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Study on Correlation Coefficient of A. C. Conductivity and Relaxation Time of Soils with Moisture Content at 5.3 Ghz

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ABSTRACT: An automated C-band microwave set-up in the TE_{10} mode with Gunn source operating at frequency 5.3 GHz is used for measuring dielectric properties of soils. Soil samples are collected from four different locations lying in the Indore district of Madhya Pradesh state (India). The parameters such as a. c. electrical conductivity (σ), and relaxation time (τ) of soil are determined from the experimentally measured values of complex dielectric constants of soils. Statistical correlation coefficient of a. c. conductivity and relaxation time of soils with moisture content for these soil samples are reported. For all the soil samples, the dielectric constant (ε') and dielectric loss (ε") in general, are found to increase with increase in percentage gravimetric Moisture Content (MC %). Further, our results give high degree positive and relatively small negative correlation coefficient for a. c. conductivity and relaxation time respectively with MC (%) for all the four soil samples studied.

KEYWORDS: Soil, Dielectric constant, Dielectric loss, a. c. conductivity, Relaxation time, correlation coefficient.

I. INTRODUCTION

Electrical Conductivity (EC) is a property of soil that is determined by standardized measures of soil conductance by the distance and cross sectional area through which a current travels. The movement of electrons through bulk soil is complex. Electrons may travel through soil water in macro pores, along the surfaces of soil minerals, and through alternating layers of particles and solution. Therefore, multiple factors contribute to soil EC variability, including factors that affect the amount of soil water, soil texture/structure, organic matter, electrolytes in soil water and types and quantity of minerals. Further, electrical conductivity of soil indicates the level of ability the soil water has to carry an electrical current and also gives indication of the amount of nutrients available for the crops to absorb [1-4]. Studies related with soil electrical conductivity as an indirect measurement that correlates very well with several soil physical, chemical and dielectric properties has been also reported [5,6].

Dielectric properties of soils mainly vary with moisture content, frequency and temperature. The measurements of dielectric constant of soils as a function of moisture content over wide microwave frequency range were carried out in the past by many investigators [7-14]. These investigators have used soils covering different parts all over world and with different texture/structures. Almost all these investigators have concluded that the dielectric constant of soils is strongly dependent on moisture content. It is because; the relaxation frequency of water lies in the microwave frequency region. Thus, when placed in the electromagnetic field, the dipolar relaxation of water molecules results in absorption of the microwave energy which can be used as a measure of soil moisture content [15,16]. Electric conduction and various polarization mechanisms contribute to the dielectric loss factor. The other electric parameter a. c. conductivity of soil is found to increase with the loss factor and also the frequency of the applied Electro-Magnetic (EM) field. In dielectric materials, the dielectric polarization depends upon the applied EM field and the nature of the material itself. If an EM field changes, the polarization relaxes towards a new equilibrium. Some of the investigators have determined a. c. electrical conductivity (σ), and relaxation time (τ) of soil from experimentally measured values of complex dielectric constants of soils at X-band frequency [17,18].

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In the present research work, experimental results on the correlation coefficient of a. c. conductivity and relaxation time of soils with moisture content at C-band frequency are presented. Four soil samples are collected from four different locations lying in the Indore district of Madhya Pradesh state (India). An automated C-band microwave set-up in the TE_{10} mode with Gunn source operating at frequency 5.3 GHz are used for measuring dielectric properties of these soils.

II. MATERIALS AND METHODS

Preparation of Soil Samples

Four soil samples (S1-S4) were collected from different locations lying in the western part of Indore district of Madhya Pradesh State. These top-soil samples (depth ranging 0-20cm) are first sieved by gyrator sieve shaker to remove the coarser particles. The sieved out fine particles are then oven dried to a temperature around 110^oC for several hours in order to completely remove any trace of moisture. Such dry sample is then called as dry base sample when compared with wet samples. Soil samples of desired gravimetric moisture contents are prepared by adding an exact amount of distilled water to the known mass of the oven dry soil.

Soil Physical and Chemical Properties

The soil analysis report of the samples, S1-S4 used in this study was obtained from Government Agricultural College, Pune (Maharashtra). **Table-1 and 2** show the physical and chemical properties of the soil samples respectively. All the soil samples are of blackish colour and have either loamy or sandy loam texture (**Table-1).** The bulk and particle densities of these soil samples have ranged from 1.34 to 1.44 Mg m^{-3} and from 2.57 to 2.68 Mg m^{-3} respectively and are found to lie within the normal specified range.

