June 2009 Volume 5 Issue 3

Trade Science Inc.

Materials Science
An Indian Journal
Full Paper
MSAIJ, 5(3), 2009 [222-225]

A study of comparative quantitative performances of different models for the variation of dielectric parameters of semihardy winter barley with moisture content at 2.45 GHz

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Pacs nos: 72.80 Tm; 77.20– d; 77.84 Lf; 78.70 Gq; 81.40 Tv
Received: 22nd February, 2009 ; Accepted: 27th February, 2009

ABSTRACT

In the present work, two models namely, quadratic and cubic, for the variation of relative permittivity and dielectric loss factor of semihardy winter barley (*Hordeum vulgar L.*), with decimal moisture content at 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 Kraszewski and Nelson. The models chosen for comparison with the present models are also due to 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), and lower average percentage errors 1.5 and 1.6 for relative permittivity and $\approx$ 9.9 and 9.0 respectively for both the present models compare them favourably with the established models.

KEYWORDS

Relative permittivity;
Dielectric loss factor;
Nonlinear regression;
Microwave frequency;
Barley.

1. INTRODUCTION

The use of electrical properties of grains for moisture measurement has been one of the most prominent agricultural applications 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[2]. It is why, several efforts to model the dielectric properties of grains have been made[3-5].

The purpose of the present paper is to consider a more general approach towards modeling the dielectric properties of Semihardy Winter Barley *(Hordeum vulgar L.)* using the data of results for them at a fixed frequency of 2.45 GHz at 24^0C in order to present empirical expressions which allow predictions of permittivity and loss factor. The data of results for relative permittivity and dielectric loss factor have been taken from plots showing their variations as functions of percentage moisture content, wet basis (w.b), as contained in Nelson's Paper[1]. The values of bulk density at the eleven moisture contents ranging from 8.7 % to 24.3 % were derived from the works of Kraszewski and Nelson[1].

Data for dielectric properties have been chosen at microwave frequency keeping in view the fact that the ionic conductivities and bound-water relaxation effects almost disappear in this range of frequency[7-9]. Thus microwaves offer a non-destructive, 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. Two general forms of the equations are[2]:

$$\varepsilon' = [1+\{A_{2\text{-}}B_2 \log f + (C_{2\text{-}}D_2 \log f)M\}\rho]^2 \tag{1}$$

and $$\varepsilon'' = [1+\{A_{3\text{-}}B_3 \log f + (C_{3\text{-}}D_3 \log f)M\}\rho]^3 \tag{2}$$

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

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

Where $\rho = \rho_b$ = bulk density of the material in gram/cm³, M =100m = percentage moisture content; wet basis f = frequency of operation in MHz.

The values of constant viz., A_2, B_2, C_2, D_2 and A_3, B_3, C_3, and D_3 of equation (1) and (2) for Semihardy Winter Barley were taken from TABLE 1 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:

Quadratic

$$\varepsilon' = am^2 + bm + K_1 \tag{4a}$$

and $$\varepsilon'' = cm^2 + dm + K_2 \tag{4b}$$

Cubic

$$\varepsilon' = am^3 + bm^2 + cm + K_1 \tag{5a}$$

and $$\varepsilon'' = dm^3 + em^2 + fm + K_2 \tag{5b}$$

The values of the constants, K_1 and K_2 were estimated through the extrapolation of the plots of relative permittivity and loss factor as function of moisture content. The K_1 and K_2 are the values of relative permittivity and loss factor respectively, corresponding to M = 0.

The constants for the first part of each of the two sets of models as envisaged in equation 4(a) and 5(a) were evaluated using the method of least-squares-fit for non-linear 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 Nelson[1], as referred to earlier in the text.

2. RESULTS AND DISCUSSIONS

Data of results for relative permittivity, loss factor and bulk density of semihardy winter barley (*Hordeum vulgar L.*) at 2.45 GHz and 24⁰C and at eleven 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.

