

Effect of Calcium Carbonate on Microwave Dielectric Behavior of Soils

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Abstract

An attempt has been made to study the impact of calcium carbonate on soil dielectric properties. The dielectric constant (ϵ') and dielectric loss (ϵ'') of soil with increasing percentage of calcium carbonate are measured at 7.0 GHz. These measurements are carried at room temperature. The J-band microwave setup with slotted section and a crystal detector is used for measurements. The two point method is found suitable for these measurements. Abrupt change in values of dielectric constant and dielectric loss due to addition of calcium carbonate is observed. This data is used to determine the a.c. electrical conductivity, relaxation time, and tangent loss. The dielectric properties of soils are in good agreement with the earlier reported work.

Keywords: Calcium carbonate, Dielectric constant, Dielectric loss, Tangent loss, Conductivity and Relaxation Time.

Introduction

When electromagnetic field is applied to the dielectric material such as soil, energy is dissipated in it as a result of dielectric relaxation process. This interaction of electromagnetic waves with the material depends upon the complex dielectric permittivity, relative to the free space. The dielectric properties of soil are function of chemical constituents such as organic carbon, calcium, sodium, potassium, magnesium, iron, calcium carbonate 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. Researchers working on dielectric properties of soils studied dielectric parameter of different materials with various methods [1-13]. The effect of cow manure on dielectric properties of clay loam soil at microwave frequency have been measured using a vector network analyzer with varied moisture contents in the frequency range 150 MHz to 2.2 GHz. Measurements of complex dielectric permittivity in this frequency range were also carried out for different concentration of cow manure in soil [1]. The dielectric properties of soil-organic matter mixtures using coaxial impedance dielectric reflectometry are measured [2]. Dielectric response of a variable saturated soil contaminated by non-aqueous phase liquids (NAPLs) hydrocarbon contamination in soils and groundwater by means of the time domain reflectometry technique is observed [3]. The dielectric properties of soil collected from Karmad area of Marathwada region of Maharashtra state with organic and inorganic matter at four different frequencies 8 GHz, 9 GHz, 10 GHz, 11 GHz using microwave X-band are reported [4]. The

dielectric properties of soil with varied percentage of calcium carbonate at 3.0 GHz frequency with microwave S-band using infinite sample method are reported [5]. The dielectric properties of soil with organic matter at S-band microwave frequency are reported [6]. Dielectric properties of different soil textures collected from Karnataka state, at X-band microwave frequency using infinite sample method has been studied [7]. Variation in dielectric properties with increase in saline water are reported. The effect of saline water on the emissivity of soils is also reported [8]. Variation of dielectric constant of soils with their physical constituents and naturally available nutrients at C-band microwave frequency are reported. Also the correlation coefficients between dielectric constant and different soil properties is determined [9]. Measurements of the a.c. electrical conductivity and relative dielectric permittivity, are conducted (0.1 Hz –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 [10]. The dielectric properties of some fertilizers in aqueous solution at different temperatures at microwave frequency are reported [11]. The dielectric properties of soil samples collected from Chhattisgarh state at X-band frequency are studied using infinite sample method [12]. Dielectric Study of Soils with varied Organic Matter at Microwave Frequency is presented [13].

On this basis, the present study has been undertaken to have an idea of microwave dielectric properties of soils studied [13] with increase in calcium carbonate.

Materials and Methods

Soils are composed of solids, liquids and gases mixed in variable proportions. The relative amounts of water and air present in particular soil depend upon soil particles are packed together. The soil texture depends upon the size of the partical and the structure of soil depends on the way these particals are arranged. This 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. The soil texture is recognized by the percentage of each of these constituents. Each soil has its own and unique set of constituents depending upon its origin, location, nature etc.

For the present study, soils having different textures are 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 aere measured at soil analysis laboratory.

The field capacity (FC) can be approximated by the empirical formula on soil composition [14].

$$FC = 25.1 - 0.21 (\% \text{ Sand}) + 0.22 (\% \text{ Clay})$$

Wilting coefficient (Wp) and transition point (Wt) are calculated by using the Wang and Schmutge model [15].

$$W_p = 0.06774 - 0.00064(\% \text{ Sand}) + 0.00478 (\% \text{ Clay})$$

$$W_t = 0.49 W_p + 0.165$$

The complex dielectric constant is calculated using the relation

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

The two point method described by Altschuler [16] is used for the measurement of dielectric constant (ϵ') and dielectric loss (ϵ'').

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

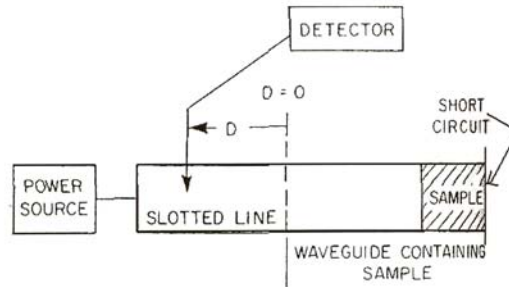


Fig. (1): Two Point Method of Measuring Dielectric Constant

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 connect 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 (1). Note r , the VSWR in the slotted line. Repeat the same procedure for soil sample of different length sample lengths $l_{1\epsilon}$ and $l_{2\epsilon}$.

