Study of Dielectric behavior and emissivity of red soils of North Maharashtra at C-band microwave frequency

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Abstract -The dielectric properties of red soil have been study with various percentage of moisture content. Microwave transmission line waveguide technique has been used for this purpose. The dielectric properties including dielectric constant (ε') and dielectric loss (ε") have been measured for the red soil samples collected from the three places located each in the Dhule (S1,S3) and Jalgaon (S2) districts of north Maharashtra region (India) at 5.1 GHz frequency of varied moisture content at C-band . The experimental observations shows that the dielectric constant of these red soil samples increased from about 2.64 to 19.59 for sample S1, 2.61 to 18.75 for sample S2 and 2.51 to 20.23 for sample S3, when its corresponding gravimetric MC changed from 0 % (oven dry) to around 30 %. Estimations of emissivity $e_p(\theta)$ by using emissivity model for vertical and horizontal polarizations at various incident angles show decrease in emissivity with increase in MC / dielectric constant. Electrical a.c. conductivity is also reported. This data is very useful in designing passive sensors for microwave remote sensing.

Index Terms— Dielectric properties, dielectric loss, red soil, a.c. conductivity, emissivity

INTRODUCTION - Every material has a unique set of electrical characteristics that are dependent on its dielectric properties. Accurate measurements of these properties can provide scientists and engineers with valuable information to properly incorporate the material into its intended application. Soil dielectric constant measurements are reviewed and the dependence of the dielectric constant on various soil parameters is determined. Moisture content is given special attention because of its practical significance in remote sensing and because it represents the single most influential parameter as far as soil dielectric properties are concerned.

D.H.Gadhani et al.[1,2] studied dielectric constant and dielectric loss of soils collected from different districts of Gujarat state for various moisture contents have been measured at X and C-band microwavefrequencies. It has been observed that the dielectric constant of soils depend on the moisture content in the soils and frequency of measurement. Gosh A.et al [3] reported the increase in dielectric constant of soils slowly with increase in the moisture content up to the transition moisture, after which it increases rapidly with moisture content. Calla O.P.N. et al. [4,5,6,7] have carried out extensive and systematic studies on the dielectric behavior of soils of Rajasthan and also from many parts of northern India. These investigators have also estimated emissivity's from dielectric constants of dry and wet soils using emissivity model for different microwave frequencies. They have used the waveguide cell method for measuring dielectric constant of soils. Their results have shown that the emissivity values of soils generally lie between 0.3 and 1.0. They have concluded that the value of emissivity of the soils decreases with increase in moisture content. Myron C. Dobson. et al.[8] have determined the dielectric parameters for five different soil types as a function of moisture content, temperature and soil textural composition at microwave frequencies between 1.4 and 18 GHz. Their results indicate that the dielectric constant of soil sample is a function of its volumetric moisture content and of the soil's textural composition. Srivastava S.K. and Mishra G.P.[9] have carried out study on dielectric properties of Chhattisgarh soils at X-band frequency using infinite sample method.

Dielectric properties of black and red soils at X-band microwave frequencies using infinite sample method were also studied by Chaudhari H.C. et al.[10,11]. Ramshetti R.S. and Navarkhele V.V. [12, 13] have studied the dielectric permittivity and loss of saturated black soil samples from Marathwada region (Maharashtra) at microwave frequencies. Results of these studies also confirmed the dependence of dielectric constant on volumetric moisture content and texture of soils. Microwave transmission and reflection of moisture-laden brown and black soils of Kolhapur (Maharashtra) using Ku-band is also reported by Puri V. et al.[14]. D.V.Ahire et al. [15] also reported electrical conductivity and dielectric properties of black soils of north Maharashtra region at X-band. The measured values of complex permittivity of dry and wet soils are compared with the values calculated from the empirical models and are found to be in agreement.

