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Dielectric Study of Soils with varied Organic Matter at Microwave Frequency

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Abstract

The real (ε') and imaginary (ε") parts of the complex dielectric constant (ε) of soil with variation of organic matter content are measured at 7.0 GHz. The J-band microwave setup with slotted section and a crystal detector is used for measurements. All measurements are made at room temperature. The two point method is used for these measurements. The dielectric properties of soils are in good agreement with the earlier work. The value of ε' and ε'' increases with increase in organic matter of soils. This data is used to estimate the tangent loss, a.c. electrical conductivity and relaxation time. The result shows the change in dielectric properties with addition of orgnic matter. These parameters are useful for researchers working in the field of agriculture and microwave remote sensing for soils.*

Keywords: Dielectric constant, Dielectric loss, Tangent loss, Conductivity, Relaxation Time.

Introduction

Dielectric properties of the material depend on the activity of permanent electrical dipoles, ionic conduction and degree of dipole alignment with the applied time varing electric field. In case of non-homogeneous material such as soil, the dielectric properties are affected by the composition of the material which affects the molecular movement. The microwave soil dielectric measurement uses absorption of microwaves corresponding to rotational energy of molecules. When electromagnetic field is applied to the dielectric material, energy is dissipated in these materials as a result of dielectric relxation process. The interaction of electromagnetic field depends upon the complex dielectric permittivity, relative to the free space. The dielectric properties of soil are function of its naturally available chemical constituents such as carbon, sodium, potassium, Iron and physical properties such as sand, silt, clay**.** In a non-homogeneous medium such as soil, the dielectric constant is combination of individual dielectric constant of its physical properties, naturally available macronutrients, micronutrients, minerals, organic and inorganic matter content. Many researchers working on this aspect, studied dielectric parameter of different materials with various methods [1-9]. The dielectric properties of soil with organic and inorganic matter at four different frequencies 8 GHz, 9 GHz, 10 GHz, 11 GHz using microwave X-band are reported [1]. The dielectric properties of soil with inorganic matter at 3.0 GHz with S-band microwave frequency are reported [2]. The dielectric properties of soil with organic matter at S-band microwave frequency are reported [3].

Study of dielectric properties of different soil textures collected from Karnataka state, at X-band microwave frequency using Infinite sample method has been studied [4]. Effect of saline water on the dielectric properties and also on the emmisivity is reported [5]. Variation of dielectric constant of dry soils with their physical constituents and available nutrients at C-band microwave frequency are reported. Also the correlation coefficients between dielectric constant and soil properties is determined [6].

Measurements of the electric conductivity and relative dielectric permittivity, were conducted (0.1Hz –15 MHz) on 40 air-dried soil samples that were subsequently analyzed for pH, total organic matter in soil P_2O_5, Fe_2O_3 and heavy metal concentrations [7]. The dielectric properties of urea and diammonium phosphate fertilizers in aqueous solution at different temperatures in microwave frequency are reported [8]. The characteristics of the soil of Chhattisgarh at X-band frequency are studied using Infinite sample method [9]. Microwave emission depends upon the dielectric constant of the soil [10]. On this basis, the present study has been undertaken to have an idea of electrical properties of soils with increase in humus at J-band microwave frequency.

Materials and Methods

Soils is nonhomogenious mixture of solids, liquids and gases mixed in variable proportions. The relative amounts of water and air present depend upon the way these soil particles are packed together. The soil texture depends upon the size of the particle and the structure of soil depends on the way the particles are being arranged. Both of them influence the amount of pore space and its distribution in the soil. Soil texture is characterized by percentage of sand, silt and clay in it. Depending upon the percentage of each of these constituents, the soil texture is differently recognized. Each soil has its own set of constituents depending upon its origin, location, nature etc. It is observed that the soil with more sand content lacks the water holding capacity while more silt soil has better water holding capacity.

The soil sample taken for present study belongs to the marathwada region of Maharastra state. Soil samples having different textures were collected from both irrigated and non-irrigated areas. The locations are recorded using Garmin make GPS 60. The Physical and chemical properties of the soil were measured at soil analysis laboratory. Elmake model 7200 is used to measure pH, TDS, Salinity etc. Number of soil samples having different physical and chemical properties are used for study.

The field capacity (FC) can be approximated by the empirical formula on soil composition [11]. $FC = 25.1 - 0.21 (\% Sand) + 0.22 (\% Clay)$

Wilting coefficient (Wp) and transition point (Wt) are calculated by using the Wang and Schmugge model [12].

