Dielectric Properties of Soils with Inorganic Matter at S-Band Microwave Frequency

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Abstract

An *attempt has been made to study the effect of inorganic matter on the dielectric properties of soil, at microwave frequency. Dielectric constant (ε') and dielectric loss (ε'') of different soils with increasing percentage of inorganic matter (calcium carbonate) are measured with S-band setup at 3.0 GHz. These measurements are carried out using Infinite sample method at room temperature. The value of dielectric constant (ε') and dielectric loss (ε'') increases with increase in percentage of calcium carbonate in soils. This data is used to determine the electrical conductivity and relaxation time. The result shows the remarkable variations in electrical properties of soils with addition of calcium carbonate. The measured values of dielectric properties of soils are in good agreement with earlier reported work. These parameters are useful for researchers working in the field of agriculture.*

Keywords: Microwave S-band**,** Dielectric constant, Dielectric loss, conductivity, Relaxation Time, calcium carbonate.

Introduction

The soil has physical, chemical and electrical properties. The physical properties of the soil are its colour, texture etc. The chemical properties are its naturally available nutrients, organic matter, inorganic matter etc. The electrical properties include dielectric constant, dielectric loss, electrical conductivity, permeability etc.

Dielectric properties of soil are the parameters of natural, artificially created electrical fields in soils and influenced by distribution of mobile electrical charges, mostly inorganic ions, in soils. Distributions of electrical charges and properties in various soil profiles are results of the soil-forming processes. Soil properties influencing the density of mobile electrical charges are related with electrical resistivity and potential based on Boltzmann's law of statistical thermodynamics. When the electromagnetic waves interact with the soil, from the reflected wave we can give away the basic information, which will be useful for the microwave remote sensing. The dielectric properties of soil are function of its chemical constituents and physical properties**.** In a non-homogeneous medium such as soil, the dielectric constant is combination of individual dielectric constant of its constituents such as sand, silt, clay, organic and inorganic matter etc. Different studies predict that the dielectric properties of soil at microwave frequencies are the function of its physico-chemical constituents[1-5].

A comprehensive study of complex permittivity of soils of Maharashtra and Karnataka state has been undertaken. The dielectric properties of black and red soil collected from different locations of Karnataka state as a function of its moisture content are repored[6]. Dielectric properties of different soils with varied moisture content collected from various locations of Maharashtra state using X-band are studied[7]. Navarkhele et al reported the dielectric properties of black soil with increasing organic and inorganic matter content at different microwave frequencies with help microwave bench[8]. They have reported the values of dielectric constant and dielectric loss for varied organic and inorganic matters at four different frequencies. The decrease in values of dielectric constant and dielectric loss with increase in frequency is also reported. Gadani et al have studied the effect of saline water on the emissivity of different soils with C-band microwave frequency[9]. Variation of dielectric constant of dry soils with their physical constituents and naturally available nutrients with the particular soil samples at C-band microwave frequency is studied and the positive correlation between the dielectric constant with the available calcium carbonate is reported[10]. Dielectric properties of soils are studied with increasing percentage of humus content at S-band microwave frequency [11]. Microwave emissivity of soils using a dielectric model at different organic matter levels for a range of soil moisture values is studied[12]. The estimation of dielectric properties from the texture of soils is given[13]. Yadav et al reported the dielectric behavior of fertilized soil at microwave frequency [14]. Yadav et al reported dielectric parameters of mixture of fertilizers and water at wide range of frequency for different temperatures[15].

In the present work, the experimentally determined values of the dielectric constant and dielectric loss for soils with increasing calcium carbonate are reported. These values are used to estimate the a.c. electrical conductivity and relaxation time.

Materials and Methods

Soils are a mixture of minerals, rocks and dead, decaying plants and animals. Soil content, in proportion, may be differ from one location to another. Typically soil consists of organic and inorganic materials, water and air. The inorganic materials are the rocks that have been broken down into smaller pieces. The size of the pieces varies. It may appear as pebbles, gravel or as small as particles of sand or clay. The organic material is decaying living matter. It could be dead plants or animals and decay until they become part of the soil. The amount of water in the soil is linked with the climate and other characteristics of the region. The amount of water in the soil is one thing that can affect the amount of air. The composition of the soil affects the plants growth.

