International Journal of Physics and Mathematical Sciences ISSN: 2277-2111 (Online)
An Online International Journal Available at http://www.cibtech.org/jpms.htm
2013 Vol. 3 (1) January-March, pp.32-39/Ahire and Chaudhari
Research Article

EMISSION AND SCATTERING BEHAVIOR OF DRY AND WET BLACK SOIL FROM KARNATAKA AT MICROWAVE FREQUENCY

D. V. Ahire* and P. R. Chaudhari
Department of Physics, Z.B.Patil College, Dhule-424002 (India)
**Author for Correspondence*

ABSTRACT
The paper presents the data on dielectric constant and physico-chemical properties for black soil of Muddur site (Karnataka State, India). Measurements of dielectric constant of dry and moist soil sample are made by using wave-guide cell method. An automated microwave set-up operating at C-band (5.3 GHz) frequency is used for this purpose. Measured values of dielectric constant are then used to estimate emissivity and scattering coefficient by using emissivity model and perturbation model respectively, for both vertical and horizontal (VV and HH) polarizations and for different angles of incidence. For vertical polarization, at constant value of incident angle, emissivity of soil sample is found to decrease significantly whereas its scattering coefficient is found to increase significantly with increase in the values of its MC (%) from 0 % and 20 % MC. Further, the magnitudes of scattering coefficient of soils at same incident angle are greater for vertical polarization rather than for horizontal polarization. These results on emissivity and scattering coefficient can be used for designing passive and active remote sensing sensors for dry and wet soil.

Key Words: *Dielectric Constant, Emissivity, Scattering Coefficient, Black Soil, Vertical and Horizontal Polarizations*

INTRODUCTION
Microwave remote sensing of natural earth materials depends on the dielectric constant. It is also a basic parameter required to estimate the scattering coefficient and emissivity of dry soils. Emission and scattering behavior of soils depends upon the dielectric constant, moisture content, chemical composition, surface roughness, physical temperature, frequency, incident angle and polarization. Thus natural objects have different scattering coefficients depending on their physical and electrical properties. The surface smoothness of the target is found to have a great effect in this case. If the surface is very smooth, the power will be highest in the direction of the reflection angle, i.e. in the specular direction. On the other hand, if the surface is very rough, it will be scattered in all the directions. This roughness parameter is usually defined in relation to the wavelength.

Various investigators have studied the emission and scattering behavior of soils by measuring its dielectric constant. Calla and Hannan (2001); Calla and Sharma (2001**)** studied the emission and scattering behavior of soils from a given texture and made comparative study of dry and wet soils at microwave frequencies. The emission and scattering behavior of different soils as function of their type, MC (%), frequencies, polarization and incidence angles have been studied experimentally by several other investigators (Calla *et al*., 2004; Calla and Kalita, 2004; Calla *et al*., 2005; Fung *et al*., 1992, Gupta and Jangid, 2011; Ulaby, 1974). Results of all these investigations confirm that the variations of emissivity and scattering coefficient have inverse trends. They also found that the scattering coefficient increases with increase in MC (%) and incident angles but decreases with frequency.

In the present experiments, the dielectric constants of dry and wet black soil sample are measured at C-band microwave frequency, 5.3 GHz using waveguide cell method. Results of dielectric constant are used to estimate the corresponding values of emissivity and scattering coefficients of soil. Such study of emission and scattering behavior of black soils having various MC (%) and for incident angles varied from 0^o to 80^o will be helpful for designing of passive and active microwave remote sensors.