Table 1. Physical Parameter Analysis of Indore (M.P.) Soil Samples

Sample No.	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Textural class**	**Colour**	**Bulk Density Mg m^{-3}**	**Particle Density Mg m^{-3}**
1	41.75	40.25	18	Loam	Faint Black	1.34	2.57
2	52.0	32	16	Sandy Loam	Black	1.42	2.68
3	41.5	34.25	24.25	Loam	Faint Black	1.44	2.59
4	57.25	26.50	16.25	Sandy Loam	Black	1.39	2.63

From **Table-2,** we see that all the soils samples S1-S4 have alkaline nature and their EC values lie in the normal range. According to Methods Manual, Soil Testing in India [19], the critical limits of (N), (P) and (K) for normal growth of plant are 280 kg/ha, 10 kg/ha and 108 kg/ha respectively. Comparing our data with these critical limits show very low values of available N (88-113 kg/ha), medium to very high values for P (16.63 – 74.02 kg/ha), while the available K (213-704 kg/ha) values are moderate to very high. The organic carbon (OC) values for these soil samples have ranged from 1.40 to 1.67% . These values are found to be very high when compared with their normal specified range.

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Table 2. Chemical Analysis of Indore (M.P.) Soil Samples

Sample No.	**pH (1: 2.5)**	**E.C. (dSm^{-1})**	**Available Nitrogen ($kgha^{-1}$)**	**Available Phosphorus ($kgha^{-1}$)**	**Available Potassium ($kgha^{-1}$)**	**Organic Carbon (%)**
1	7.8	0.13	113.0	37.15	366.0	1.45
	Mildly alkaline	Normal	Very low	Very High	Very High	Very high
2	7.8	0.12	88.0	48.51	704.0	1.40
	Mildly alkaline	Normal	Very low	Very High	Very High	Very high
3	7.9	0.09	88.0	16.63	213.0	1.59
	Moderately alkaline	Normal	Very low	Medium	Moderately High	Very high
4	8.0	0.12	113.0	74.02	515.0	1.67
	Moderately alkaline	Normal	Very low	Very High	Very High	Very high

Method of Measurement of Dielectric Properties

The waveguide cell method is used to determine the dielectric properties of soil samples. An automated C-band microwave set-up in the TE_{10} mode with Gunn source operating at frequency 5.3 GHz, PC-based slotted line control and data acquisition system is used for this purpose. The solid dielectric cell with soil sample is connected to the opposite end of the source. The signal generated from the microwave source is allowed to incident on the soil sample. The sample reflects part of the incident signal from its front surface. The reflected wave combined with incident wave to give a standing wave pattern. These standing wave patterns are then used in determining the values of shift in minima resulted due to before and after inserting the sample. Experiments were performed at room temperatures ranged between 25^o-30^o C. The dielectric constant ε' and dielectric loss ε'' of the soils are then determined by using equations (1) and (2)

$$\varepsilon' = \frac{g_\varepsilon + (\lambda_{gs}/2a)^2}{1 + (\lambda_{gs}/2a)^2} \qquad (1)$$

$$\varepsilon'' = -\frac{\beta_\varepsilon}{1 + (\lambda_{gs}/2a)^2} \qquad (2)$$

From the measured values of dielectric constant (ε'), dielectric loss (ε''), other electric parameters such as a. c. conductivity, and relaxation time can be obtained by using equations (3) and (4)

$$\sigma = \omega \varepsilon_o \varepsilon'' \qquad (3)$$
$$\tau = \varepsilon'' / \omega \varepsilon' \qquad (4)$$

Where, a = Inner width of rectangular waveguide.

λ_{gs} = wavelength in the air-filled guide.

g_ε = real part of the admittance

β_ε = imaginary part of the admittance

ω = $2\pi f$ = angular frequency, f = 5.3 GHz

ε_o = permittivity of free space.

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III. RESULTS AND DISCUSSION

Our results on the dielectric constant (ε'), dielectric loss (ε''), a. c. conductivity (σ) and relaxation time (τ) of four soil samples and their variations with gravimetric MC(%) and at microwave frequency (5.3 GHz) are summarized in Table 3 and Fig. 1 (a) - (d). Experiments are performed for MC variations ranging from 0% (dry-base) to 30 %.