Soils with different texture are collected from various locations of agricultural areas. The soil sample taken for present study belongs to the Marathwada region of Maharashtra state. The soil samples are collected from the Godavari river basin. The soil from this region is mostly black. Physical and Chemical properties of the soil are measured at Soil analysis laboratory. The textural composition is reported by the methods of sieving and sedimentation of the soil. The soil type is obtained from the soil triangle.

Large numbers of soil samples with different texture are collected. The soils are oven dried and crushed to make fine powder. Dielectric properties of dry soil and the soil with varied calcium carbonate in percentage, ranging from 0 % to 10 % are measured. All the measurements were made at room temperature. The 0% calcium carbonate means naturally available value of calcium carbonate.

The field capacity (FC) can be approximated by the empirical formula on soil composition[16].

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

Wilting coefficient (Wp) and transition point (Wt) are calculated by using the Wang and Schmugge model[17].

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

$$Wt = 0.49\ Wp + 0.165$$

Table 1 : The Physical and Chemical properties of the soils.

Soil type /Parameters	Physical parameters						Chemical properties				
	Sand %	Silt %	Clay %	FC	Wp	Wt	organic carbon (%)	$CaCa_3$ %	Ca %	Mg %	Na %
Clay	20.9	32.9	46.2	30.88	0.28	0.30	0.37	0.25	29.18	21.35	1.43
Silty Clay Loam	16.7	50.7	32.6	32.96	0.30	0.23	0.53	0.50	29.14	19.71	0.44

Infinite sample method is used for the measurement of dielectric constant and dielectric loss[18]. The S-band microwave bench operating at a fixed frequency 3 GHz with slotted section is used for measurement of VSWR and the shift of minima. The complex dielectric constant is obtained using the relation

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

$$\varepsilon^* = \frac{1}{1+\left[\frac{\lambda_c}{\lambda_g}\right]^2} + \frac{1}{1+\left[\frac{\lambda_g}{\lambda_c}\right]^2}\left[\frac{r - j\tan[k(D-D_R)]}{1 - jr\tan[k(D-D_R)]}\right]^2$$

Separating the real (ε') and imaginary (ε'') part of dielectric constant from above equation, the dielectric constant (ε') is given by

$$\varepsilon' = \frac{1}{1+\left[\frac{\lambda_c}{\lambda_g}\right]^2} + \frac{\left[\frac{\lambda_c}{\lambda_g}\right]^2}{1+\left[\frac{\lambda_c}{\lambda_g}\right]^2}\left[\frac{\left(r^{2-}E^2\right)\left(1-r^2E^2\right)+\left(2rE\right)^2}{\left(1-r^2E^2\right)+\left(2rE\right)^2}\right]$$

and dielectric loss (ε”) is given by

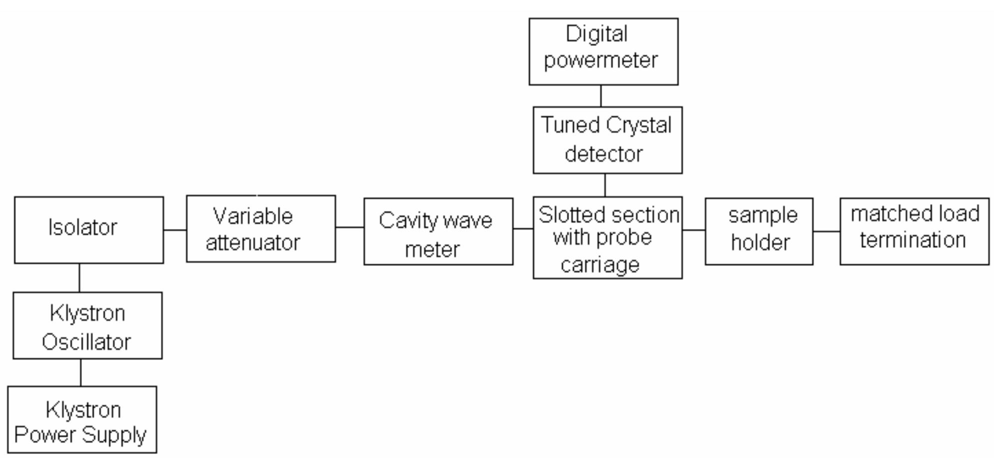
$$\varepsilon'' = \frac{\left[\frac{\lambda_c}{\lambda_g}\right]^2}{1+\left[\frac{\lambda_c}{\lambda_g}\right]^2}\left[\frac{2rE\left(\left(1-r^2E^2\right)-\left(r^2-E^2\right)\right)}{\left(1-r^2E^2\right)^2+\left(2rE\right)^2}\right]$$