TABLE 1: Data of results for relative permittivity, loss factor and bulk density of Semihardy Winter Barley (Hordeum Vulgare L). measured at 2.45 GHz and 24⁰C at eleven moisture contents, wet basis

Moisture content %, wet basis	Bulk density in gram x cm^{-3}	Relative permittivity ε'	Dielectric loss factor ε''
8.7	0.552	1.97	0.121
9.1	0.572	2.04	0.126
9.7	0.563	2.10	0.152
9.8	0.562	2.09	0.155
11.2	0.545	2.13	0.224
13.1	0.536	2.23	0.259
15.2	0.566	2.49	0.328
17.6	0.590	2.62	0.345
19.9	0.566	2.90	0.554
22.2	0.570	3.09	0.499
24.3	0.546	3.15	0.687

TABLE 2: Constants for different proposed models connecting relative permittivity and dielectric loss factor with moisture content for semihardy winter barley *(Hordeum Vulgare L.)* at 2.45 GHz and 24⁰C

Models for relative permittivity		Models for dielectric loss factor	
QM[a]	CM[b]	QM	CM
a=17.61918637	a=45.8520431	c=9.06106949	d=-24.275220253
b=2.025475708	b=-0.017391179	d=0.40565492	e = 17.35761737
K_1= 1.72	c =3.623590957	K_2= 0.037	f =-0.234137873
	K_1 = 1.72		K_2= 0.037

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 2.25 % and 2.98 % for quadratic and cubic models, respectively. The corresponding average errors of prediction for the present two models are 1.49 % and 1.59 %. The average percentage error of prediction in Nelson's solitary model for dielectric loss factor against moisture content is too high ≈17.09 %. The deviation in the newly proposed quadratic model is ≈9.87. On the contrary, the deviation is too small ≈8.99 with the newly proposed cubic model. The r^2-values for all the models for

TABLE 3: Quantitative comparative performances of present models and those of Nelson for moisture dependence of relative permittivity and loss factor of Semihardy Winter Barley *(Hordeum Vulgar L.)* measured at 2.45 GHz and 24^{0}C

TABLE 3(a)

Models for relative permittivity

Nelson's Models				**Present Models**			
QM		**CM**		**QM**		**CM**	
Predicted values	**r^2/Average % error**	**Predicted values**	**r^2/Average % error**	**Predicted values**	**r^2/Average % error**	**Predicted values**	**r^2/Average % error**
2.04	0.9864/ 2.25	2.04	0.9849/ 2.98	2.03	0.9917/ 1.49	2.00	0.9990/ 1.59
2.10		2.12		2.05		2.02	
2.13		2.13		2.08		2.06	
2.13		2.13		2.16		2.06	
2.18		2.18		2.28		2.16	
2.29		2.28		2.43		2.30	
2.53		2.54		2.63		2.46	
2.81		2.82		2.82		2.66	
2.90		2.91		3.03		2.85	
3.10		3.12		3.24		3.04	
3.16		3.18				3.20	

TABLE 3(b)

Models for dielectric loss factor

Nelson's mdels		**Present mdels**			
QM		**QM**		**CM**	
Predicted values	**r^2/Average % error**	**Predicted values**	**r^2/Average % error**	**Predicted values**	**r^2/Average % error**
0.11	0.8946/ 17.09	0.14	0.9883/9.87	0.13	1.00/8.99
0.12		0.15		0.14	
0.13		0.16		0.16	
0.13		0.16		0.16	
0.15		0.20		0.19	
0.18		0.24		0.25	
0.25		0.31		0.31	
0.35		0.39		0.40	
0.40		0.47		0.48	
0.49		0.57		0.57	
0.53		0.67		0.66	

relative permittivity are ≈ 0.98 to 1.00. Thus, all the models show good fits with experimental data.

Thus, on the basis of present study, it may be opined that the new cubic models 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 microwave frequency.

4. CONCLUSIONS

The moisture dependence of relative permittivity and dielectric loss factor of semihardy winter barley, *(Hordeum Vulgar L.)* over moisture range of 8.7 % to 24.3 % at 2.45 GHz and 24^{0}C 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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