Table 3 : Variation of Dielectric Constant, ε' and loss ε'' With Moisture Contents at Microwave Frequency 5.3 GHz.

MC (%)	Sample 1		Sample 2		Sample 3		Sample 4	
	ε'	ε''	ε'	ε''	ε'	ε''	ε'	ε''
0	3	0.07	3.15	0.072	2.85	0.06	3	0.085
5	4.2	0.21	4.3	0.2	3.9	0.17	4.3	0.21
10	8.1	0.38	8.2	0.35	7.7	0.26	7.1	0.38
15	15.2	0.4	14.7	0.38	15	0.32	14.9	0.43
20	21.5	0.45	20	0.4	21.6	0.37	20	0.46
25	22	0.47	20.8	0.43	21.6	0.41	20.1	0.48
30	22.1	0.48	20.9	0.47	21.3	0.39	20.3	0.5

Table 3 shows the variations of dielectric constant (ε') and loss with different gravimetric MC for soil samples (S1-S4). For these samples, the ε', in general, is found to increase with increase in percentage MC. However, this variation is nonlinear and rate of increase is relatively more for MC values from 10% to 20%. For samples S1-S4, the values of ε' ranges from 3 to 22.1, 3.15 to 20.9, 2.85 to 21.3, and 3 to 20.3 respectively for gravimetric MC (%) changed from 0% to 30%. In a Similar manner, Table 3 also shows the variations of dielectric loss (ε'') with different gravimetric MC for soil samples (S1-S4). The ε'' is found to increase with increase in MC from 0% to 30 %. For samples S1-S4, the values of ε'' range from 0.07 to 0.48, 0.072 to 0.47, 0.06 to 0.39 and 0.085 to 0.5 respectively for gravimetric MC (%) changed from 0% to 30%. Our experimental results show fairly good agreement with those reported by earlier investigators [7,8,9,10,12,14,17].

Variation of a. c. conductivity (σ) and relaxation time (τ) of four soil samples with gravimetric MC are shown in Fig. 1 (a) - (d). The σ is found to increase with MC and the trends are almost similar for all soil samples S1-S4. But the trends of variations τ of all the four soil samples with gravimetric MC are exactly opposite to that for σ. The relaxation time is found

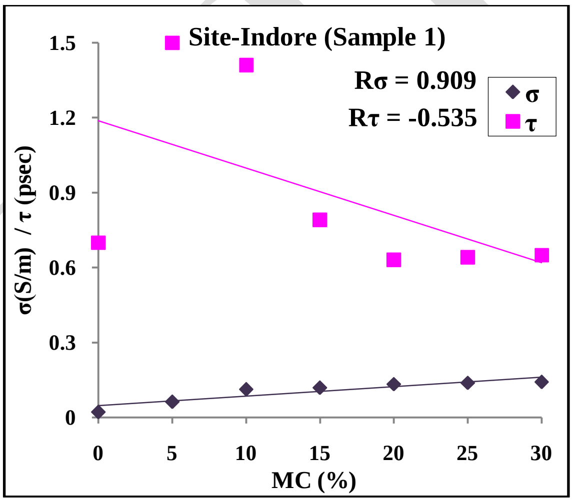

Fig. 1 (a)

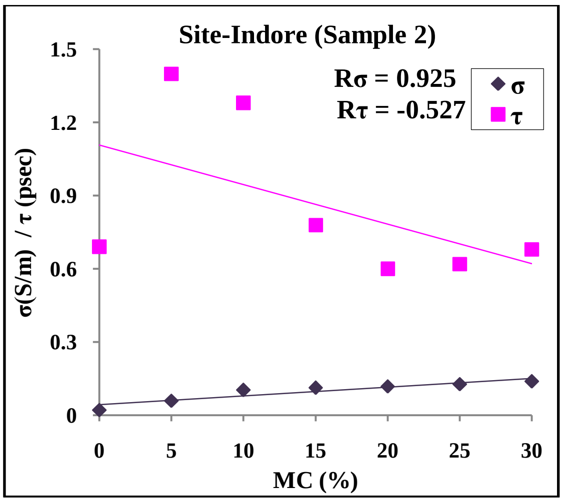

Fig. 1 (b)

