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Dielectric Properties of Grain and Seed

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Dielectric Properties of Grain and Seed

Based on research by S. O. Nelson and others; proposed by ASAE's Electric Power and Processing Division Technical Committee (EPP-03); reviewed by ASAE's Physical Properties of Agricultural Products Committee; approved by EPP-03; adopted by ASAE December 1965; reconfirmed December 1970, January 1972, December 1976, December 1977, December 1978; revised February 1984; revised editorially March 1985; reconfirmed by the Food and Process Engineering Institute Standards Committee December 1988; revised June 1989; revised editorially April 1994; reaffirmed December 1994; revised editorially February 1995; reaffirmed December 1999, February 2005; revised editorially February 2009; reaffirmed for two years January 2010; revised October 2010; revised January 2012; reaffirmed October 2016.

Keywords: Dielectric properties, Grain, Seed

1 Purpose and scope

1.1 These data are provided for use in the design of equipment for radiofrequency (RF) or microwave dielectric heating applications, for applications in grain and seed moisture measurement by electrical methods, and for use in the development of other capacitive or RF energy-absorption sensing devices. The data are also useful in predicting the dielectric heating behavior of grain and seed subjected to high frequency and microwave electromagnetic fields.

1.2 Frequency ranges for which detailed dielectric-properties data are available on several kinds of grain and seed include those from 1 to 50 MHz and 250 Hz to 20 kHz, and such data are provided over a range of moisture contents for some materials. Wide-frequency-range data (250 Hz to 12 GHz) are available on only a few commodities. Data for this wide frequency range are presented graphically when dependence on moisture content is also known. Tabular data are provided for single moisture contents on some commodities. Dependence of the dielectric properties of grain and seed on temperature is not well documented, and the only information included relates to shelled corn. An equation is included that takes into account changes in the dielectric constant of a given grain or seed lot that result from a change in bulk density. The dielectric properties presented are given with particular wet-basis moisture contents and test weights, when available. Although most values are for specific varieties and origins, these data are believed to be representative, and crop origin is of minor significance. With materials as variable as grain and seed, some deviation from listed values can be expected in dielectric properties of particular lots, even though moisture content, test weight, and bulk density may be similar.

2 Dielectric-properties data

2.1 Definition of terms and symbols. Values presented are those of the dielectric constant, ε_r', and the dielectric loss factor, ε_r'', respectively, the real and imaginary parts of the complex relative permittivity, $\varepsilon_r^* = \varepsilon_r'' - j\,\varepsilon_r''$ (Nelson, 1973). Values for the loss tangent, tan $\delta = \dfrac{\varepsilon_r''}{\varepsilon_r'}$ (where δ is the loss angle of the dielectric) and the *a – c* conductivity, σ, are not presented, because they can be calculated from the ε_r' and ε_r'' values presented. The dielectric constant, loss factor, and loss tangent (sometimes called the dissipation factor) are dimensionless quantities. The conductivity $\sigma = \omega\ \varepsilon_o \varepsilon_r''$, where ω is the angular frequency, 2π*f*, and ε_0 is the permittivity of free space (8.854×10^{-12} farad/m), can be calculated as $\sigma = 55.63\ f\ \varepsilon_r'' \times 10^{-12}$ siemens/m (100 S/m = 100 mho/m = 1 mho/cm). Power factor can be calculated as $\tan\delta / (1 + \tan^2\delta)^{1/2}$.

2.2 Graphical data. Wide-frequency-range data on the dielectric properties of hard red winter wheat and shelled, yellow-dent field corn are presented as contour plots of ε_r' and ε_r'' as functions of frequency and wet-

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basis moisture content in Figures 1 and 2. Dielectric properties of several kinds of grain and seed are shown at several moisture contents over the frequency range from 1 to 50 MHz in Figures 3 to 11 (Nelson, 1965).

2.3 Tabular data. Wide-frequency-range (1 kHz to 10 GHz) data on the dielectric properties of a few kinds of grain and seed at single moisture contents are presented in Table 1. Data in the frequency range between 1 and 50 MHz are presented for a much wider range of commodities, and for different moisture contents in many instances, in Table 2. Data on several kinds of grain and seed are presented for frequencies from 250 Hz to 20 kHz in the audio frequency range in Table 3.