where $E = \tan [k(D-D_R)]$

and λ_c, λ_g and k are cut-off wavelength, guide wavelength and wave vector respectively, r is voltage standing wave ratio (VSWR) and D & D_R are the positions of first minima with and without sample respectively. The soil was filled and pressed manually in 50 cm long wave-guide. The wave-guide was terminated with matched load. The measurements of D, D_R and λ_g were made using a slotted line. For measurement of VSWR, double minimum power method is used.

The experimental set-up consist of a reflex klystron, as the microwave source and frequency range 2.60 - 3.95 GHz. A broadband isolator is used to avoid the interference between source and reflected signals, with maximum isolation of 18 dB and insertion loss of 1.0 dB. A variable attenuator, to control the power at desired level, follows isolator. A transmission type cavity wave meter with high Q-factor is used to measure frequency of the microwave. The diode detector with square law characteristics is employed to detect the microwave power. For accurate measurements of minima and VSWR, the probe carriage was equipped with a dial gauge which has 1 mm range with 0.001 mm scale divisions.

The block diagram of the experimental arrangement is shown.



The values of dielectric constant and dielectric loss are used to estimate the a.c electrical conductivity and relaxation time using the relation[6]

$$\sigma = \omega\varepsilon_0\varepsilon'' \qquad \text{and} \qquad \tau = \frac{\varepsilon''}{\omega\varepsilon'}$$

where, ω is angular frequency, ($\omega = 2\pi f$; f = 3.0 GHz)

and ε_0 is permittivity of free space, ($\varepsilon_0 = 8.85 \times 10^{-12}$ F/m

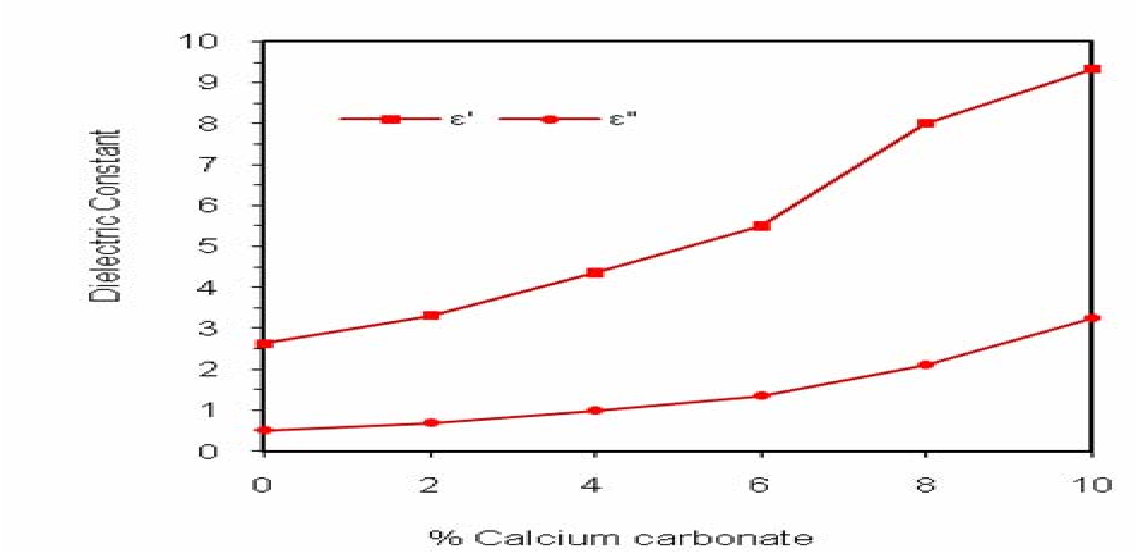


Fig.1: Variation of Dielectric constant and Dielectric loss with percentage calcium carbonate content in Clay Soil.

