Study of Dielectric Behaviour of Soils at Microwave Frequency

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Abstract: Dielectric Behaviour (ε', ε") of soils has been observed at 9.45 GHz for various moisture content at a temperature of 27^0C. Samples are collected from different region of Rajasthan. Physical and Chemical properties of soil samples are also reported. The dielectric constant of dry soil is found in good agreement with reported in literature. The dielectric constant and dielectric loss of moist soil increases with increase in moisture content in soil.

Keywords: Soil samples, Dielectric constant, Dielectric loss, Moisture content, Emissivity

1. Introduction

The dielectric study of dry and wet soils at microwave frequency play important role in remote sensing of soil moisture [1-3]. It also describes the behaviour of soil to an incident electromagnetic wave. Study of soil helps in proper selection of crops, fodder production, better land use as at the village level, soils are complex and highly variable and leads to different parent materials. The dielectric response of soil is divided in two part (real and imaginary) which determine the wave velocity and energy loss respectively [4]. The theoretical basis for soil moisture measurement is based on large contrast between the dielectric constant of dry soil (≈2-4) and that of water (80). At microwave frequencies the dielectric constant and dielectric loss mainly varies with moisture content. These parameter are also depends on the frequency, texture, porosity, salinity and temperature of soil. Data are used in active and passive microwave technique.

Soils are constituent of solids, liquid and gases mixed together in variable proportional. The relative amount of air and water present depends on the soils particles are packed together and the types of spacing are different for different structures. Several workers have studied the dielectric properties of soil at microwave frequency [5-8] of Rajasthan. In present work to gain more information regarding dielectric properties of soil, detailed study of soils of Rajasthan has been conducted at 9.45 GHz (X-band) frequency and the results are reported in this paper.

2. Experimental details

2.1 Sample preparation

Five soil samples were collected from different districts of Rajasthan at depth of ranging from 5-25cm in zigzag pattern.

I. Bikaner (Nokha 28° 1' 22.44"N, 73° 18' 42.84"E)
II. Jodhpur (lohawat 26° 59' 0" N, 72° 35' 0" E)
III. Nagaur (Ladnun 27° 38' 39.48" N, 74° 23' 17.16" E)
IV. Jaisalmer (Mandai 26° 21' 8.208"N, 71° 7' 58.44"E)
V. Pali (Jaitpur 25° 17' 12.48" N, 79° 34' 37.92"E)

Three pits were dug for each soil sample and 3 to 5 kg soils were collected. Stones and gravels were removed from the soil samples and then the soil samples were oven dried. Measured quantity of distilled water added to the soil and was kept for 24 hours to facilitate for internal homogenous mixing and adjustment for dielectric measurement. The physical and chemical properties of the five soil sample given in Tables 1 & 2.

The wilting point (WP) and transition moisture (Wt) were calculated [9-10] using the relation as follows:

$$(WP) = 0.06774 - 0.00064 \times Sand + 0.00478 \times Clay \quad (1)$$

$$(Wt) = 0.49 \times (WP) + 0.165 \quad (2)$$

Where, Sand and Clay stand for the sand and clay content in percentage of dry weight of the soil. They are also presented in Table 1. The gravimetric soil moisture in percentage WC (%) is calculated using wet (W1) and dry (W2) soil masses using the following relation.

$$W_c\% = \frac{W_1 - W_2}{W_2} \times 100$$

(3)

Table 1: The Texture, Physical Properties of soil

Sample No.	Location (Region)	Texture	Sand%	Silt %	Clay %	Particle density	Porosity	Wilting Point WP,cm3/ cm3	Transition moisture Wt, cm3/ cm3
1	Bikaner (Nokha 28° 1' 22.44"N, 73° 18' 42.84"E)	Sand	94.80	2.00	3.20	1.62	39.6	0.022364	0.1759584
2	Jodhpur (lohawat 26° 59' 0" N, 72° 35' 0" E)	Loamy Sand	82.8	8.90	8.3	1.53	43.31	0.054422	0.1916668
3	Nagaur (Ladnun 27° 38' 39.48" N, 74° 23' 17.16" E)	Sandy loam	77.79	9.80	13.0	1.48	46.40	0.080094	0.2042463
4	Jaisalmer (Mandai 26° 21' 8.208"N, 71° 7' 58.44"E)	Sandy loam	61.83	18.60	17.10	1.42	48.40	0.121876	0.2247192
5	Pali (Jaitpur 25° 17' 12.48" N, 79° 34' 37.92"E)	Sandy loam	60.30	25.60	19.6	1.37	50.01	0.110886	0.2193341