2.4 Equations. Equations 1, 2, and 3 provide estimated values for the dielectric constants of shelled, yellow-dent field corn as functions of moisture content, bulk density and temperature at frequencies of 20, 300 and 2450 MHz, respectively (Nelson, 1979).

$$\varepsilon'_{r20} = 3.51 + 0.132(M - 10) + (\rho_b - \overline{\rho_b})(0.839 - 0.086M + 0.027\,M^2) + 0.012(T - 24) \quad (1)$$

$$\varepsilon'_{r300} = 2.89 + 0.098(M - 10) + (\rho_b - \overline{\rho_b})(0.460M - 2.16) + 0.015(T - 24) \quad (2)$$

$$\varepsilon'_{r2450} = 2.48 + 0.099(M - 10) + (\rho_b - \overline{\rho_b})(0.387M - 3.22) + 0.013(T - 24) \quad (3)$$

where

M = moisture content, percent, wet basis (range: 10 to 35%)

ρ_b =specific gravity of the bulk material, or density in g/cm^3, (range: 0.64 to 0.74)

T = temperature of the grain or seed, °C (range: 25 to 60°C)

$\overline{\rho_b} = 0.6829 + 0.01422M - 0.000979M^2 + 0.0000153M^3$

The dielectric constant of a granular material at bulk density ρ_2 is predicted by the following equation (Nelson, 1984):

$$\varepsilon'_{r2} = [((\varepsilon'_{r1})^{1/3} - 1)\,\rho_2/\rho_1 + 1]^3 \quad (4)$$

where

ε'_{r1} = dielectric constant of the bulk material at bulk density ρ_1.

Equation 4 predicts the dielectric constant of granular material, such as grain and seed, at any bulk density, when the dielectric constant of the material is known at any given bulk density. If the density of the individual kernels or seeds is known, the dielectric constant of the kernels or individual seeds can be estimated with equation 4 from the dielectric constant of the bulk material at a known density.

Additional equations for estimating the dielectric constants of cereal grains and soybeans are presented in Table 4.

Equations for estimating the microwave dielectric constants and loss factors of several cereal grains and oilseeds are presented in Table 5 for the 5- to 15-GHz frequency range.

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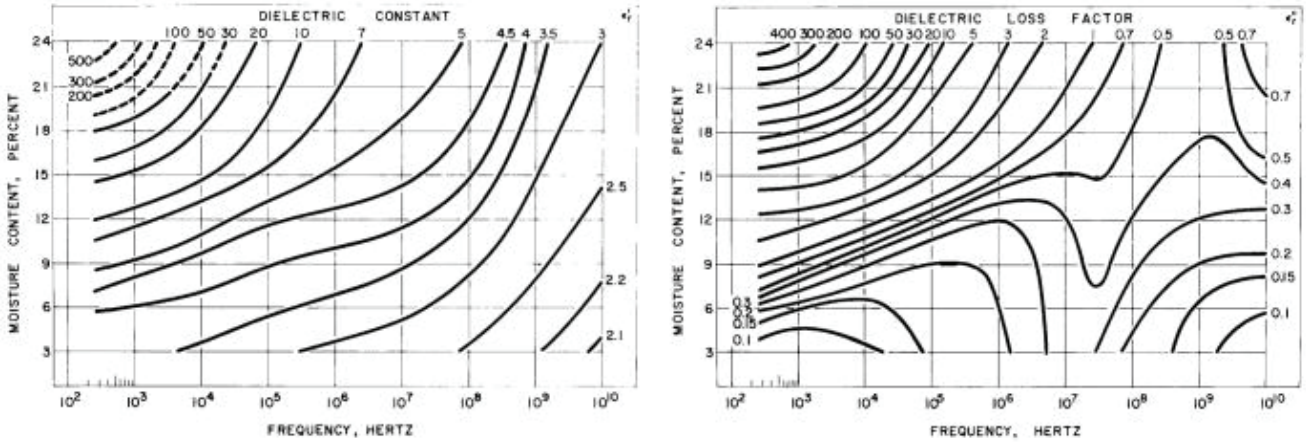

Figure 1 – Dielectric properties of hard red winter wheat (*Triticum aestivum* L.) at 24°C (average for seven lots of sound clean wheat; Nelson, 1982)

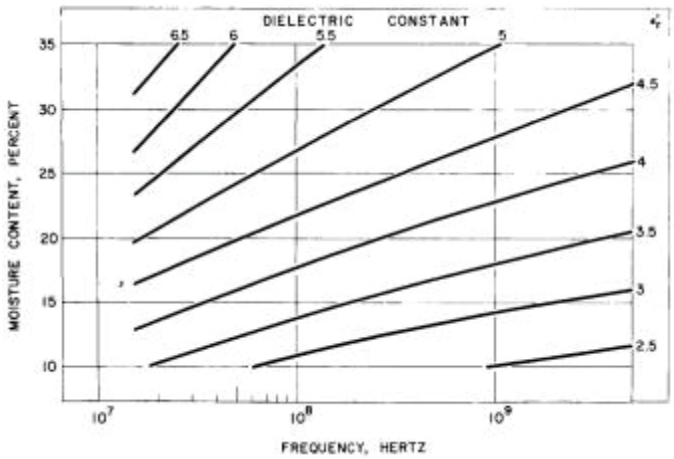

Figure 2 – Dielectric constant of shelled, hybrid, yellow-dent field corn (*Zea mays* L.) at 24°C (averages for 21 lots of sound, clean corn; condensed from Nelson, 1979; corrected and redrawn from Nelson, 1982)

