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New Density-Independent Model for Microwave Measurement of Grain Moisture Content

마이크로파 곡물함수율 측정을 위한 새로운 밀도보정방법

Jong-Heon kim Dept.of Radio Science and Eng., Kwangwoon University
Ki-Bok Kim Dept. of Agricultural Eng., Seoul National University
Sang-Ha Noh Dept. of Agricultural Eng., Seoul National University

김종헌 광운대학교 공대 전파공학과
김기복 서울대학교 농대 농공학과
노상하 서울대학교 농대 농공학과

Abstract

A free space transmission method using standard gain horn antennas in the frequency range from 9.0 to 10.5GHz is applied to determine the dielectric properties of grain such as rough rice, brown rice and barley. The dielectric constant and loss factor, which depend on the moisture content of the wetted grain are obtained from the measured attenuation and phase shift by vector network analyzer. The effect of density fluctuation, which is an important parameter governing the dielectric properties of grain, on the dielectric constant and loss factor is presented. A new density-independent model in terms of measured attenuation and moisture density is proposed for reducing the effects of density fluctuation on the moisture content measurement.

1. Introduction

The moisture content of agricultural products very much influences their physical and chemical properties and hence is an important parameter governing their storage, processability and quality. Several methods are proposed to measure the moisture contents, but the resistivity cell method and parallel plate capacitor method are commonly used.

The moisture content measurement using the resistivity cell method uses the principle of decreasing of resistance due to increased moisture content of grain [1]. In this case the measured values vary with respect to the variation of the pressure and repeated measurements are necessary. The errors in the measured values at high moisture content are greater than other method because there is very small variation of resistance at high moisture contents (over 20%).

The parallel plate method measures the capacitance of the sample between two electrodes forming a capacitor and from which the dielectric constant of the grain is calculated. This method can be used at high frequencies up to 30MHz [2].

As on-line machinery are being recently used in storage and processing of grain, the development of non-destructive and non-contactive measurement technology for measuring the moisture content of grain is required. Free space microwave measurement method is a very useful for on-line measurement of the moisture content [3-5].

In this paper the free space microwave measurement method using standard horn antennas is presented for determining the complex permittivity of grain which depends on the moisture content (from 11% to 25% on its wetted condition). A grain samples of rough rice, brown rice and barley with varying bulk density and moisture density are used.

One of the ciritical parameters in moisture content measurements is the variation of bulk density. Since attenuation and phase shift increase with higher bulk density, the density influence must be eliminated for accurate measuring of moisture content. Some methods for reducing the effects of density variation are presented.

In this paper a new density-independent model for microwave measurement of grain moisture is proposed and the results obtained using this model are compared with those obtained using existing models by means of the statistical analysis.

2. Experimental set up

A pair of a X-band standard gain horn antenna with 7.9cm x 5.4cm and 16.5dB gain are mounted on an acrylic plate stand. The horns are connected to the two ports of the HP8510C network analyzer via waveguide/coaxial adaptors. Between the transmit and receive horns the sample holder is mounted. The sample holder is a rectangular container made of acrylic plates with 2mm wall thickness. The dimensions of the sample holder used in this experiment are 42.5mm thickness, 119.6mm width and 155.2mm height.

The network analyzer was calibrated in the CW transmission mode with the through connection of transmit and receive antennas to measure the S_{21}-parameter for transmission coefficient. The attenuation and phase shift due to the wetted grain samples are obtained from the measured S_{21} value. The attenuation is derived from the magnitude of S_{21} and the phase shift from the phase of S_{21} as follows;

$$S_{21} = |S_{21}| \exp(j\Phi) \quad (1)$$

$$A = -20 \log |S_{21}| \quad (2)$$

$$\Phi = 2\pi n + \varphi \quad (3)$$

where A is the attenuation, Φ is total phase, φ is phase shift and n is integer number.

3. Density-independent model

Since the determination of dielectric properties is influenced by the amount of sample mass which interacts with the electromagnetic field, the bulk density defined by

$$\rho_b = \frac{m_w + m_d}{V} \quad (4)$$

where m_w is the mass of water, m_d is the mass of dry grain and V is the volume of the sample holder, is an important factor affecting the dielectric properties of grain.

For the microwave moisture content measurement the measured attenuation is directly affected by the variation of the bulk density and thus the fluctuation in density is the main source of error.

There are some methods to compensate the effect of bulk density fluctuations. The density-independent method proposed by Meyer is based on the simultaneous measurement of the dielectric constant and loss factor [6]. However, the use of this factor is valid only for the small range of densities. For a wide range of densities this factor cannot compensate the effect of the density fluctuation well [7]. An improved method for reducing the effects of density over a broader range of density is reported by Powell [8].

