ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XX [2022] | Fascicule 2 [May]

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A BRIEF OVERVIEW ABOUT DIELECTRIC PARAMETERS OF SOILS

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Abstract: Engineering applications may include such investigations, which play important role in the innovative agriculture. Investigations have to be carried out to isolate the effects of specific characteristics through laboratory and field experiments. The most important soil characteristics are moisture content, salinity, organic matter content, bulk density, texture and structure. Continuous and improving innovation in soil investigations is utilising electromagnetic methods (electromagnetic waves) to measure soil parameters. Of course, the parameters can be measured using conventional techniques, too. But dielectric characteristics of soils can be evaluated from both an agricultural and a technical perspective. Undoubtedly, the most significant and easiest to isolate is soil moisture. Dielectric test method can be potentially utilised in agricultural researches. Furthermore, technical education, research, development and innovation provide opportunities for resilience and reinvention. This paper presents how the dielectric parameters of soils characterize and describe the properties of soils, evaluate the effects of soil properties on microwave complex dielectric constants and outlines a dielectric model.
Keywords: soil, microwave, dielectric parameters, innovation

1. INTRODUCTION

It is important to raise awareness and increase knowledge of the secret life beneath our feet (URL1). The global union of soil scientists (International Union of Soil Sciences – IUSS) considers stopping soil degradation as one of its most important tasks so preserving this unique resource and life itself. We need to revitalize our care for the soil over and over again, and strengthen the role of the soil (Várallyay, 1994) as an essential natural resource to preserve the environment. This is very relevant for reaching many of the Sustainable Development Goals (SDGs). This short summary paper would like to contribute to the initiatives under the umbrella of the International Decade of Soils 2015–2024 which shall support to increase the awareness about the importance of soil.

Soil is a polydisperse porous system, mainly consists of three phases (Stefanovits, 1977, 1999; Powrie, 2013):

- a solid phase which is typically clay, silt and sand minerals;
- a liquid phase which is typically water;
- and a gas phase which is normally air.

The soil properties are essentially governed by these three phases, their composition, and their arrangement (Stefanovits, 1977, 1999; Powrie, 2013). In addition, it may contain various proportions of organic matter and microorganisms.

Taking into account the above, different geophysical techniques are used in engineering and non-engineering applications to characterise the subsurface, mapping soil and rock conditions, and to gather information about underground features.

A material having the ability to store energy when it is exposed to an electromagnetic field, called dielectric. In the absence of an electromagnetic field electrical charges in a dielectric material are randomly oriented. When the dielectric material is placed in an electromagnetic field, these electric charges begin to orient under the influence of the electromagnetic field, this phenomenon is the polarization of the material (Santamarina et al., 2001). The behaviour of a material exposed to an electromagnetic field can be described by a complex number (1) called dielectric constant (Huisman et al., 2003; URL2; URL3).

$$\varepsilon = \varepsilon' - j\varepsilon'' \quad (1)$$

The real part (ε') of dielectric constant is a measure of the degree ability to store electrical charges of the material, which is related to its polarizability. The imaginary part (ε'') of dielectric constant represents the losses that occur due to polarisation and electrical field. Under an electromagnetic field of varying polarity, charges moving with finite velocity are not be able to move fast enough to adapt their polarity to the external electromagnetic field, therefore, the dielectric permittivity may be a function of the frequency (Stillman – Olhoeft, 2008; Pozar, 2012; URL2).

Each typical phase of soil has its own value for dielectric constant, which are published in the papers of international research groups (Ulaby et al. 1981; Olhoeft, 1981; Davis – Annan, 1989; Daniels, 1996; Schön, 2015); $\varepsilon' = 1$ for air, $\varepsilon' = 2–7$ for soil solid particles, and $\varepsilon' = 80$ for water. Moreover, the dielectric constant of soils is related to the phases volume fractions, their spatial distributions, and their orientations relative to the direction of the applied electrical field (Wobschall, 1977; Endres – Knight, 1991; Robinson – Friedman, 2002; Friedman, 2011).

Dielectric properties of soil which are influenced by soil moisture content, salinity, density, porosity and mineralogy and the operational frequency of geophysical surveys play a crucial role in electromagnetic (EM) wave-based geophysical investigations, such as ground-penetrating radar (GPR), EM prospections, and light detection and ranging (LIDAR) (Topp et al., 1980; Roth et al., 1990; Drnevich et al., 2001; Liu – Mitchell, 2009; Lauer et al., 2010; Wagner et al., 2011; Schön, 2015).

In these geophysical investigation techniques, the operational frequency can typically vary between 10 MHz and 1 GHz. For point sensors such as Time Domain Reflectometry (TDR) probes, 50 MHz and 1 GHz, for Ground Penetrating Radar (GPR), and 400 MHz and 10 GHz for remote sensing applications. Furthermore, the purpose of the investigation governs the most suitable frequency range for a given application (URL3).

This paper presents how the dielectric parameters of soils characterize and describe the properties of soils, evaluate the effects of soil properties on microwave complex dielectric constants and outlines a dielectric model. The research work was conceived and described in a previous research paper (Nagy – Kovács, 2022).