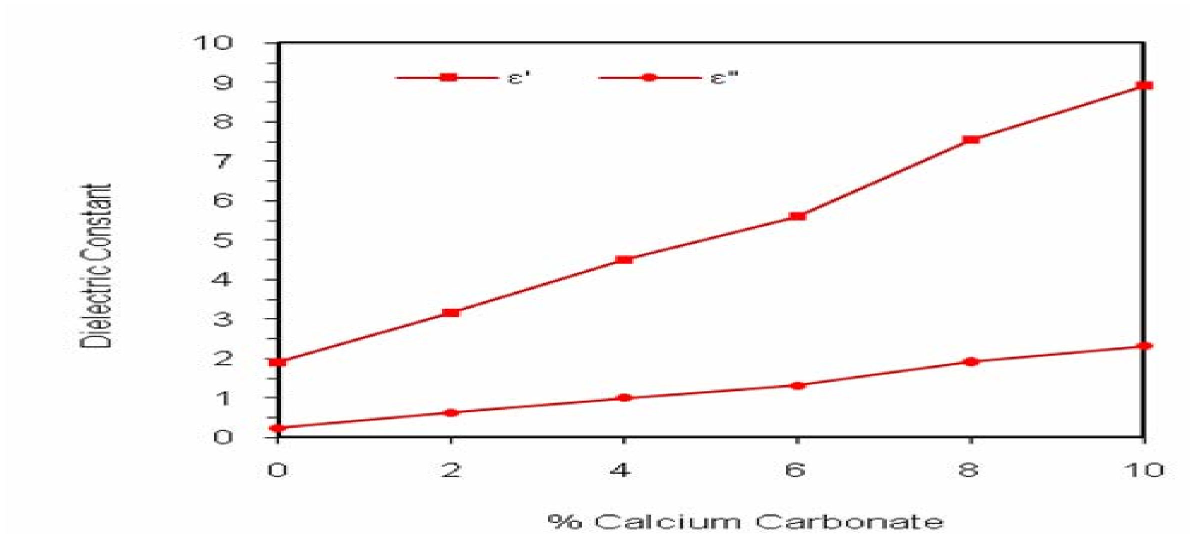


Fig.2: Variation of Dielectric constant and Dielectric loss with percentage calcium carbonate content in Silty Clay loam Soil.

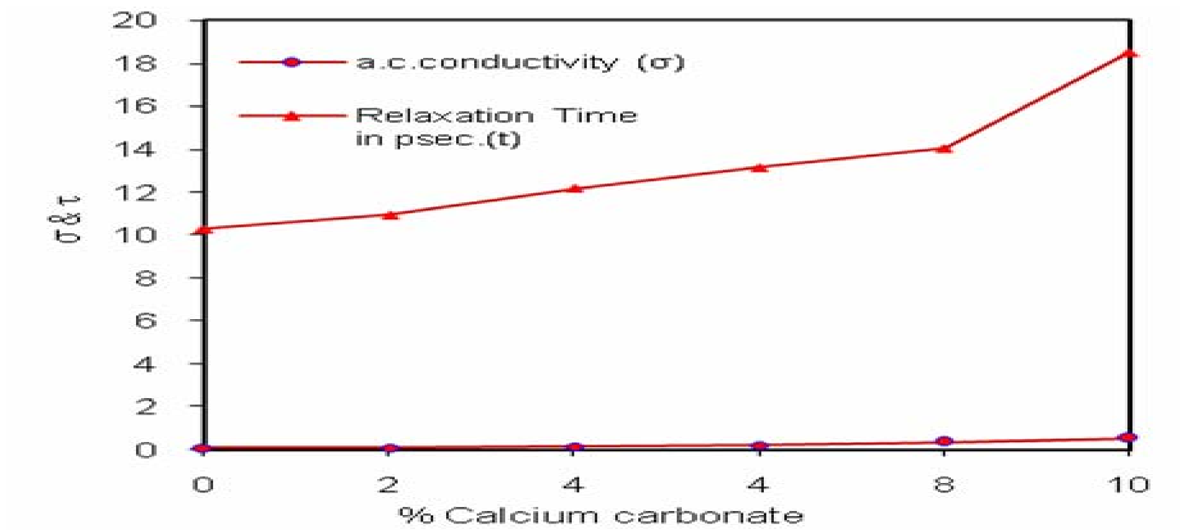


Fig.3: Variation of conductivity and Relaxation time with percentage calcium carbonate content in Clay Soil.