In this paper a new density-independent method using the moisture density is introduced. The moisture content is defined as product of bulk density by the moisture content:

$$\rho_m = \rho_b \psi \quad (5)$$

where

$$\psi = \frac{m_w}{m_w + m_d} \times 100\% \quad (6)$$

where ψ is moisture content based on its wetted condition.

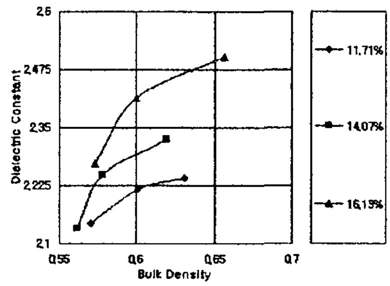
A new density-independent function is developed in terms of measured attenuation and moisture density;

$$A = a \times \rho_m + b \quad (7)$$

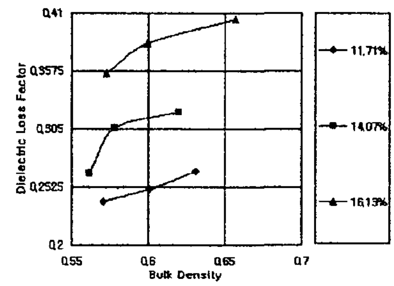
where a and b are coefficients.

4. Experimental results

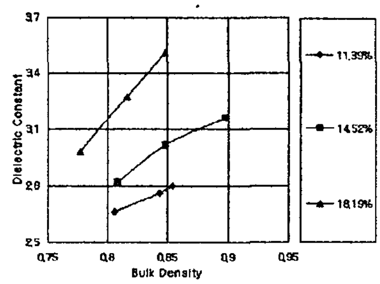
Dependence of the dielectric constant and loss factor of grain samples on its bulk density is determined for rough rice, brown rice and barley at 9.5GHz, and results are shown in Fig 1.



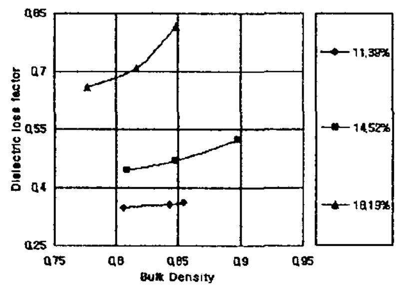
(a-1) Dielectric constant for rough rice



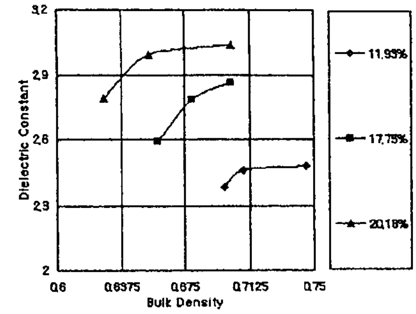
(a-2) Dielectric loss factor for rough rice



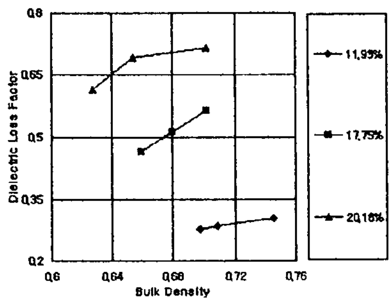
(b-1) Dielectric constant for brown rice



(b-2) Dielectric loss factor for brown rice



(c-1) Dielectric constant for barley



(c-2) Dielectric loss factor for barley

Figure 1: Bulk density dependence of the dielectric properties of (a) rough and (b) brown rice and (c) barley samples at 9.5 GHz

It is clear that the fluctuations in bulk density result in different values of the dielectric constant and loss factor. The dielectric constant and loss factors are found to increase with the bulk density.

A new density-independent model proposed for reducing the effects of density variation on the moisture measurement is compared with an existing model by the regression analysis using the statistical analysis software (SAS). The regression model expressing relationship between the ratio of phase shift to attenuation and moisture content is given by

$$\frac{\Phi}{A} = a \times \psi + b \tag{8}$$

The result of the regression analysis of this model for rough rice is shown in Table1 for the frequency range of 9.0GHz to 10.5GHz, and the ratio of phase shift to attenuation and moisture content as a function of moisture content at 9.5GHz is plotted in Fig. 2.