From the literature review given above, it is inferred that studies on the dielectric behavior and emissivity of red

soils of different regions of Maharashtra at microwave frequencies will be very useful to analyze the data available from remote sensing of these regions. Such studies will provide the detailed ground truth experimental data on the dielectric properties and emissivity of red soils of the above mentioned regions of Maharashtra This data is very useful in designing passive sensors for microwave remote sensing. Research of this kind enriches our knowledge of soil science and thus beneficial to the farmers of our country. Therefore, in the present study, we have reported experimental results on the variations of dielectric constant, dielectric loss and emissivity of red soils with percentage moisture content (MC) at C-band microwave frequency. These red soil samples are of irrigated and non-irrigated bare land and were collected from the three places located in the north Maharashtra region. The physical and chemical properties of these red soils are also provided.

MATERIALS AND MEASUREMENT

Properties of the soil: Soils are composed of solids, liquids and gases mixed together in variable proportions. The relative amount of air and water present depends on the way the soil particles are packed together. The structure of soil depends on the way the particles are arranged and also on the size of the particles. Both of them influence the amount of the pore space and its distribution in the soil. Soil texture is characterized by percentage of sand, silt and clay in it. Red soils have been formed from variety of rocks and these soils differ greatly in fertility and depth. The colour of the soils is due to colours of their constituents. Kaolinite and hydrous oxides of iron and aluminum are the dominant clay minerals in these soils. In the present study the three red soil samples are used from the northern part of Maharashtra (India) and their physical and chemical properties are listed.

Preparation of soil samples: Samples of red soils were collected from Haranmal, Aamli (Dhule district) and Parola (Jalgaon district). All these locations are situated in the northern region of Maharashtra state (India)These red soils are collected from non-irrigated bare and irrigated lands respectively and their depths ranged between 0-10 cm (top soil). These topsoil samples 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°C for half an hour in order to completely remove any trace of moisture. Such dry samples are then called as oven dry or dry base samples when compared with wet samples. Soil samples of various moisture contents are prepared by adding an exact amount of distilled water to the known mass of the oven dry soil. The soil-water mixtures are well mixed and are kept in a closed container for proper settling. These red soil samples of desired MC (%) are then inserted into the solid dielectric cell for measuring their dielectric properties using microwave bench. Extreme care was taken to expose the moist soil to the atmospheric air as little as possible.

Physical and Chemical Properties of Soil: Table-1 represents the physical and chemical properties of the three topsoil samples (Dhule-Sample 1), (Parola – Sample 2)and (Aamli – Sample 3). It shows that both the red soil samples used are alkaline in nature and have sandy clay loam (S1 and S2) and sandy loam (S3) texture. This soil analysis report was obtained from Agricultural College, Dhule.

Table-1: Physical and Chemical Properties of Red Soils.

Physical Properties								
Soil sample	**Sand %**	**Silt %**	**Clay %**	**Textural Class**	**Bulk density M gm/cm^{-3}**	**Particle Density M gm/cm^{-3}**	**Wilting Point WP**	**Transition Moisture W_t**
1	64.5	10.2	25.3	Sandy clay loam	1.52	2.64	0.147	0.237
2	62.4	12.3	25.3	Sandy clay loam	1.55	2.66	0.149	0.230
3	74	15	11	Sandy loam	1.43	2.6	0.072	0.200

Chemical Properties						
Soil Sample	pH (1:25)	EC (dSm^{-1})	Organic Carbon OC) %	Nitrogen (N) (kgha^{-1})	Phosphorous (P) (kgha^{-1})	Potassium (K) (kgha^{-1})
1	7.7	0.19	0.37	269	17.00	548
2	7.8	0.23	0.26	255	13.77	425
3	8.0	0.18	0.44	201	5.00	480

The Wilting Point (WP) and Transition Moisture (Wt) of the soils are calculated by using the Wang and Schmugge16 model as follows:

WP = 0.06774 - 0.00064 X Sand (%) + 0.00478 X Clay (%) (1)

Wt = 0.49 X WP + 0.165 (2)

