

Dielectric properties of dry and wet soils at X-band microwave frequency

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ABSTRACT

Interaction of electromagnetic waves with the materials of planet earth provides the information for microwave remote sensing. From the reflected wave it is possible to reveal the information, which is useful for the measurement of dielectric properties. The dielectric properties of material are function of its chemical constituents and physical properties. Measurements of real (ϵ') and imaginary (ϵ'') parts of the complex dielectric constant (ϵ^*) of soil with varied moisture content were made at 9.85 GHz. The X-band microwave setup in the TE_{10} mode with slotted section and a crystal detector is used for measurements. Infinite sample method is found suitable for measurement of these soils. The measurements are made at room temperature. The dielectric properties of dry soil samples are in good agreement with the earlier work. The value of ϵ' and ϵ'' first increases slowly and then increase rapidly with moisture content. From this data, the a.c. conductivity and relaxation time are also reported. The result shows the change in electrical properties of dry and moisture-laden soils. These results provide a basis for using high-frequency electromagnetic sensors in the detection of soil moisture content or in ground-penetrating radar.

Key words: Dielectric constant, dielectric loss, conductivity, relaxation time.

INTRODUCTION

Over last decades, Microwave remote sensing became the emerging field for the study of natural resources. It emphasizes the interaction of electromagnetic waves with the materials under study. The study of dielectric properties of different earth constituents at microwave frequencies plays a vital role as they provide interpretation of various remote sensing data. Dielectric properties are primarily a function of frequency, water saturation, porosity, texture, component geometry and electrochemical interactions. Dielectric dispersion in low frequency region is helpful to understand the behaviors of induced polarization in the materials, while high frequency dielectric measurements are useful in planning ground penetrating radar survey (Sengwa, 2005). Many researchers working with this aspect, studied dielectric properties of different materials with various methods. Study of dielectric

properties of different soil textures collected from Bidar region of Karnataka state, at X-band microwave frequency using Infinite sample method has been studied (Chaudhari *et al.*, 2007). The dielectric properties of soil collected from different regions of Uttarpradesh has been studied at X-band microwave frequency using Infinite sample method. (Srivastava *et al.*, 2004). Dielectric constant of soil is function of moisture content is studied. (Narasimha Rao *et al.*, 1990). Microwave emission depends upon the dielectric constant of the soil (Calla *et al.*, 2004). The dielectric constant of red soil in frequency range 12 GHz to 18 GHz has been studied. (Puri *et al.*, 2004). Microwave transmission and reflection of moisture-laden brown and black soil using Ku-Band is also reported (Puri *et al.*, 2005). Laboratory measured dielectric property data and related electromagnetic wave propagation parameters (Curtis J.O., 1998, 2001) for a broad range of soil texture and the variation of

dielectric permittivity and conductivity as functions of moisture content is studied. The dielectric constant of soil samples from Uttar Pradesh and Kashmir are measured at different frequencies in the range 8 GHz -10 GHz using waveguide cell method and variation of dielectric constant with frequency is reported (Calla *et al.*, 2005) Also a model for estimation of dielectric constant is developed. The variation of dielectric constant of dry soil with its physical constituents is reported by Calla *et al.* (Calla *et al.*, 2005) for this study number of soil samples were collected from northern India. The measurements done using waveguide cell method at X-band microwave frequency are used to develop a model named as CVCG model. This can be used to compute the dielectric constant from known soil texture. Measurements of dielectric constant and conductivity of soil samples contaminated by diesel oil in the frequency range 2-250 MHz were reported (Darayan *et al.*, 1998). The measurement of dielectric constant and tangent loss of some Indian clay minerals (Mahan *et al.*, 1980) at microwave frequency are reported. Conductivity and relaxation time for metal powders collected from mines of Chattisgarh are determined from the parameters measured using X-band microwave frequency (Srivastava *et al.*, 2004). The vector network analyzer is used for the measurement of dielectric constant. (Logsdon *et al.*, 2005). On this basis, the present study has been undertaken to have an idea of electrical properties of different soil texture of the Bidar region of Karnataka State. In this paper, the experimentally determined values of the real and imaginary parts of the complex dielectric constant have been shown for red and black soils under study at different moisture content. These parameters are used to determine the a.c. electrical conductivity and relaxation time.