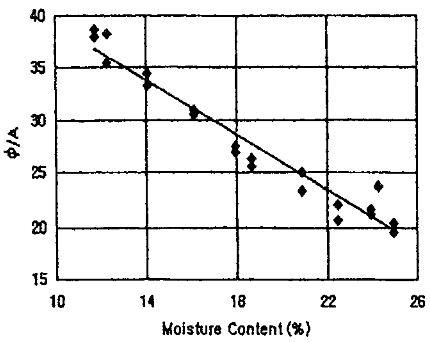
Table 1: Regression analysis expressing relationship between the ratio of phase shift to attenuation and moisture content of (a) rough rice and (b) brown rice

(a)

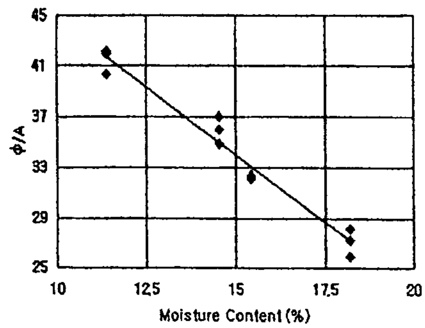
f (GHz)	a	b	R^2	SEC
9	-1.5793	60.1468	0.9369	1.9864
9.2	-1.9999	69.5475	0.9134	2.9865
9.5	-1.2901	51.9702	0.9363	1.6321
10.0	-2.5267	85.9999	0.9181	3.9030
10.5	-2.1850	78.0023	0.9325	3.0400

(b)

f (GHz)	a	b	R2	SEC
9	-2.6290	76.4986	0.9840	0.9382
9.2	-2.6413	76.7122	0.9668	1.3662
9.5	-2.1455	66.2077	0.9677	1.0951
10.0	-3.5190	95.2077	0.9898	1.0007
10.5	-3.3915	92.7403	0.9808	1.3256



(a) Rough rice



(b) Brown rice

Figure 2: Relationship between the ratio of phase shift and attenuation and moisture content of (a) rough rice and (b) brown rice at 9.5GHz.

The coefficients of determinants obtained for rough rice are from 0.91 to 0.93 while those for brown rice calculated from 0.96 to 0.98.

The regression analysis of new model for rough rice and brown rice results are given in Table 2. The attenuation for them as a function of moisture density at 9.5 GHz is shown in Fig. 3.

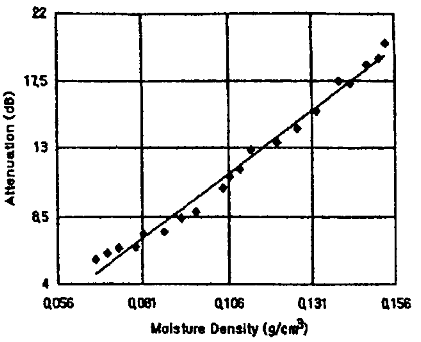
Table 2: Regression analysis expressing relationship between the moisture density and attenuation of (a) rough and (b) brown rice

(a)

f (GHz)	a	b	R^2	SEC
9	156.090	-6.3462	0.9849	0.5330
9.2	162.962	-7.2175	0.9925	0.4369
9.5	160.544	-5.8134	0.9919	0.4462
10.0	179.175	-9.0985	0.9894	0.5735
10.5	194.261	-9.5194	0.9878	0.6654

(b)

f (GHz)	a	b	R2	SEC
9	119.529	-4.6785	0.9835	0.3875
9.2	117.405	-4.3677	0.9780	0.4413
9.5	126.201	-4.5658	0.9769	0.4858
10.0	126.917	-5.9135	0.9796	0.4592
10.5	134.017	-6.0732	0.9784	0.4992



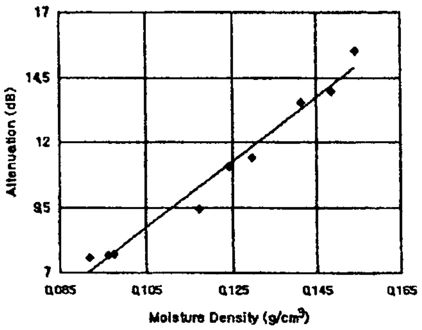


Figure 3: Relationship between the moisture density and attenuation of (a) rough and (b) brown rice at 9.5GHz.

The coefficients of determinants for rough rice determined using new model are from 0.98 to 0.99 and those for brown rice resulted in the range of 0.97 to 0.98. Because of the high coefficients of determinants, the new density-independent model is very suitable for the prediction of moisture content of grain, independent on the density variation.

5. Conclusions

The free space transmission method using standard gain horn antennas is used for non-destructive and non-contactive measurement in the frequency range from 9.0 to 10.5 GHz.

A new density-independent model in terms of measured attenuation and moisture density is proposed and the results obtained using this model are compared with those obtained by existing model using the ratio of phase shift to attenuation.

From the results of the comparison between these models using the regression analysis, the new model results in higher values of determinant coefficients than those with the other models. Therefore this new model can be uses for the compensation of the effect of the density dependence on the moisture content measurement.

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