$Wp = 0.06774 – 0.00064 (\%Sand) + 0.00478 \quad (\%Clay)$

$Wt = 0.49\ Wp + 0.165$

The complex dielectric constant is calculated using the relation

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

The two point method described by Altschuler [13] is used for the measurement of Dielectric constant (ε') and dielectric loss (ε'').

The theory underlying the methods to follow is based on consideration of Fig. 1(a) shows an empty short-circuited waveguide (sample holder) with a probe located at a voltage minimum D_R. Fig.1 (b) shows the same waveguide, now containing a sample of length l_ε with the probe located at a new voltage minimum D. The sample is adjacent to the short circuit. Looking from $T_{\varepsilon 1}$, towards the right and the left, one can write the impedance equation

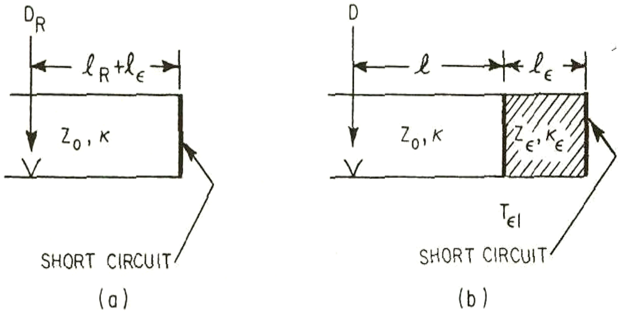


Figure 1: Dielectric constant Measurement with short-circuited waveguide.

$$Z_0 \tan k.l = - Z_\varepsilon \tan k_\varepsilon l_\varepsilon \qquad (1)$$

Likewise, in Fig. 1 (a), looking toward the right, one has

$$Z_0 \tan K (l_R + l_\varepsilon) = 0 \qquad (2)$$

Now, consider

$$\tan k (D_R - D + l_\varepsilon) = \tan k [(l_R + l_\varepsilon) - (l + l_\varepsilon) + l_\varepsilon]$$
$$= \tan k [(l_R + l_\varepsilon) - R]$$

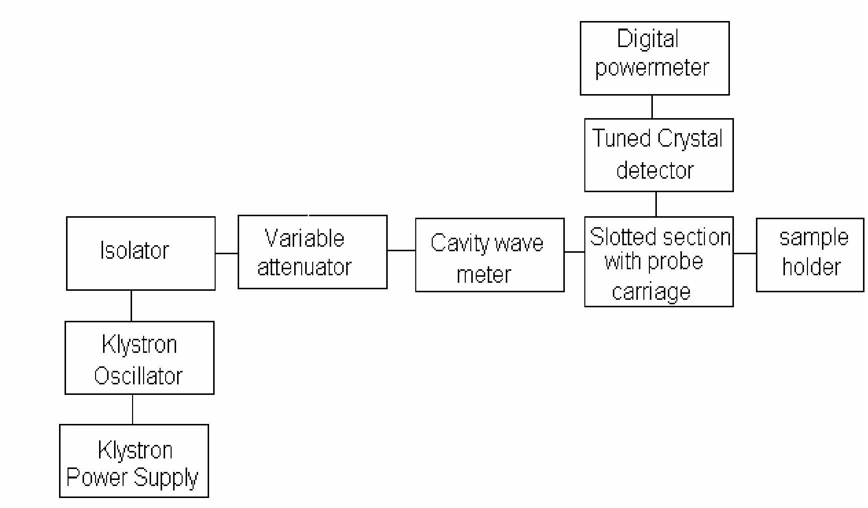
Expanding the tangent and making use of equation (2) , substitution into equation (1) yields

$$Z_0 \tan k (D_R - D + l_\varepsilon) = Z_\varepsilon \tan k_\varepsilon l_\varepsilon \qquad (3)$$

When it is recalled that $Z_0/Z_\varepsilon = k_\varepsilon/k$, one can rewrite equation (3) in the form,

$$\frac{\tan k (D_R - D + l_\varepsilon)}{k\, l\varepsilon} = \frac{\tan k_\varepsilon l_\varepsilon}{k_\varepsilon l_\varepsilon} \qquad (4)$$

It is now noted that all the quantities associated with the left-hand member are measurable, while the right-hand member is of the form tan Z / Z, so that once the measurement has been performed, the complex number, $Z = k_\varepsilon l_\varepsilon$ can be found by the solution of the transcendental equation. In view of the periodic nature of the tangent function, there exists an infinity of solutions for ε_r. It is consequently either necessary to know ε_r approximately in order to pick the right solution, or to perform a second identical experiment with a sample of different length l_ε. The proper solution in the latter case is the one common to the two sets of solutions.