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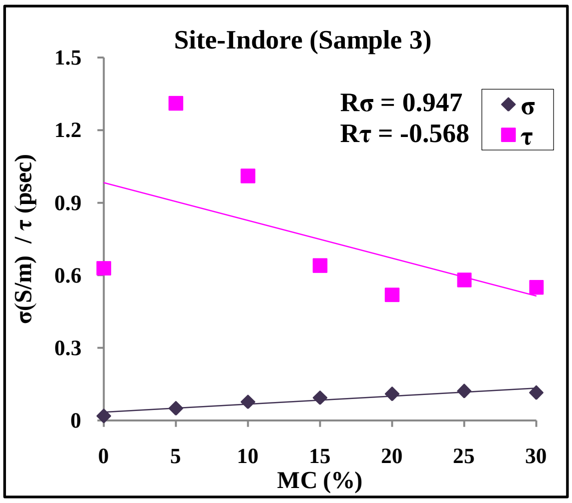

Fig. 1 (c)

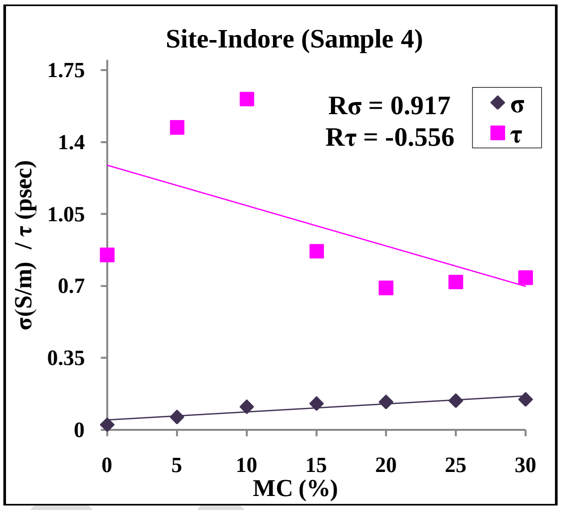

Fig. 1 (d)

Fig. 1 (a)-(d) Variation of a. c. conductivity and relaxation time with moisture content (%) for four soil samples (S1-S4) at 5.3 GHz.

to decrease with increase in MC and the trends are almost similar for all soil samples S1-S4. Our results shown in Fig. 1 (a) - (d) thus give high degree positive statistical correlation of σ with MC (%) for all the four soil samples studied. The values of correlation coefficients for a. c. conductivity (R_σ) range from 0.909 to 0.947 at C-band frequency 5.3 GHz and for MC (%) changed over 0% (dry-base) to 30 %. This result is expected, because the motion of charges in the dielectric (soil) gives rise to the conduction current and hence polarizes the dielectric. This dielectric polarization is thus found to increase with the MC level of soils. This shows that the conduction is by displacement current and therefore contributes to the dielectric attenuation/loss. Such dielectric studies of materials, thus is a powerful tool in assessing the structure and behavior of molecular materials [17,18]. Further, our results give moderate negative statistical correlation of τ with MC (%) for all the four soil samples. The values of correlation coefficients for relaxation time (R_τ) range from -0.527 to -0.568. This suggests that the mobility of the molecules (dipoles) of soils is found to increase with the MC level of soils. This result is expected, as τ is proportional to the dissipation factor (ε''/ ε'). Our results discussed here found in agreement with the experimental results of earlier investigators [18]. Molecular relaxation time is assumed to be due to the inner friction of the medium that hinders the rotation of the polar molecules. Therefore τ is also a function of MC.

IV. CONCLUSIONS

i) For all the four soil samples, the dielectric constant (ε') and dielectric loss (ε''), in general, are found to increase with increase in MC at C-band microwave frequency, 5.3 GHz. However, this variation is nonlinear and the trend is almost similar for all samples, except their relative magnitudes.

ii) Our results give high degree positive statistical correlation of a. c. conductivity (σ) with MC (%) for all the four soil samples studied. The values of correlation coefficients for a. c. conductivity (R_σ) range from 0.909 to 0.947 at C-band frequency 5.3 GHz.

iii) Our results give moderate negative statistical correlation of relaxation time (τ) with MC (%) for all the four soil samples. The values of correlation coefficients for relaxation time (R_τ) range from -0.527 to -0.568.