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

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

where $\phi = 2k(D - D_R - l_\epsilon)$

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

solve the complex transcendental equation for T and τ to get conductance (G_ϵ) and susceptance (B_ϵ)

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

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

$$\epsilon' = \frac{G_{\epsilon} + \left[\frac{\lambda_g}{2a} \right]^2}{1 + \left[\frac{\lambda_g}{2a} \right]^2} \quad \text{and} \quad \epsilon'' = \frac{-B_{\epsilon}}{1 + \left[\frac{\lambda_g}{2a} \right]^2}$$

The block diagram of microwave experimental setup for measurement of dielectric properties is shown in Fig. (2). The experimental set-up consist of a reflex klystron KPS151 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.

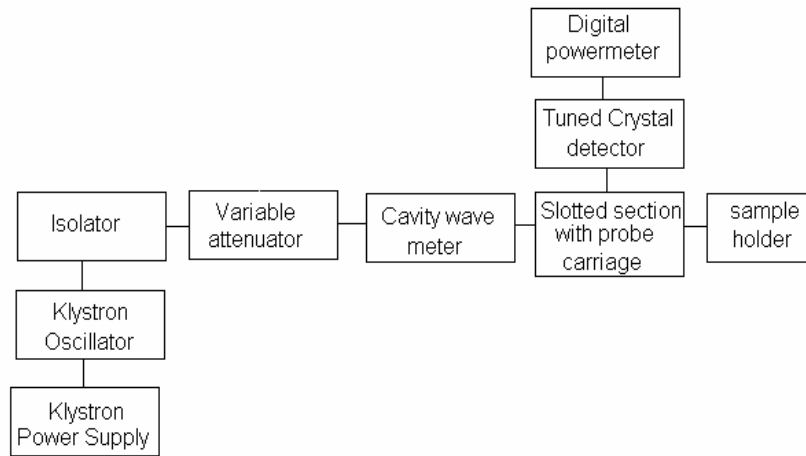


Fig. (2): Block diagram of experimental setup for measurement of dielectric properties.

The values of dielectric constant and dielectric loss are used to determine a.c electrical conductivity, relaxation time and tangent loss using the relation.

$$\sigma = \omega \epsilon_0 \epsilon'', \quad \tau = \frac{\epsilon''}{\omega \epsilon'} \quad \text{and} \quad \tan \delta = \frac{\epsilon''}{\epsilon'}$$

where, ω is angular frequency,

($\omega = 2\pi f$; $f = 7.0$ GHz) and

ϵ_0 is permittivity of free space,

($\epsilon_0 = 8.85 \times 10^{-12}$ F/m)

Results and Discussion

The physical properties of soil samples are listed in Table 1. The locations and physical parameters of these soils are reported in Table 2. Chemical properties of soil samples are given in Table 3.

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 1: Physical Properties of Soil Samples¹³.

Soil Sample	Location		FC	Wp	Wt
	Latitude	Longitude			
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 2: Location and Physical Parameters of Soils¹³.

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

Table 3: Chemical Properties of Soil Samples¹³.

The variations in the values of dielectric constant and dielectric loss with percentage calcium carbonate are measured and plotted in figures 3 and 4 for four soils with different physico-chemical properties respectively. The variation of dielectric constant for clay soils (Soil I and IV) is similar in nature and also that for clay loam soils (Soil II and III) are similar in nature. It is obvious that the dielectric constant and dielectric loss of soils varies abruptly with calcium carbonate content. The variation of a.c. electrical conductivity and relaxation time with percentage increase in calcium carbonate are plotted in figure 5 and 6 respectively. The variation in tangent loss with calcium carbonate for these soils is shown in figure 7. The dielectric loss is proportional to the a.c. electrical conductivity (σ), relaxation time (τ) and tangent loss ($\tan\delta$). This proportionality can be observed from nature of graphs of all these properties. The physical parameters viz. field capacity, wilting coefficient and transition point are determined from sand, silt and clay percentage of the soils. These physical parameters along with

physico-chemical and dielectric properties can be used to make a database. Such database may be useful for researchers working in field of remote sensing and agriculture. These results are in good agreement with earlier reported work.

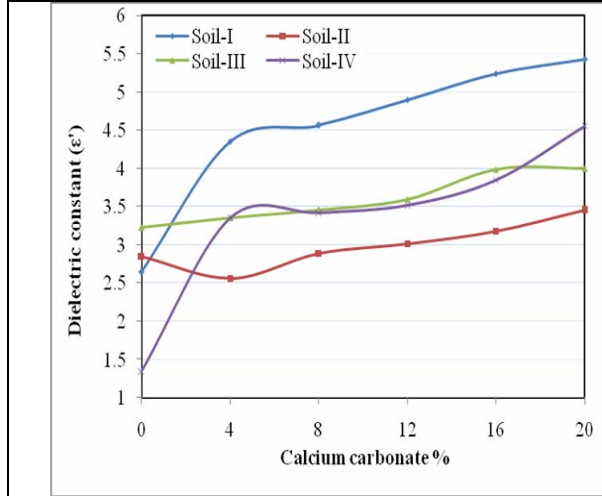


Fig. (3): Variation of dielectric constant with percentage calcium carbonate for soils.