The basic arrangement of equipment for this measurement technique is shown in Fig. (2).

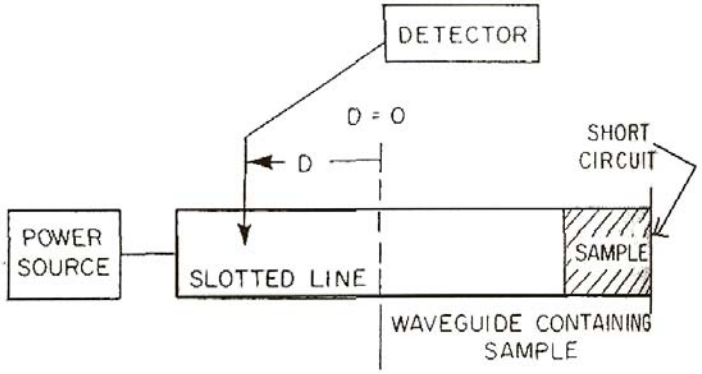


Figure 2: Two Point Method of Measuring Dielectric Constant.

Without sample dielectric in the short circuited line, find D_R, the position of the minimum in the slotted line with respect to an arbitrarily chosen reference plane (D=0). Measure the guide wavelength, λ_g, by measuring the distance between alternate minima in the slotted line.

Remove the short circuit, insert the soil sample dielectric, and replace the short circuit in such a manner that the short circuit touches the end of the sample. Measure D, the position of the minimum in the slotted line, with respect to the reference plane (D=0) as shown in Fig. (2). Note r, the VSWR in the slotted line. Repeat the same procedure for soil sample of different length sample lengths $l_{1\varepsilon}$ and $l_{2\varepsilon.}$

Propagation constant (in the empty waveguide) is calculated as

$$k = \frac{2\pi}{\lambda_g}$$

The complex number $c\angle\psi$ can be obtained from the equation

Figure 3: Block diagram of experimental setup for measurement of dielectric properties.

$$c\angle-\psi = \frac{1}{jkl_\varepsilon}\frac{1-|\Gamma|e^{-j\phi}}{1+|\Gamma|e^{j\phi}}$$

where $\phi = 2k\,(D- D_R\text{-}l_\varepsilon)$

and $|\Gamma| = \frac{r-1}{r+1}$

solve the complex transcendental equation for T and τ to get conductance(Gε) and susceptance(Bε)

$$c\angle-\psi = \frac{\tanh(T\angle\tau)}{(T\angle\tau)}$$

The dielectric constant (ε') and dielectric loss (ε") of the soil sample can be calculated with the equations

$$\varepsilon' = \frac{G_\varepsilon + \left[\frac{\lambda_g}{2a}\right]^2}{1+\left[\frac{\lambda_g}{2a}\right]^2} \qquad \text{and}$$

$$\varepsilon'' = \frac{-B_\varepsilon}{1+\left[\frac{\lambda_g}{2a}\right]^2}$$

The block diagram of experimental setup for measurement of microwave dielectric properties is shown in Fig. 3. The experimental set-up consist of a KPS151 reflex klystron as the microwave source, with maximum output power of 25 mW and frequency range 5.85-8.2 GHz. To avoid the interference between source and reflected signals, the source is connected with a broadband isolator with minimum isolation of 20 dB and minimum insertion loss of 0.4 dB. To control the power at desired level, a variable attenuator is connected after the isolator. A frequency meter is used to measure frequency of the signal. The diode detector with square law characteristics with VSWR better than 2 : 1 is used. The detected power is feed to an micro ammeter. The slotted line is employed to measure VSWR and distance. A 9 cm long wave-guide is used as sample holder. For accurate measurements, the probe carriage is mounted with a dial gauge having least count of one micron.