2. MATERIALS AND METHODS

Relationships between the dielectric parameters and moisture are the basis for the microwave sensing of soil moisture. Open-circuit coaxial transmission-line method was used to determine the electromagnetic (dielectric) parameters of different soil types (different texture and moisture) as function of frequency. The measurements were carried out in the microwave frequency range between 200 MHz and 2400 MHz. Measurements were made with DAK 3.5 dielectric measuring system (Professional Handbook, 2016).

Soil samples were collected (MSZ 21470) from 0–20(30) cm depth from arable land, pasture, garden ground around South Eastern side of Hungary. Samples were stored in a closed container until dielectric measurements were performed to preserve their original condition (e.g. moisture content). The samples were classified into structural classes using the textural triangle (URL4) in the knowledge of the percentages of clay, silt and sand. The sand particles are the largest range of diameter from 2.0 to 0.05 mm. Silt particles' diameters are ranging from 0.05 to 0.002 mm. Clay particles are smaller than 0.002 mm. Texture affects other soil properties such as bulk density, water holding capacity, permeability, and porosity. For example, soils that primarily consist of clay particles have low permeability and higher water holding capacity compared to soils with higher sand content. (Mobilian – Craft, 2021). Table 1 shows the soil samples' textures such as clay, silt and sand separate.

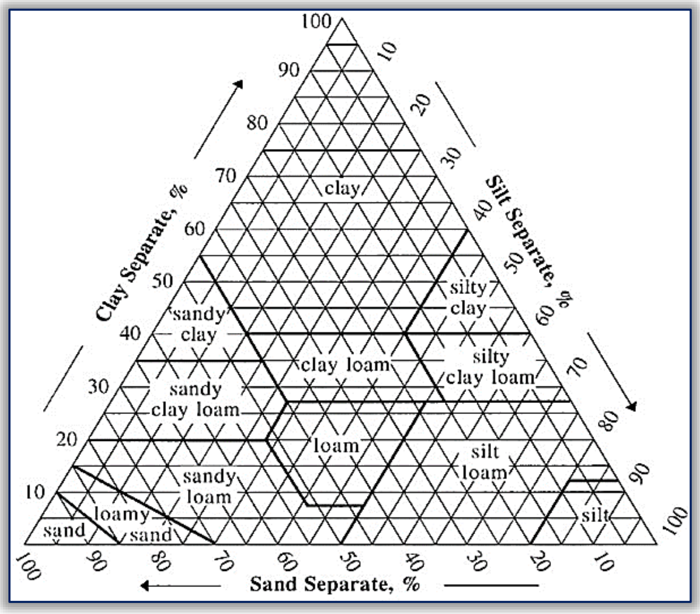

Figure 1. Soil Texture Triangle (URL4)

Table 1. Soil grain size fractions by mass (%)

SOIL SAMPLE	CLAY	SILT	SAND
clay soil	48%	28%	24%
clay loam soil	33%	33%	34%
loam soil	24%	46%	30%
sandy loam soil	19%	26%	55%
silt loam soil	20%	52%	28%

3. RESULTS

The results (Figure 2; Figure 3) show the relationship between soils physical parameters and their electrical properties (dielectric parameters). Dielectric measurements (ε′ and ε″ as function of microwave frequency) were help to evaluate the dependence of the dielectric constant as function of soil parameters (e.g. moisture content). The effects of dry density or degree of compaction on the dielectric constant of different soil types (ranging from sand to bentonitic clay) must be experimentally investigated and evaluated. There are significant variations for the real part (ε′) and large variations for the imaginary part (ε″) of dielectric constant among soils in the test frequencies ranging from 200 MHz to 2400 MHz. The real part of the dielectric constant for higher moisture cases (for example clay soil, clay loam soil) correlates energy store of electric field and the imaginary part for all soils correlates the extent of electrical energy converted to heat and characterize moisture conditions. The trend lines following the tendencies of the measurement results as pre-experimental models can be used for soils with similar characteristics.

In all cases, the finding must be based on typical experimental results and relevant theories and models. As shown in Figure 2, Figure 3, for these samples with low water content, the effect of frequency on the real dielectric constant is insignificant. However, the effect of frequency emerges as the water content increase and the real dielectric constant becomes dependent on the frequency of measurements.

This effect is more pronounced for samples with higher clay content, whereas samples with low clay content show marginal sensitivity to frequency (within the range studied here).