Method of Measurement of Dielectric Properties: The waveguide cell method is used to determine the dielectric properties of these red soil samples. An automated C-band microwave set-up in the TE10 mode with Gunn source operating at frequency 5.1 GHz. PC-Based slotted line control and data acquisition system is used for this purpose. It consists of Microcontroller (8051), ADC-12 Bit- MCP (3202) Visual Based software. The main advantages resulted due to atomization are increased resolution of output, reduction of backlash error in slotted line, visual representation of standing wave pattern. The solid dielectric cell with red 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 red soil 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 minimaresulted due to before and after inserting the sample. Experiments were performed at room temperatures ranged between 30-40°C. The dielectric constant ε', dielectric loss ε'' emissivity $e_p(\theta)$ and a.c. conductivity (σ) of these soil samples are then determined from the following relations:

$$\varepsilon' = \frac{g_\varepsilon + (\lambda_{gs}/2a)^2}{1 + (\lambda_{gs}/2a)^2} \quad (3)$$

$$\varepsilon'' = -\frac{\beta_\varepsilon}{1 + \left(\lambda_{gs}/2a\right)^2} \quad (4)$$

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

The emissivity $e_p(\theta)$ for vertical polarization can be written as,

$$e_p(\theta) = 1 - r_p(\theta) = 1 - |R_p(\theta)| \quad (5)$$

$$e_p(\theta) = 1 - \quad (6)$$

For horizontal polarization,

$$e_p(\theta) = 1 - \frac{\cos\theta - \sqrt{\varepsilon' - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon' - \sin^2\theta}} \quad (7)$$

Where, θ = Angle of observation.

$e_p(\theta)$ = Emissivity of the surface layer.

$r_p(\theta)$ = Reflection coefficient.

$Rp(\theta)$ = Fresnel reflection coefficient

Estimations of emissivity values for red soil samples S1, S2 and S3 are made by using emissivity model for incident angles varying from 0° (normal incidence) to 60° for vertical and horizontal polarizations.

Variation of dielectric constant (ε′), dielectric loss (ε′′), emissivity ($e_p(\theta)$) and a.c. conductivity (σ) with the moisture content for sample S1, S2 and S3 are shown in fig. 1 to 6 respectively. All these measurements are carried out at C-band microwave frequency (5.1 GHz).

RESULT AND DISCUSSION

Variation of dielectric constant (ε′), dielectric loss (ε′′), emissivity ($e_p(\theta)$) and a.c. conductivity (σ) with the moisture content for sample S1, S2 and S3 are shown in fig. 1 to 6 respectively. All these measurements are carried out at C-band microwave frequency (5.1 GHz).

The variation in dielectric constant and dielectric loss with various % moisture content for red soil samples are shown in Fig. 1 and Fig. 2 respectively. For all the samples initially dielectric constant increases slowly with increase in moisture content and then increases rapidly whereas dielectric loss increases with increase in moisture content. The observations are made for 0%(dry soil) MC to 30% MC. For sample S1 dielectric constant increases from 2.69 to 19.5, for sample S2 it increases from 2.65 to 19.2 and for sample S3 the values changes from 2.53 to 20.2. It is observed that for all the three samples dielectric constant suddenly increases after 15% moisture content. It is obvious that the relative permittivity of soils increases slowly with moisture content initially, this may due to bi-phase dielectric behavior of water molecule in soil that have smaller permittivity values as compare to free water molecule below transition point and after reaching a transition point, they increase rapidly. From the study, it is observed that the relation between the dielectric constant and the gravimetric water content is 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.