The values of dielectric constant and dielectric loss are used to estimate the tangent loss, a.c electrical conductivity $(\Omega\text{-m})^{-1}$ and relaxation time (psec) using the relation

$$\tan\,\delta = \frac{\varepsilon''}{\varepsilon'}\ ,\ \sigma = \omega\varepsilon_0\varepsilon''\ \text{ and }\ \tau = \frac{\varepsilon''}{\omega\varepsilon'}$$

where, ω is angular frequency, ($\omega = 2\pi f$; f = 7.0 GHz) and ε_0 is permittivity of free space, (ε_0 = 8.85 x 10^{-12} F/m).

Results and Discussion

Physical properties of soil samples are listed in Table 1. Locations and Physical parameters of these soils are reported in Table 2. Chemical Properties of Soil Samples are given in Table 3.

Table 1: Physical Properties of Soils.

Soil Sample	Texture	Sand %	Silt %	Clay %	W.H.C %	Particle Density	Porosity
I	Clay	13.79	39.89	46.32	55.30	2.30	53.10
II	Clay Loam	26.40	44.40	29.20	54.50	1.80	45.90
III	Clay Loam	24.99	47.20	27.81	40.40	2.00	41.80
IV	Clay	12.50	39.89	47.61	50.00	2.30	49.50

Table 2: Location and Physical Parameters of soils.

Soil Sample	Location of soil		Physical Parameters of soils		
	Lattitude	Longitude	FC	Wp	Wt
I	$19^0$26’28.1’’N	$75^0$29’11.7’’E	32.39	0.2803	0.3024
II	$20^0$26’6.3’’N	$73^0$43’10’’E	25.98	0.1904	0.2583
III	$19^0$52’37.1N	$74^0$28’52.9’’E	25.97	0.1847	0.2555
IV	$19^0$21’5.8N	$75^0$42’23.5’’E	32.95	0.2873	0.3058

Table 3: Chemical Properties of Soil.

Soil Sample	pH	E.C. mS/cm	Organic Carbon %	Ca %	Mg %	Na %	$CaCO_3$ %
I	8.51	0.22	0.55	43.87	32.89	0.51	6.25
II	7.83	0.38	0.92	41.70	31.24	0.30	3.00
III	8.10	0.28	0.78	37.53	26.39	0.71	5.87
IV	8.46	0.19	0.39	35.44	26.39	0.52	4.62

The variations in the values of dielectric constant and dielectric loss with percentage humus content are measured and plotted in figure 4 and 5, for four different soils, respectively. The relation between the dielectric constant and the humus content is non-linear. The a.c.electrical conductivity and relaxation time with variation of percentage humus content are plotted in figure 6 and 7 respectively. The variations in tangent loss with percentage humus content for these soils is shown in figure 8.

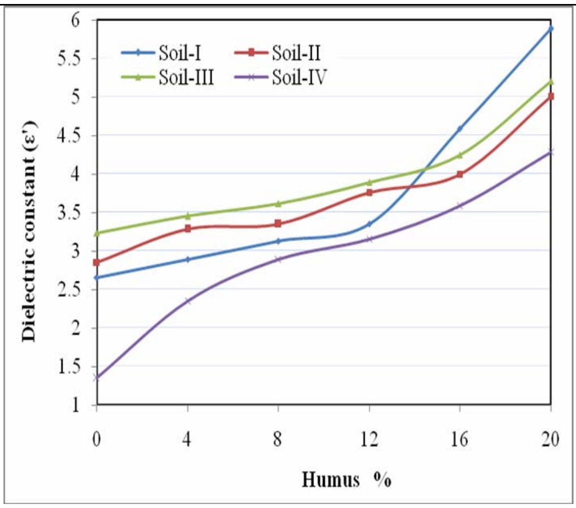


Figure 4 : The variations in dielectric constant with percentage humus content for soils.

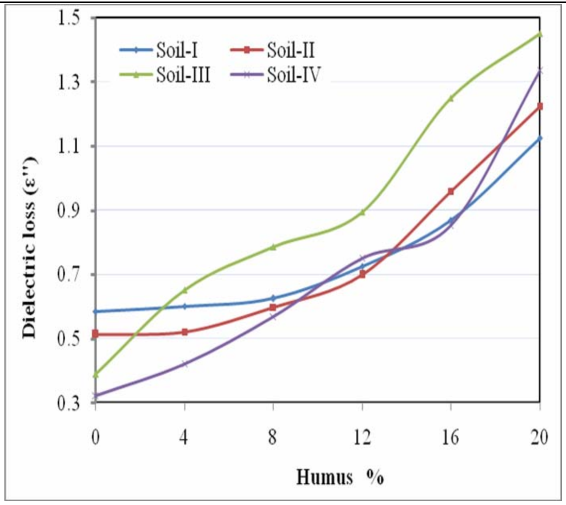


Figure 5: The variations in dielectric loss with percentage humus content for soils.