MATERIAL AND METHODS

The infinite sample method described by Altshuler is used for the measurements of dielectric properties. An X-band microwave bench operating at 9.85 GHz in the TE₁₀ mode with slotted section and a crystal detector used for measurement of VSWR and the shift of minima is needed in this technique. The complex dielectric constant is calculated using the relation

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

...(1)

Where λ_c , λ_g and k cut-off wavelength, guide wavelength and wave vector respectively, r is voltage standing wave ratio (VSWR) and D and D_R are the positions of first minima with and without sample respectively. The samples were filled and pressed manually in 40 cm long wave-guide, which was terminated with matched load. The measurements of D , D_R and λ_g were made using a slotted line. The VSWR was determined using double minimum power method. The soil sample taken for present study belongs to the Nanded region of Karnataka state. Samples were collected from both irrigated and non-irrigated areas of the state. The Physical & Chemical properties of the soil were measured at Soil analysis laboratory; Department of Agriculture, Govt. of Maharashtra situated at Parbhani. Eight samples of various soil textures having different physical and chemical properties are used for study. The gravimetric soil moisture content in percentage $W_c(\%)$ is calculated using wet (W_1) and dry (W_2) soil masses using the following relation.

$$W_c(\%) = \frac{W_1 - W_2}{W_2} \times 100 \quad \dots(2)$$

Measurements have been carried out at 9.85 GHz. The experimental set-up consist of a 2K25 reflex klystron as the microwave source, with maximum output power of 25 mW and frequency range 8.2-12.4 GHz. To avoid the interference between source and reflected signals, the source was connected with a broadband isolator with maximum isolation of 30 dB and insertion loss of 1.25 dB. To control the power at desired level, a variable attenuator is connected after the isolator. A resonance type frequency meter was used to measure frequency of the signal. The slotted line was employed to measure VSWR and distance. For accurate measurements of minima and VSWR, the

probe carriage was mounted with a dial gauge having least count one micron.

From the measurement of dielectric constant and dielectric loss, other electrical parameters can be obtained. (Srivastawa (2004), Barathan, (2006)).

$$\sigma = \omega \epsilon_0 \epsilon'' \quad \dots(3)$$

And

$$\dots(4)$$

where

ω is angular frequency, $f = 9.85$ GHz

ϵ_0 is permittivity of free space

RESULTS AND DISCUSSION

The Texture, Physical and Chemical properties of the samples under study are reported in table 1. The variations in the values of dielectric constant

and dielectric loss with percentage moisture content are measured and plotted in figures 1 and 2 for soil sample I and II respectively. Similarly, the a.c. electrical conductivity and relaxation time with variation of percentage moisture content are plotted in figure 3 and 4. It is obvious that the relative permittivity of the soils increase slowly with moisture content initially, this may be due to bi-phase dielectric behavior of water molecule in soil that have smaller permittivity values as compared to free water molecules below transition point and after reaching a transition point they increase rapidly. From this study, it is observed that the relation between the dielectric constant and the gravimetric water content is almost non-linear. This is because, for a composite material such as moist soil, the dielectric constant is not a simple function of the values for the individual components. The value of dielectric loss for sandy loam soil is more than that of loam soil, this may be due to higher value of partial density and higher percentage of organic carbon in sandy loam soil. The a.c. electrical conductivity (σ) and relaxation time (τ) shows a

Table 1: The Texture, Physical and Chemical properties of soil

Soil Sample	Texture	Sand %	Silt %	Clay %	W.H.C. %	Particle Density	Porosity
I	Sandy Loam	54.80	28.40	16.77	51.1	2.0	45.4
II	Loam	50.43	32.15	17.41	61.7	1.8	50.5
III	Clay Loam	27.68	33.59	38.73	45.6	2.2	45.9
IV	Clay Loam	22.08	44.38	33.94	58.0	2.0	49.5
V	Clay	13.69	39.78	46.60	55.3	2.3	53.1
VI	Clay	12.28	39.98	47.74	67.3	1.8	51.0
VII	Slity Clay Loam	16.66	52.09	31.25	57.5	1.9	50.0
VIII	Slity Clay	2.95	45.28	51.17	51.3	2.2	50.0