MATERIALS AND METHODS

Preparation of Soil Samples

Soil is a heterogeneous body. Therefore, it is not possible to collect a soil sample which would be representative of the heterogeneous land. So, first of all the heterogeneity of the land is minimized by dividing the land into smaller units. It is, therefore, important that samples should be representative of the soil for the area under investigation. Unless this is ensured, sampling may be the greater source of error in the whole process. Topsoil sample having black colour was collected from Muddur site near Banglore, Karnataka (India). These samples have depths ranging between 0-20 cm. It is first sieved by gyrator sieve shaker (size 425 µm) to remove the coarser particles. The sieved out fine particles are then dried in the hot air oven to a temperature around 110°C for about 24 hours in order to completely remove any trace of moisture. Such dry sample is then called as oven-dry or dry base samples with 0 %MC, when compared with wet samples. Soil samples of various gravimetric moisture contents (upto 20%) are prepared by adding an exact amount of distilled water to the known mass of the oven dry soil. The single pan precision balance having digital readout accuracy of 0.1 mgm is used for weighing the sample. The soil-water mixtures are well mixed and are kept in a closed container for proper settling over several hours. These samples of desired gravimetric MC (%) are then inserted into the solid dielectric cell for measuring their dielectric properties.

Physico-Chemical Properties of Black Soil Sample

The analysis of physical and chemical properties of black soil sample was obtained from Soil Science Division, College of Agriculture, Pune. Table 1 shows physical and chemical properties of the soil used in these investigations. From the soil texture, the textural class of this soil is clay. Further, it is non-saline and alkaline in nature.

Table 1: Physical and chemical properties of soil

Physical Properties		**Chemical Properties**	
Sand (%)	31.47	*pH (1:2.5)*	7.4
Silt (%)	22.22	*EC* (dSm^{-1})	0.21
Clay (%)	46.31	*OC (%)*	0.66
Textural Class	Clay	$CaCO_3$ *(%)*	1.75

Dielectric Constant Measurement

The wave-guide cell method is used to determine the dielectric constant of the soil. An automated microwave set-up in the TE_{10} mode with Gunn source operating at desired C band frequency, PC-Based slotted line control and data acquisition system are used for this purpose. It consists of Microcontroller (8051) and ADC-12 Bit- MCP (3202) Visual-Based software. The sample lengths are usually taken in the multiples of $\lambda/4$. It is very important parameter and inaccuracy in its measurement may lead to serious errors. The solid dielectric cell with black 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. This standing wave pattern is then used in determining the values of shift in minima resulted due to before and after inserting the soil sample. The dielectric constant is calculated by measuring the standing wave ratio of the dielectric material and the shift in minima of the standing wave pattern in a rectangular waveguide. This shift takes place due to change in the guide wavelength when a dielectric material is introduced in waveguide. Using the value of dielectric constant of black soil sample having different MC (%), the estimations of emissivity and scattering coefficient are made.

Figure 1: Automated C-Band Microwave Setup for Measurement of Dielectric Constant of Soils

Dielectric constant (ε') is determined by using the equation

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

Estimation of Emissivity

For the estimation of emissivity of the soil samples, different models (Kerr and Njoku, 1990; Li *et al.*, 2008; Ulaby *et al.*, 1990) can be used. They are:

(i) Zero order non-coherent radiative transfer model
(ii) First order non-coherent radiative transfer model
(iii) Coherent model
(iv) Emissivity model
(v) Coherent model for multilayer medium

In the present work, the estimations of the microwave emission from the clay type black soil has been carried out by using emissivity model. The basic expression for emissivity is

$$e_p(\theta) = 1 - r_p(\theta) \quad (2)$$

Where,
$e_p(\theta)$ = Emissivity of the surface layer
p = Polarization either vertical or horizontal,
$r_p(\theta)$ = Reflectivity coefficient

In case of smooth surface over a homogeneous medium $r_p(\theta)$ can be obtained from Fresnel reflection coefficient $R_p(\theta)$ as

$$r_p(\theta) = |R_p(\theta)|^2 \quad (3)$$

Where, Fresnel reflection coefficient for horizontal polarization is given by

$$R_p(\theta) = \frac{\cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}} \quad (4)$$

And, for vertical polarization it is

$$R_p(\theta) = \frac{\varepsilon_r\cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\varepsilon_r\cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}} \quad (5)$$

Where, θ is the angle of observation and ε_r the dielectric constant of the material. Using Eqs. (2)-(5), the estimations of emissivity are made.