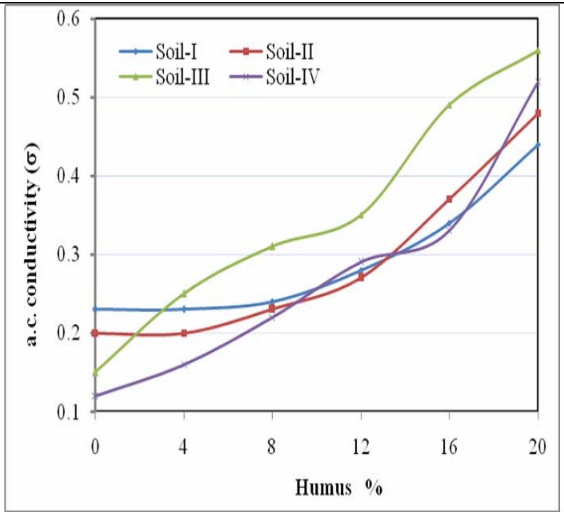


Figure 6: The variations in a.c.electrical conductivity with percentage humus content for soils.

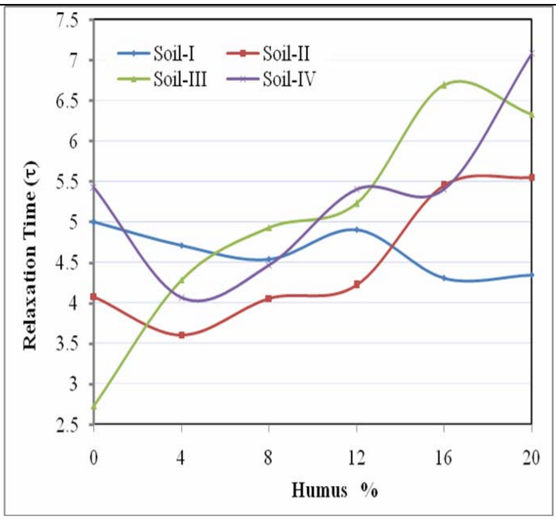


Figure 7: The variations in relaxation time with percentage humus content for soils.

It is obvious that the dielectric constant and dielectric loss of the soils increases slowly with humus content. The a.c. electrical conductivity (σ) also increases with increase in humus. The dielectric loss is proportional to the a.c. conductivity, relaxation time (τ) and tangent loss (tanδ) shows a abrupt change with increase in humus. The physical parameters viz. field capacity, wilting coefficient and transition point are determined from naturally available sand, silt and clay percentage of the soils.

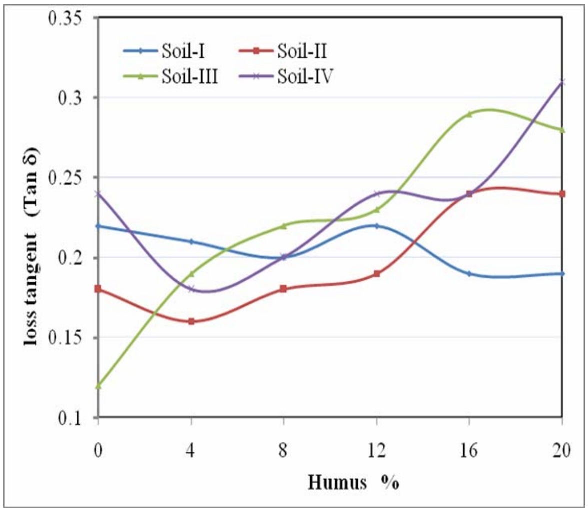


Figure 8: The variations in tangent loss with percentage humus content for soils.

These parameters are useful for researchers working in the field of agriculture and microwave remote sensing for soils. Also these parameters are useful to prepare soil health card which may be further used to determine the soil fertility. These results are in good agreement with earlier reported work[1,3,6].

Conclusions

Physical and chemical properties show remarkable variation in dielectric properties. Organic matter in soil significantly affects the dielectric properties of soil. The tangent loss, a.c. electrical conductivity and relaxation time depend upon the dielectric loss, which represents attenuation and dispersion. These dielectric properties can be used to predict the soil fertility and health.

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