Such dielectric studies of soils, thus is a powerful tool in assessing the structure and behavior of molecular materials. Research of this kind enriches our knowledge of soil science. Besides this, data reported here may find uses in designing sensors for microwave remote sensing and also for the retrieval of soil moisture content from the remotely sensed satellite data.

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REFERENCES

[1] Papendick R. I. and Parr J. F., "Soil quality-the key to a sustainable agriculture", Amer. Journal of Alternative Agric., 7 (1,2), pp. 2-3, 1992.

[2] Martin C., Resources, Agriculture Solutions LIC, 2011.

[3] Malicki M. A. and Walczak R. T., "Evaluating soil salinity status from bulk electrical conductivity and permittivity", European Journal of Soil Sci., Vol. 50(3), pp. 505-514, 1999.

[4] Hilhorst M. A., "A pore water conductivity sensor", Soil Science Society of America Journal, Vol. 64(6), pp. 1922-1925, 2000.

[5] D.V.Ahire, P.R.Chaudhari, Vidya D. Ahire and A. A. Patil, **"**Correlations of electrical conductivity and dielectric constant with physico-chemical properties of black soils", International Journal of Scientific and Research Publications, Vol. 3(2), pp. 1-16, 2013.

[6] P. R. Chaudhari, D. V. Ahire, Manab Chkravarty and S. Maity, "Electrical Conductivity as a Tool for Determining the Physical Properties of Indian Soils", International Journal of Scientific and Research Publications, Vol. 4, Issue 4, pp .1-8, 2014.

[7] Srivastava S. K. and Mishra G. P., "Study of the characteristics of the soil of Chhattisgarh at X-band frequency", Sadhana , Vol. 29, issue 4, pp. 343-347, 2004.

[8] Calla O.P.N., Bohra D., Mishra S. K. Alam M., Hazarika D. and Ramawat L., "Effect of Microwave radiation on the electrical parameters of soil", Indian J. of Radio and Space Physics, 36, pp. 229-233, 2007.

[9] Alex Z. C. and Behari J., "Complex dielectric permittivity of soil as function of frequency, moisture and texture", Indian J. Pure and applied Physics., Vol. 34, pp. 319- 323, 1996.

[10] Hallikainen M. T., Ulaby F. T., Dobson M. C. and El-Rayes M. A., "Microwave Dielectric Behavior of Wet Soil-Part II: Dielectric Mixing Models", IEEE Transactions on Geoscience and Remote Sensing, 23(1), pp. 35-46, 1985b.

[11] Wang J. R., "The dielectric properties of soil-water mixtures at microwave frequencies", Radio Sci., 15, pp. 977-985, 1980.

[12] Alex Z. C., Behari J., Rufus E. and Karpagam A. V., 22nd Asian Conference on Remote Sensing, SISV, AARS, Singapore, 2001.

[13] Sami S., "Chemical and mineral composition of dust and its effect on the dielectric constant IEEE Transactions on Geoscience and Remote Sensing, 33(2), pp. 353- 359, 1995.

[14] Calla O. P. N., Baruah A., Das B., Mishra K. P., Kalita M. and Haque S. S., "Variability of dielectric constant of dry soil with its physical constituents at microwave frequencies and validation of the CVCG model", Indian J. of Radio and Space Physics, 33, pp. 125-129, 2004.

[15] James Baker-Jarvis, IEEE transaction on Dielectrics and Electrical Insulation, Vol. **7**, No. 3, pp. 374-386, 2000.

[16] Von Hippel, "The Dielectric Relaxation Spectra of Water, Iceand Aqueous Solution and their Interpretation", IEEE Transaction on Electrical Insulation, 23, pp. 801-816, 1988.

[17] Chaudhari H. C. and Shinde V. J., "Dielectric study of moisture laden soils at X-band microwave frequency", International Journal of physical Science, Vol. 3, issue 3, pp. 75-78, 2008.

[18] Yadav, V., Anil Kumar, A. Sharan, S. Sinha, A.K. Yadav, M. Gupta, V.K. and Jangid, R. A., "Measurement of dielectric behavior of fertilized soil at microwave frequency", Journal of Agricultural Science, Vol. 1 (2), pp. 42-49, 2009.

[19] Methods Manual, Soil Testing in India, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, 33, . 2011.