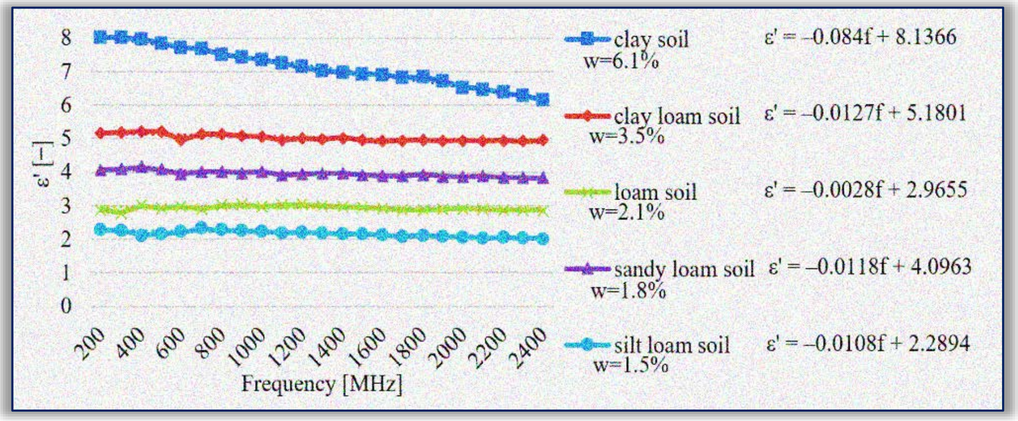

Figure 2. The real part of dielectric constant (w – gravimetric water content; f – microwave frequency)

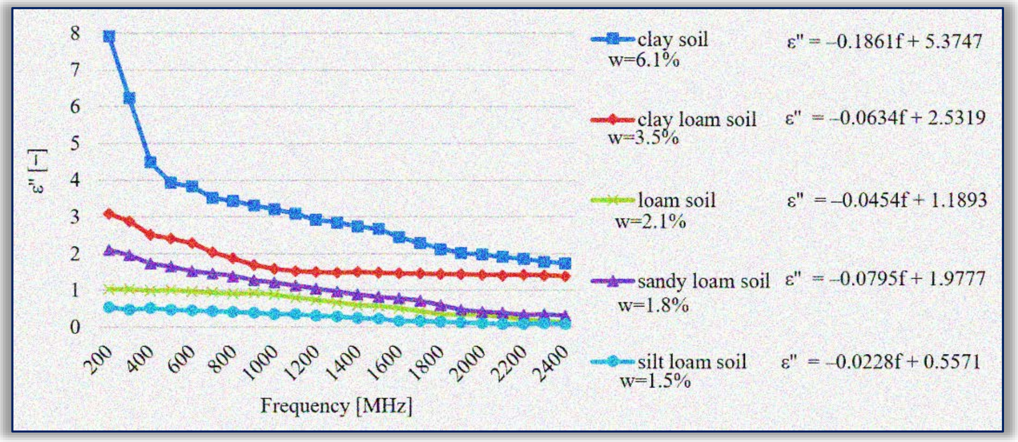

Figure 3. The imaginary part of dielectric constant (w – gravimetric water content; f – microwave frequency)

The results guide the professionals through experimental and theoretical knowledge in order to handle models and theories in practice.

If a given material has an ideal Debye (URL5) behaviour in the electromagnetic field, it shows an ideal Cole-Cole (URL6; URL7; URL8) diagram (Figure 4). That is, the function ($\varepsilon'' = f(\varepsilon')$) has a semicircular shape and the centre of the corresponding circle falls on the abscissa. However, if the behaviour is different, the shape of the function is still semicircular, but the centre is situated below the abscissa. In the case of soils, due to the changing structure, it is especially important to analyse the behaviour different from the ideal Debye behaviour.

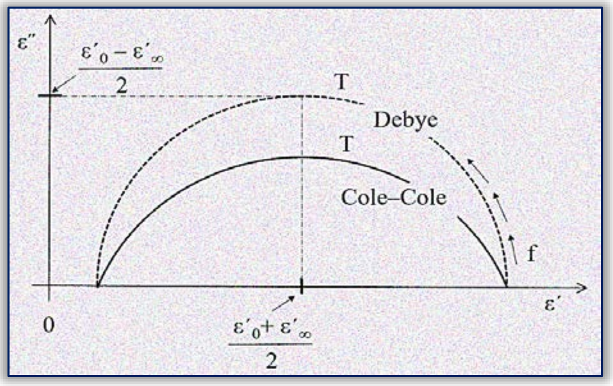

Figure 4. Cole–Cole diagram (T – temperature; f – frequency)

For the modelling based on the measurement results, a Debye relaxation spectrum can be chosen. A curve fitting application helps to search for the most appropriate values of fitting Cole-Cole model parameters. The objective of measurement results fitting is to find the values that most closely match the measurement results.

4. CONCLUSION

Soils are "unique materials", therefore soil characterization, soil fundamental parameters such as water content and density are usually required to be measured and monitored continuously to ensure successful agricultural activity. A review of the results of this paper shows an alternative way of measuring soil water content and density in agricultural discipline. Electromagnetic waves can be effectively used to gain complementary information about the soils and their behaviour. The effects of dry density on the soil dielectric constant depend on the soil type. In addition, microwave measurements should be supplemented and supported by experimental observations and agricultural field work. These results can be used as a database for future in agricultural investigations and interdisciplinary researches.

In addition to technological impact assessments, ecological impact assessments should not be neglected in the course of engineering activities.

Note: This paper was presented at ICOSTEE 2022 – International Conference on Science, Technology, Engineering and Economy, organized by University of Szeged, Faculty of Engineering (HUNGARY) and Hungarian Academy of Sciencies – Regional Commettee in Szeged (HUNGARY), in Szeged, HUNGARY, in 24th of March, 2022

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