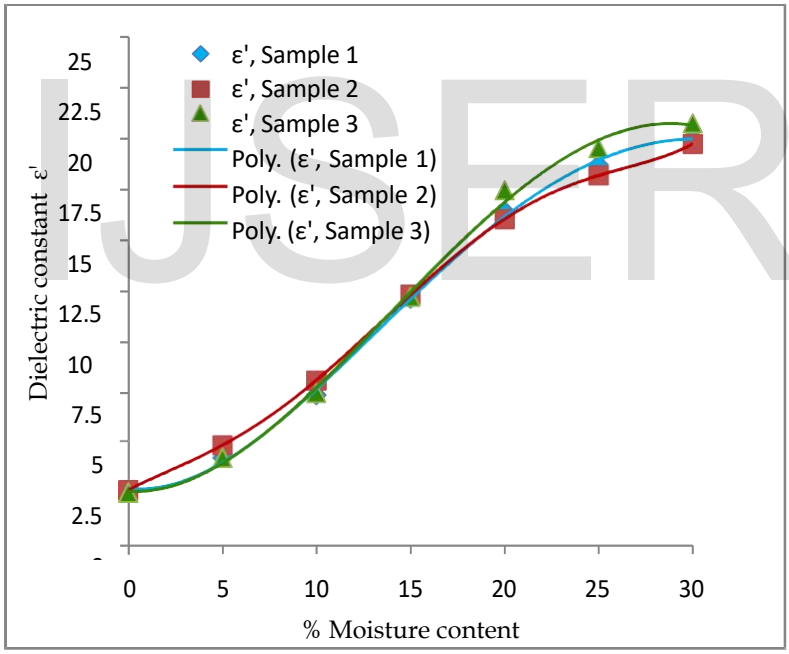

Fig.1: Variation of dielectric constant with percentage moisture content for red soils at 5.1 GHz

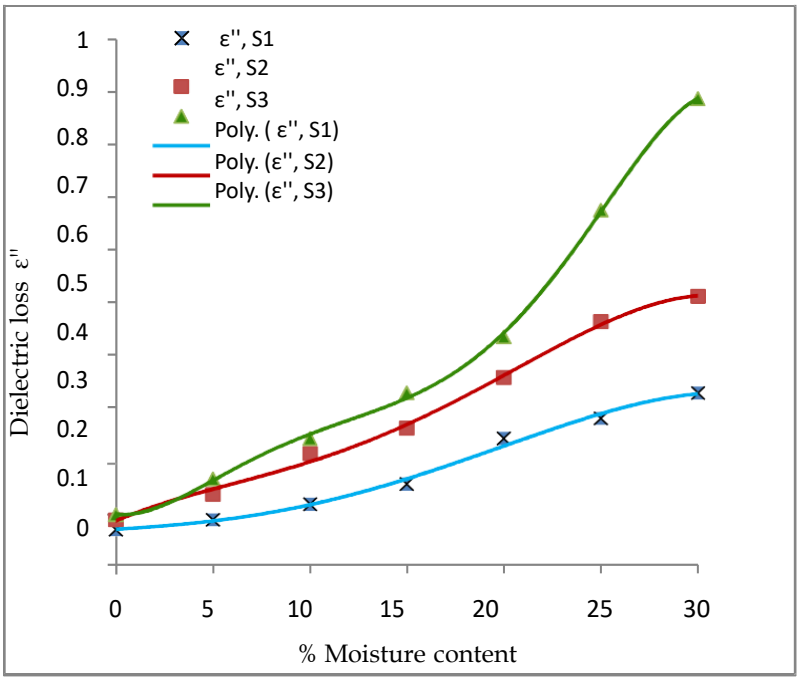

Fig.2: Variation of dielectric loss with percentage moisture content for red soils at 5.1 GHz

The variation of emissivity with % moisture content for sample S1, S2 and S3 are shown in Fig. 3, Fig. 4 and Fig. 5 for vertical and horizontal polarizations respectively. The trend is exactly reverse than the dielectric constant and dielectric loss. It shows decrease in emissivity with increase in moisture content. Emissivity is calculated for various incidence angles from 0^0 to 60^0 for vertical and horizontal polarizations. The emissivity increases for vertical polarization as angle of incidence increases while decreases for horizontal polarization. At 0^0 incidence angle emissivity curves are overlapped. Electrical a.c. conductivity is also estimated from dielectric constant at various % moisture content. The variation in a.c. conductivity with change in moisture content for sample S1, S2 and S3 are shown in Fig. 6. It shows increase in a.c. conductivity with increase in moisture content.