Table 2: Chemical Properties of soil

Sample No.	Location (region)	Texture	pH	E.C.(m mho/cm)	Organic carbon (%)	K_2o (kg/hect)	Zn (ppm)	Cu (ppm)	Mn (ppm)	Fe (ppm)
1	Bikaner (Nokha 28° 1' 22.44"N, 73° 18' 42.84"E)	Sand	9.2	0.57	0.21	201	0.12	0.28	2.64	1.18
2	Jodhpur (lohawat 26° 59' 0" N, 72° 35' 0" E)	Loamy Sand	8.7	0.20	0.02	206	0.56	0.46	3.12	2.20
3	Nagaur II (Ladnun 27° 38' 39.48" N, 74° 23' 17.16" E)	Sandy loam	9.2	0.55	0.23	201	0.35	0.23	2.89	0.96
4	Jaisalmer (Mandai 26° 21' 8.208"N, 71° 7' 58.44"E)	Sandy loam	8.0	2.00	0.03	196	0.54	0.62	7.00	4.4
5	Pali (Jaitpur 25° 17' 12.48" N, 79° 34' 37.92"E)	Sandy loam	8.8	0.25	0.14	306	0.43	0.58	6.00	2.22

2.2 Method

Dielectric measurement was carried out at 9.45 GHz (X-band) microwave frequency using two point method [11-12], standard microwave bench having reflex klystron as source was used in TE_{10} mode and experimental set up given in figure 1

Figure:-1 X-Band Microwave bench set up

The dielectric constant ε' and dielectric loss ε'' of the soil samples were than calculated as

$$\varepsilon' = \frac{G_E + \left(\frac{\lambda_g}{2a}\right)^2}{1 + \left(\frac{\lambda_g}{2a}\right)^2} \quad (4)$$

$$\varepsilon'' = \frac{-S_E}{1 + \left(\frac{\lambda_g}{2a}\right)^2} \quad (5)$$

Form the measured values of dielectric constant and dielectric loss, the ac electric conductivity is obtained using the relation

$$\sigma = w\varepsilon_0\varepsilon'' \quad (6)$$

Where $w = 2\pi f$ is angular frequency $f = 9.45GHz$ and ε_0 is the permittivity of free space $(8.85\times10^{-12} F/m)$

and ε'' is dielectric loss

The emissivity of the soil can be predicted from the measured values of dielectric constant ε' and dielectric loss ε'' of the soil by given formula [13-14].

$$e(\theta, p) = [1 - R(\theta, p)] \quad (7)$$

Where 'θ' is look angle 'P' polarisation and 'R' reflectivity

The reflectivity R is calculated by Fresnel's equations

$$R(\theta,H)=\left[\frac{\cos\theta-\left(\varepsilon-\sin^2\theta\right)^{\frac{1}{2}}}{\cos\theta+\left(\varepsilon-\sin^2\theta\right)^{\frac{1}{2}}}\right]^2 \quad (8)$$

$$R(\theta,V)=\left[\frac{\varepsilon\cos\theta-\left(\varepsilon-\sin^2\theta\right)^{\frac{1}{2}}}{\varepsilon\cos\theta+\left(\varepsilon-\sin^2\theta\right)^{\frac{1}{2}}}\right]^2 \quad (9)$$

3. Results and discussion

The measured values of dielectric constant, dielectric loss with moisture content in different soils are plotted in figure 2. The plots clearly show that the Dielectric Constant ε' of dry soils of different region of Rajasthan (Bikaner, Jodhpur, Nagaur, Jaisalmer and Pali) varies from 2.6-2.8. The dielectric constant ε' increases with the moisture content in the soil, it increases slowly up to the moisture content 10% after which it increases sharply with the moisture content in the soil, the variation depend upon the clay content of soil for higher clay content (Jaislmer and Pali) increases slowly in comparison to lower clay content Nokha and lohawat. The dielectric behaviour of sand and Loamy sand is identical but dielectric behaviour of sandy loam soil is different than the other two soils which indicate the dielectric behaviour of soil also depend on soil texture similar results were found by the earlier works [15-17].

The dielectric loss values of all soil samples increase slowly and linear with increase in moisture content in the soil. The regression values of the linear trend lines for the soil samples are shown in figure. At lower moisture content there is no visible difference between the dielectric loss of the soils having different texture structure. But at given higher moisture content the dielectric loss of the sandy soils is more than that for the high clay content soils.