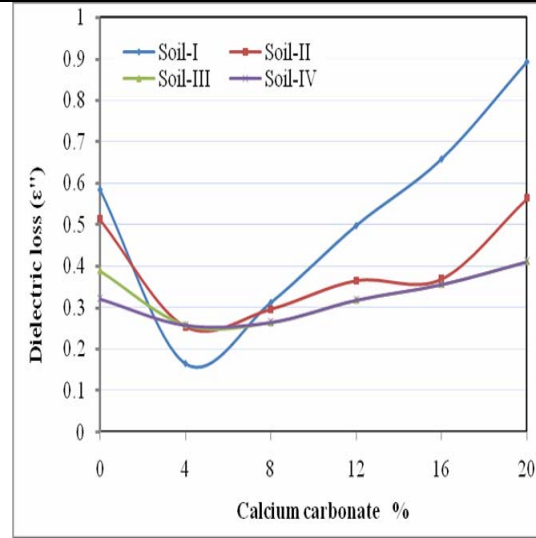


Fig. (4): Variation of dielectric loss with percentage calcium carbonate for soils.

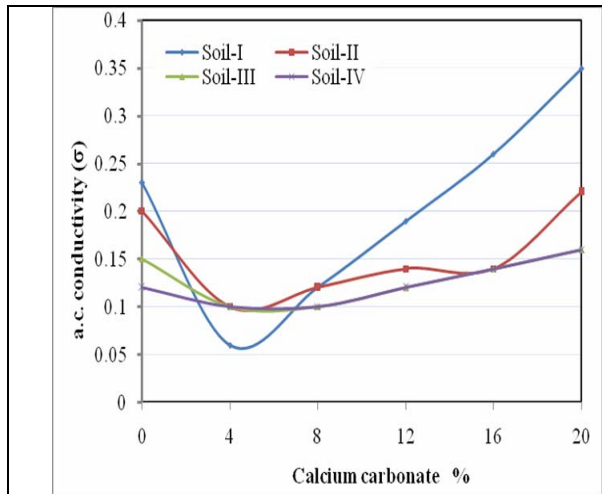


Fig. (5): Variation of a.c. electrical conductivity with percentage calcium carbonate for soils.

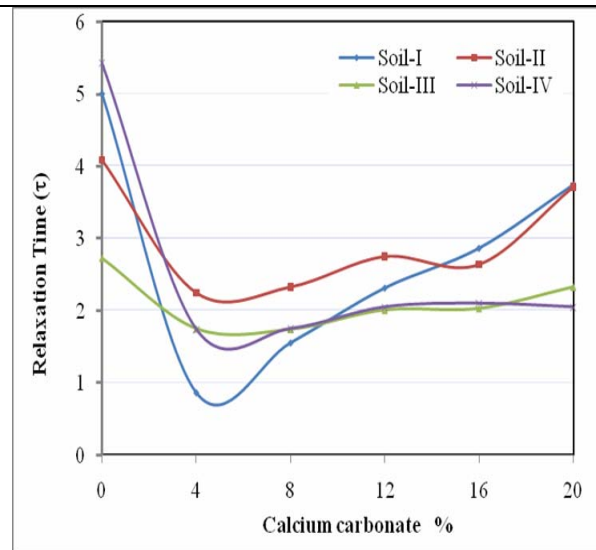


Fig. (6): Variation of relaxation time with percentage calcium carbonate for soils

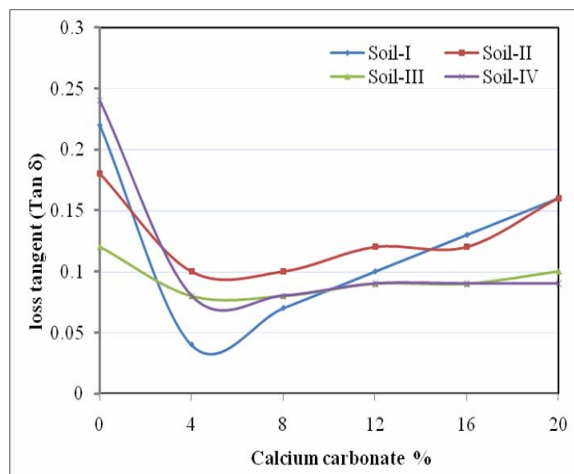


Fig. (7): Variation of loss tangent with percentage calcium carbonate for soils.

Conclusions

Physical and Chemical properties show remarkable variation in dielectric properties. Inorganic 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. The physical, chemical properties creates remarkable variation in dielectric properties, however more experimental work is required to interpret the effect of individual constituent on these properties. These parameters are useful to prepare soil health card which may be further used to determine the soil fertility.

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