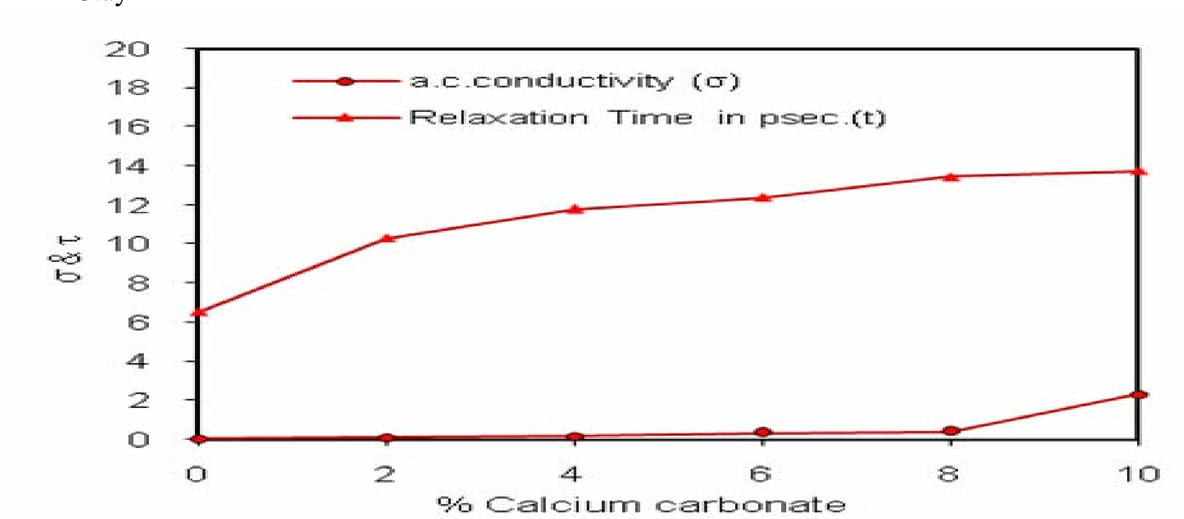


Fig.4 : Variation of conductivity and Relaxation time with percentage calcium carbonate content in Silty Clay loam Soil.

Results and Discussion

The variations in the values of dielectric constant and dielectric loss with increasing percentage of calcium carbonate have been measured and are plotted (Fig.1 and 2), for Clay and Silty clay loam respectively. Similarly, the electrical conductivity and relaxation time with variation of percentage calcium carbonate are plotted (Fig.3 and 4). It is obvious that the dielectric constant of the soils increase with addition of calcium carbonate. From this study, it is observed that the relation between the dielectric constant and the percentage calcium carbonate is non-linear. The variation of dielectric loss with calcium carbonate is almost similar for both clay and silty clay loam soils. This means the attenuation of energy is same in both soils. The a.c. electrical conductivity (σ) and relaxation time (τ) shows abrupt change with increase in calcium carbonate. The dielectric loss is proportional to the a.c. electrical conductivity. These results are in good agreement with the work reported by other researchers[8,10,14].

Conclusions

The naturally available macronutrients of soil show variation in dielectric properties. Inorganic matter in soil appreciably affects its dielectric properties. These dielectric parameters are useful for researchers working in the field of agriculture. From these we can estimate emissivity and scattering coefficient that will provide tools for designing the sensors.

Acknowledgement

Author thanks Principal B.U.Jadhav, Shri. Shivaji College, Parbhani for providing laboratory facility.

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ISSN:2319-6602
International Journal of Chemical and Physical Sciences

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