quadratic Model(Q.M)		Cubic Model(C.M)		Quadratic Model(Q.M)		Cubic Model(C.M)	
Predicted values	r^2/Mean % error	Predicted values	r^2/ Mean % error	Predicted values	r^2/ Mean % error	Predicted values	r^2/ Mean % error
2.47 2.67 3.23 3.40 3.71 4.79	$\frac{1.000}{4.18}$	2.48 2.71 3.23 3.40 3.72 4.84	$\frac{1.000}{3.23}$	2.49 2.70 3.33 3.55 3.98 5.39	$\frac{0.999}{2.17}$	2.42 2.63 3.30 3.53 3.97 5.27	$\frac{0.997}{1.57}$

Table 3(b): -Comparative Performances of different models for the variation of loss-Factor with moisture content of Corn (Zea Mays L) at 24^0C and 2.45 GHz

Nelson's Model		Present Model			
		Quadratic Model(Q.M)		Cubic Model(C.M)	
Predicted values	r^2/ Mean % error	Predicted values	r^2/ Mean % error	Predicted values	r^2/ Mean % error
0.24 0.30 0.51 0.59 0.73 0.31	$\frac{0.990}{22.15}$	0.26 0.32 0.51 0.58 0.73 1.31	$\frac{0.990}{3.30}$	0.36 0.45 0.72 0.81 0.95 1.01	$\frac{0.886}{19.49}$

3. RESULTS AND DISCUSSION

Data of results for relative permittivity, loss factor and bulk density of shelled yellow-dent field Corn at 2.45 GHz and 240C and at six moisture contents are illustrated in Table 1 and the evaluated Constants for different proposed models have been listed in Table 2. Further, the quantitative Comparative performances of the present models and those of Nelson are reported in Table 3(a) and 3(b).The coefficients of determination (r^2) and average percentage errors of prediction for each of the different models have also been reported.

Examination of data in Table 3 reveals that both quadratic and cubic models of Nelson relating relative permittivity to decimal moisture content generally predicted almost the same values, excepting a few instances where they differed by more than 5%. The average error of prediction over all moisture contents was 4.18 % for the quadratic model and 3.23 % for the cubic model. The corresponding average errors of prediction for the present two models are 2.17 % and 1.57 %. The average percentage error of prediction in Nelson's solitary model for dielectric loss factor against moisture content is too high ≈ 22.15 %. Similar is the order of deviation in the newly proposed cubic model, being ≈ 19.49 %. On the contrary, the deviation is too small ≈ 3.30 % with the newly proposed quadratic model. The r2-values for all the models for relative permittivity are ≈ 0.99 to 1.00 and thus all the models show good fitting with experimental results. The r^2-values for Nelson's model for dielectric loss factor and the present quadratic model are ≈0.99, but the present cubic model shows a bit poorer fitting having $r^2 \approx 0.89$.

Thus, on the basis of present study, it may be opined that the new quadratic models both for the relative permittivity and loss factor, proposed in the present study provide better performance as compared with others in predicting moisture dependence of relative permittivity and dielectric loss factor at the chosen range of microwave frequency.

4. CONCLUSION

The moisture dependence of relative permittivity and dielectric loss factor of shelled yellow-dent field corn,(***Zea mays L.***) over moisture ranges of 10 to 33 percent at 2.45 GHz and 240C can be accurately represented by second and third order polynomial equations, both dielectric parameters showing slowly increasing trend with the increase of moisture content. The results derived from the models are indicative of the fact that these equations should be generally useful for predictive purposes in most practical applications.

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