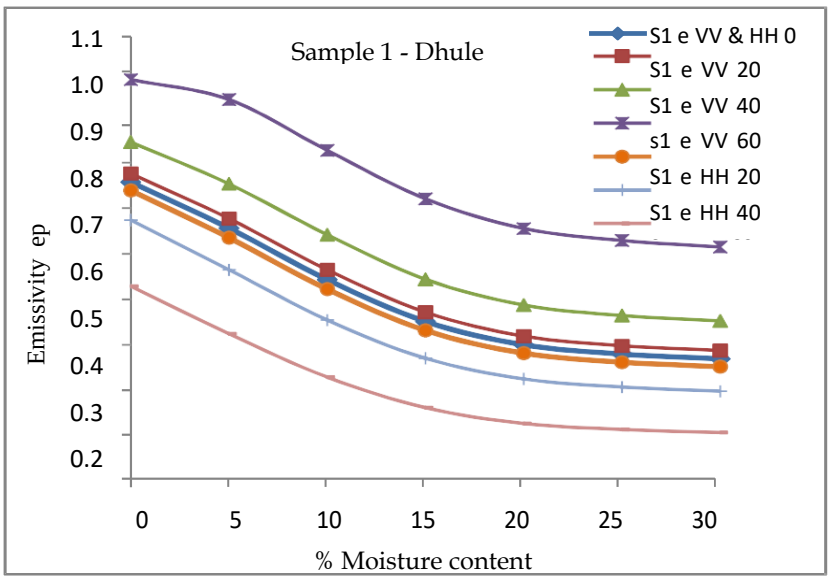

Fig.3: Variation of emissivity with percentage moisture content for red soil S1 at 5.1 GHz (vertical and horizontal polar izations at various incident angles)

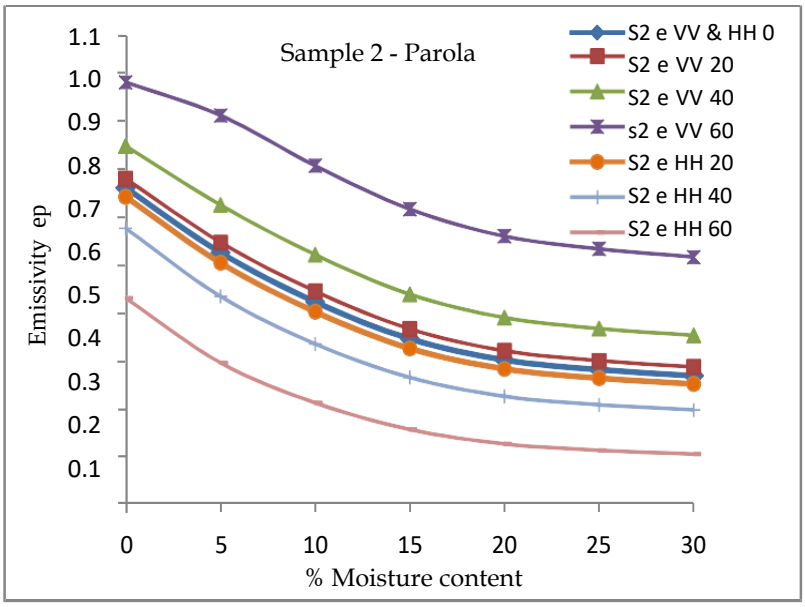

Fig.4: Variation of emissivity with percentage moisture content for red soil S2 at 5.1 GHz (vertical and horizontal polarizations at various incident angles)