It has been from the observed values of dielectric constant also depend on the particle density of soil. The measure values of particle density for different type of soils namely sand is loamy sand and sandy loam is also presented in Table 1. The soil density of these soils varies from (1.37-1.62) higher for sand and loamy sand than sandy loam. It can be seen that for higher the density more is the value of dielectric constant. The variation in ac conductivity with moisture content shown in figure 3. It also increases with the moisture content. Thus the electric loss is proportional to ac conductivity [18].

The emissivity for horizontal and vertical polarization for different moisture content for different look angles are shown in figure 4 and figure 5. It can be seen that horizontal emissivity (e_h) decreases with moisture content [19-12] and for different look angles of soil hence increase in reflectivity for a given moisture content the emissivity decreases with the look angle. This shows that wet soil is better reflector than dry soil. Emissivity for vertical polarization is more than the values of corresponding horizontal polarization. The emissivity values can be used to evaluate brightness temperature using the relation

$$T_B = e\,T \quad (10)$$

Where T_B is brightness temperature and T is the physical temperate. T_B can be measured using radiometers (Sensitive receiver) with the help of on board satellites.

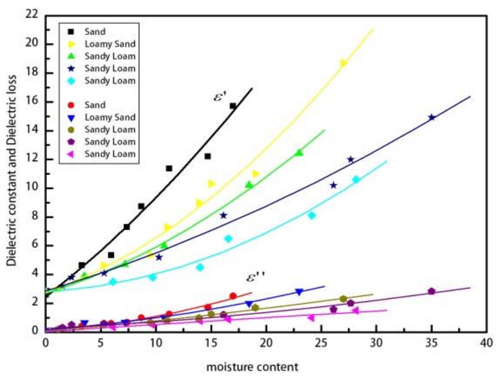

Figure:-2 Variation of dielectric constant (ε') and dielectric loss (ε'') with moisture content for different soil

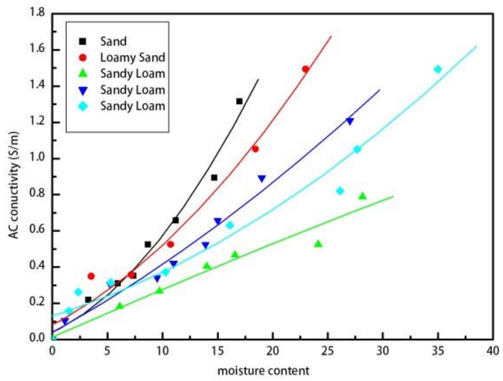

Figure:-3 Variation of ac conductivity (σ) with moisture content for different soil

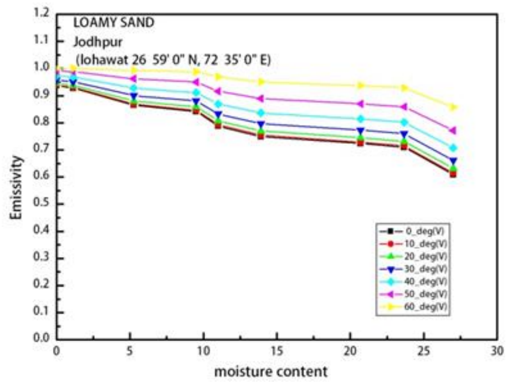

Figure:-4 Variations of vertical emissivity (e_v) of sand soil v/s moisture content

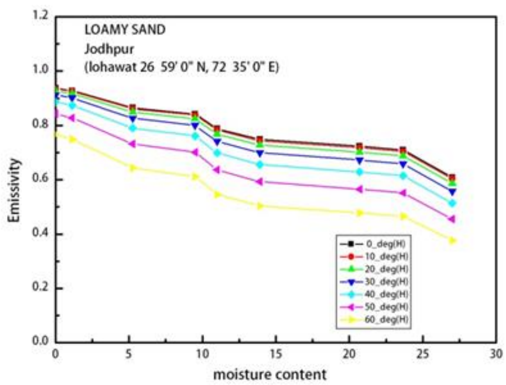

Figure:-5 Variations of horizontal emissivity (e_h) of loamy sand soil v/s moisture content

4. Conclusions

In the present study we draw following conclusion:

- Dielectric constant and dielectric loss increases with the moisture content in the soil which is due to bi phase behaviour of water in the soil.
- At higher moisture there are more free water molecules in comparison to bound water molecules therefore dielectric constant increases with soil moisture content rapidly.
- At low moisture content there is relativity less increment in the dielectric constant, in comparison to soils having higher moisture content.
  Apart from water content in the soil, chemical composition and grain geometries also affect the dielectric constant of the soil.
- At given moisture content ac conductivity is nearly proportional to sand content and inversely proportional to clay content.
- Soil texture is important for estimation of soil moisture using dielectric spectroscopy.

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