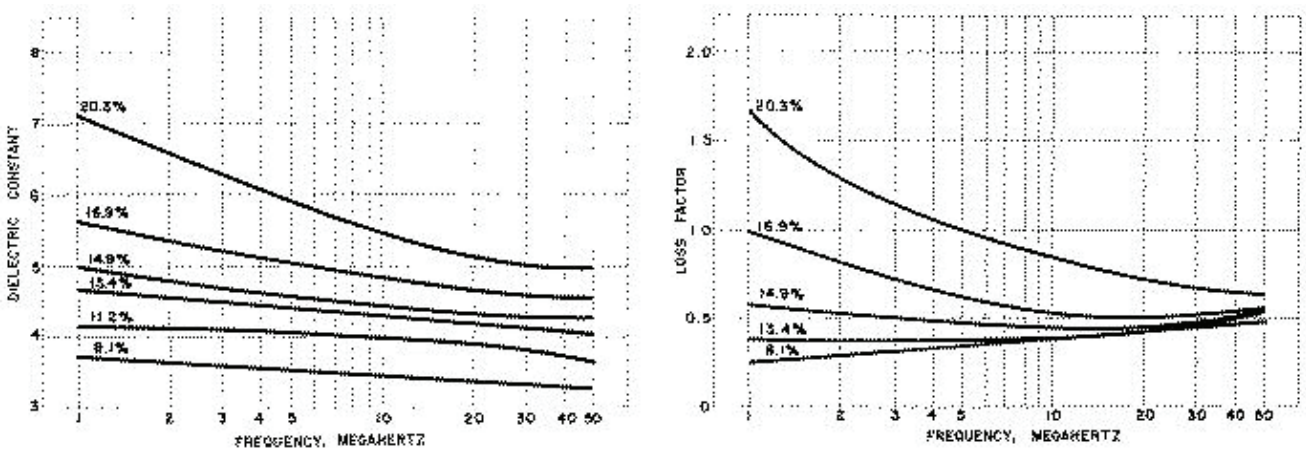

Figure 3 – Dielectric properties of 1959 Nebraska-origin 501 shelled, yellow-dent field corn (*Zea mays* L. Ungraded Kernels) at 24°C and indicated moisture contents. Test weight: 761 kg/ m^3 (59.1 lb/bu) at 11.2% moisture. Natural drying from high moisture at harvest.

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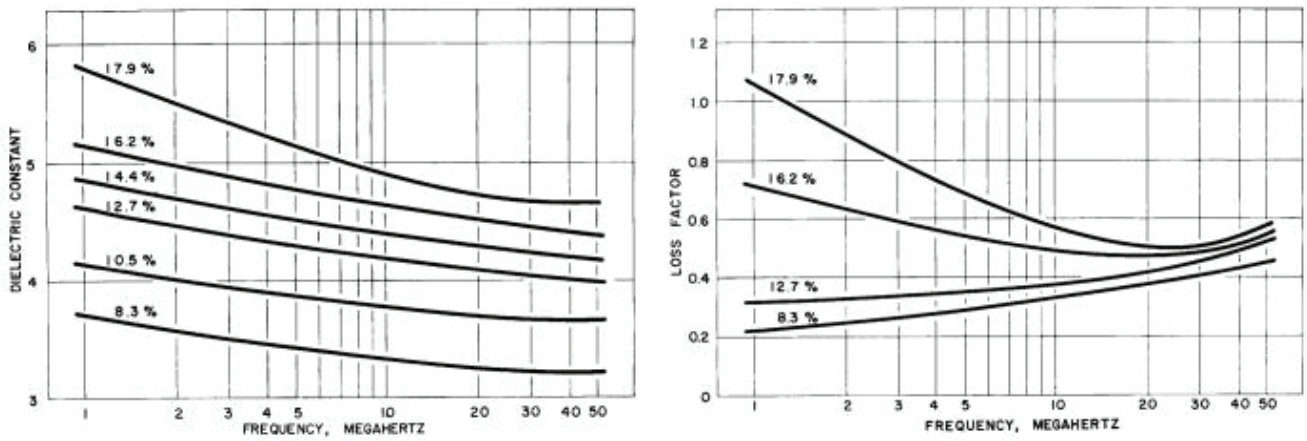

Figure 4 – Dielectric properties of 1958 Nebraska-origin 'Nebred' hard red winter wheat (*Triticum aestivum* L.) at 24°C and indicated moisture contents. Test weight: 768 kg/m^3 (59.7 lb/bu) at 13.0% moisture. Water added for moisture contents above 12.7%.