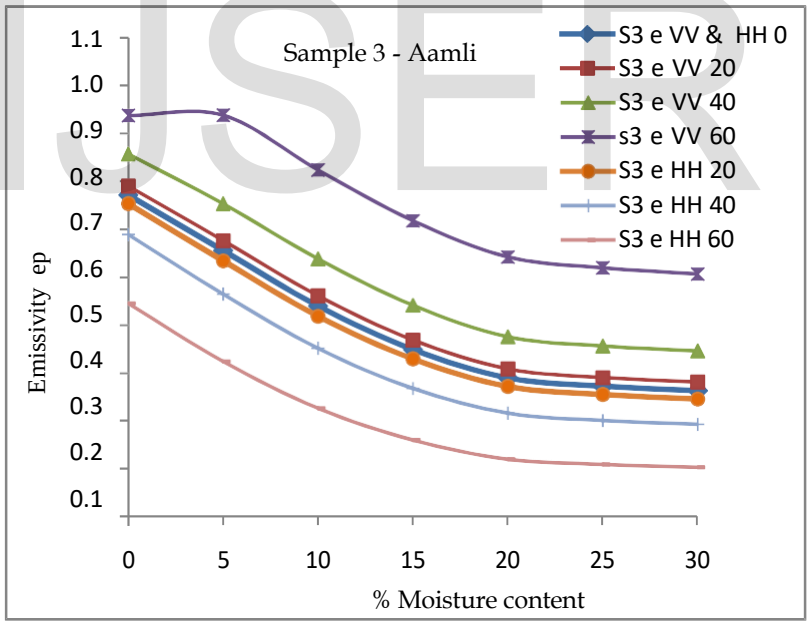

Fig.5: Variation of emissivity with percentage moisture content for red soil S3 at 5.1 GHz (vertical and horizontal polarizations at various incident angles)

In the passive microwave remote sensing the radiometer measures the emissivity of soil. Thus the knowledge of variations of dielectric constant with MC of a red soil is useful for the interpretation of data obtained by various sensors for remote sensing applications such as agriculture and meteorology.

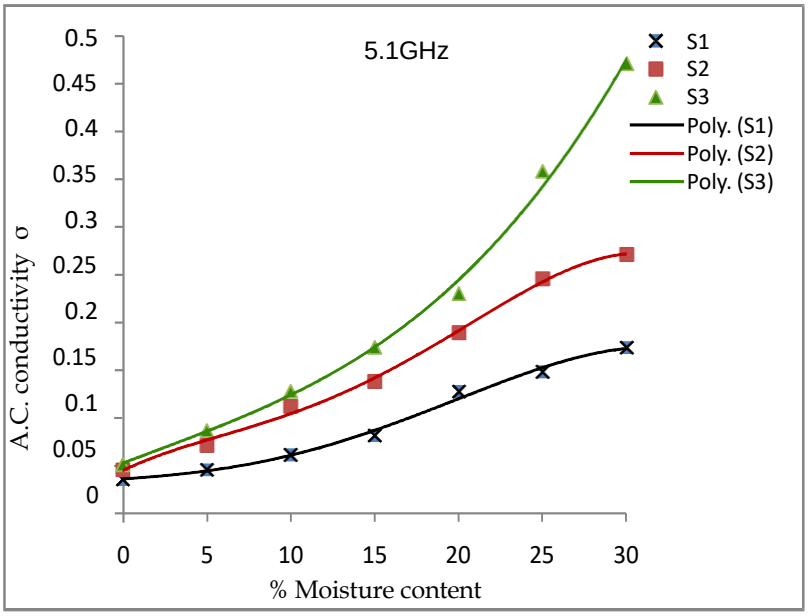

Fig.6: Variation of a.c. conductivity with percentage moisture content for red soils at 5.1 GHz

CONCLUSION

From this study, it is concluded that, The trend of variation of dielectric constant & emissivity for the samples from Haranmal (Dist. Dhule), Aamli (Dist. Dhule) and Parola (Dist. Jalgaon) of north Maharashtra (India) are nearly same. The dielectric constant of red soil increases from 2.64 to 19.59 for sample S1, 2.61 to 8.75 for sample S2 .2.51 to 20.23 for sample S3 for frequency 5.1 GHz, when its corresponding gravimetric MC changed from 0% (oven dry) to 30% and the dielectric loss increases with increase in moisture.

The emissivity decreases with increase in MC / Dielectric constant for vertical and horizontal polarizations.

Electrical a.c. conductivity also estimated from calculated dielectric constant at 5.1 GHz frequency. The result shows increase in a.c. conductivity with increase in moisture content.

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