Soil sample	pH	E.C. mS/cm	Organic Carbon %	Ca %	Mg %	Na %	CaCO ₃ %
I	8.4600	0.2700	0.6400	37.5300	36.1000	0.5300	5.0000
II	8.6200	0.2700	0.5000	43.3800	31.2400	0.9700	8.1200
III	8.9300	0.1600	0.6300	33.3600	34.6600	0.4000	5.5000
IV	8.7100	0.2800	0.5100	33.3600	23.0000	0.8100	6.6200
V	8.5100	0.2200	0.5500	43.8700	32.8900	0.5100	6.2500
VI	7.9200	5.2600	1.1500	31.2700	23.0000	3.3300	11.7500
VII	7.1200	1.6000	0.5300	29.8900	19.7300	0.4900	3.2500
VIII	8.6000	0.1900	0.4800	25.0200	16.4400	0.6600	3.6200

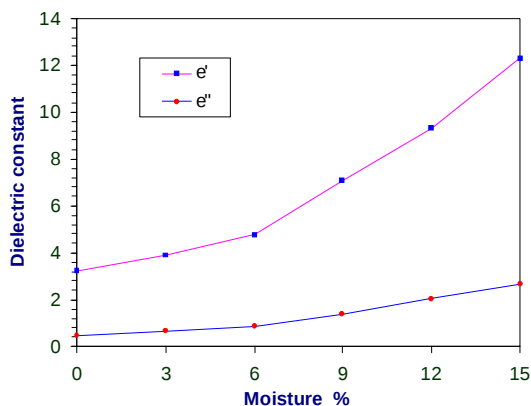
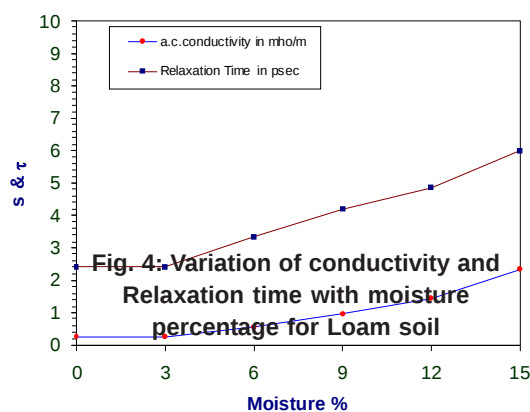


Fig. 1: Variation of Dielectric constant and Dielectric loss with moisture content for Sandy Loam soil

Fig. 2: Variation of Dielectric constant and Dielectric loss with moisture content for Loam soil.

Fig. 3: Variation of conductivity and Relaxation time with moisture percentage for Sandy Loam soil



The increase in dielectric loss with moisture for loam soil is more than of sandy loam soil, this may be due to higher percentage of Na in loam soil. These results are in good agreement with the earlier reported work.

CONCLUSIONS

Moisture in soil significantly affects the dielectric properties of soil. Physical and chemical properties show remarkable variation in dielectric properties. This is because, for a composite material such as moist soil, the dielectric constant is not a

systematic change with increase in moisture content. According to Debye, when polar molecules are very large, then under the influence of electromagnetic field of high frequency, the rotary motion of the polar molecules of a system is not sufficiently rapid to attain an equilibrium with the field. The polarization then acquires a component out of phase with the field and the displacement current acquires conductance dissipation energy. Thus, the dielectric loss is proportional to the a.c. conductivity. The increase in relaxation time due to increase in moisture content is due to increasing hindrance to the process of polarization.

simple function of the values for the individual components. The value of dielectric loss for sandy loam soil is more than that of loam soil, this may be due to higher value of partial density and higher percentage of organic carbon in sandy loam soil. The laboratory studies of dielectric properties of soils with varied moisture as well as other physical and chemical properties with actual field conditions are very useful in correlating the data recorded by remote sensing technique. The a. c. electrical conductivity and relaxation time depend upon the dielectric loss, which represents attenuation and dispersion. The increase in relaxation time due to increase in moisture content is due to increasing hindrance to the process of polarization. The increase in dielectric loss with moisture for loam soil is more than of sandy loam soil, this may be due to higher percentage of Na in loam soil. Since

a dielectric property of soil determines the properties like emissivity, scattering coefficient etc. The correlation between dielectric properties and the radar detected properties provide the basis for remote sensing. Also these values can be used for passive and active sensors in microwave remote sensing. The soil health and soil fertility can be predicted from more database.

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