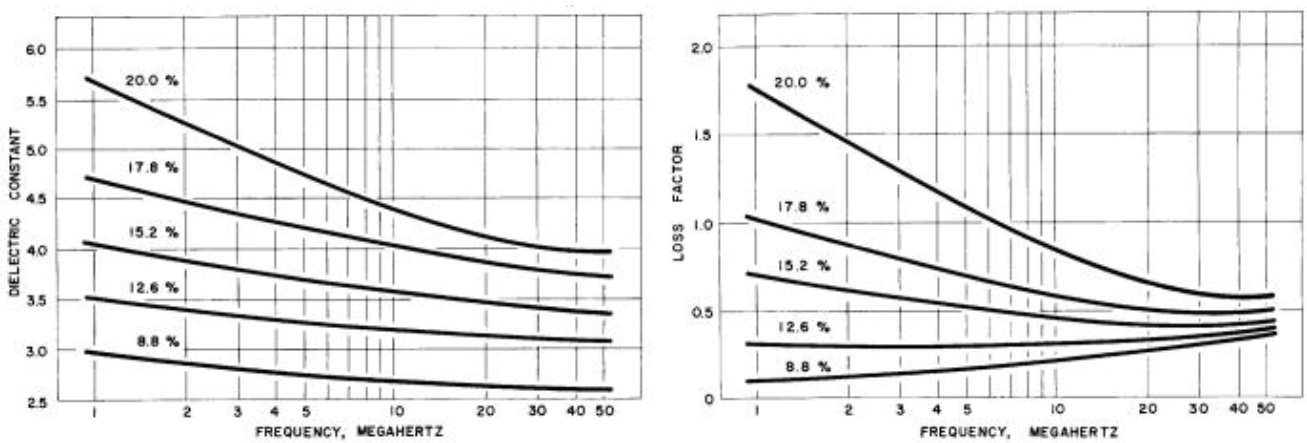

Figure 5 – Dielectric properties of 1961 Nebraska-origin 'Chase' winter barley (*Hordeum vulgare* L.) at 24°C and indicated moisture contents. Test weight: 597 kg/m^3 (46.4 lb/bu) at 12.6% moisture. Water added for moisture contents above 12.6%.

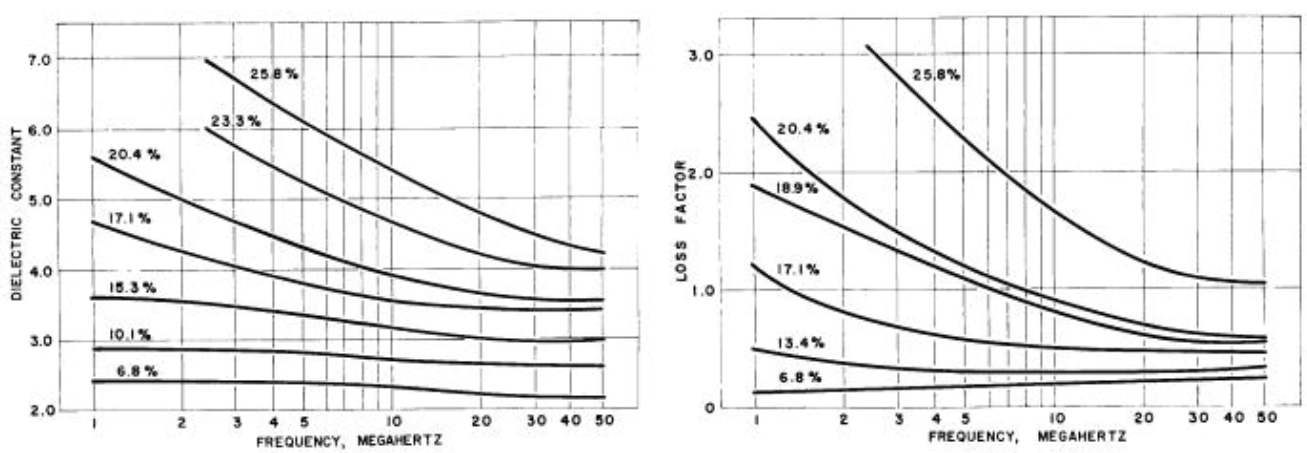

Figure 6 – Dielectric properties of 1959 Nebraska-origin 'Cherokee' spring oats (*Avena sativa* L.) at 24°C and indicated moisture contents. Test weight: 519 kg/m^3 (40.3 lb/bu) at 10.1% moisture. Water added for moisture contents above 10.6%.

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