E. Estimation of Scattering Coefficient

Different models are available for the estimation of scattering coefficients (Kerr and Njoku, 1990; Li *et al.*, 2008; Ulaby *et al.*, 1990). For estimating the scattering coefficient, we can use any of the four models, namely,

(i) Physical optics model
(ii) Geometric optics model
(iii) Perturbation model
(iv) IEM model

The selection of model depends upon the roughness of the surface and the validity conditions, both of which must be satisfied. The validity conditions are given in Table 2 which are based on the values of standard deviation of surface height or r.m.s. surface height (σ), surface correlation length (*l*), wave number k = (2π/λ) and r.m.s. surface slope (m). Any surface can be distinguished as rough surface, smooth undulating surface and two scale composite rough surfaces.

For undulating surface with small slopes and medium standard deviation of heights as compared to wavelength incident, a scalar approximation in the field expression or physical optics model is used. If the surface has larger standard deviation of surface heights, the surface is considered as rough and the stationary phase approximation or geometric optics model is used. The limitation of above two methods is expressed as $kl < 6$. When both the surface standard deviation and the correlation length are smaller than wavelength, then the surface may be approximated as smooth and perturbation model can be used. The validity conditions for this model are given in the Table 2. Here, the surface of dry and moist soils has been made smooth/plain and for such surfaces, both IEM model and perturbation model are applicable. In the present paper, the perturbation model is applied for estimation of scattering coefficient (Eqs. 6-9).

Table 2: Validity conditions for different models

Model	**Validity condition**
Physical optics model (Kirchoff's model with scalar approximation)	$m < 0.25$ and $kl > 6$
Geometrical optics model (Kirchoff's model with stationary phase approximation)	$(2k\sigma\cos\theta^2) > 10$ and $l^2 = 2.76\sigma\lambda$
Perturbation model	$k\sigma < 0.3$ and $m < 0.3$

Where,
θ = Angle of incidence
k = Wavelength number = 2π/λ
σ = Surface standard deviation
l = Surface correlation length

The validity conditions for perturbation model to be satisfied are:

$K\sigma < 0.3$ and $\frac{\sqrt{2}\,\sigma}{l} < 0.3$

In the present case, $k\sigma = 0.05$ and $k\lambda = 0.5$

the perturbation model conditions are satisfied. The backscattering coefficient in this model is calculated using following relation.

$$\sigma^0_{ppm}(\theta) = 8k^4\sigma^2\cos^4\theta \, x|\alpha_{pp}(\theta)|^2 \, W(2k\sin\theta) \quad (6)$$

where, pp = vv or hh, i.e. like polarizations.

Also, $|\alpha_{pp}(\theta)|^2 = \Gamma_h(\theta)$ is the Fresnel reflectivity for horizontal polarization given by,

$$\alpha_{hh}(\theta) = \frac{\cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}} \quad (7)$$

and for vertical polarization,

$$\alpha_{vv}(\theta) = (\varepsilon_r - 1)\frac{\sin^2\theta - \varepsilon_r(1+\sin^2\theta)}{[\varepsilon_r\cos\theta + \sqrt{(\varepsilon_r - \sin^2\theta)}]^2} \quad (8)$$

where θ is the angle of incidence, ε_r is the dielectric constant of surface, W(2ksin θ) is the normalized roughness spectrum, which is the Bessel transform of the correlation function ρ(ξ), evaluated at the surface wave number of 2ksin θ. For the Gaussian correlation function,

$$W(2k\sin\theta) = \tfrac{1}{2}\, l^2 \exp[(kl\sin\theta)^2] \quad (9)$$

Different models are to be used depending on the nature of the surface. For a smooth or rolled type surface the perturbation model is used. The surface of black soil sample in our experiment is made quite smooth, hence we have selected perturbation model for the estimation of scattering coefficient. We have considered the following assumption for estimation of scattering coefficient i.e. kσ = 0.05 and kλ = 0.5. Using the values dielectric constant of dry and wet black soil sample from the location Muddur (Karnataka), the values of emissivity and scattering coefficient are estimated and analyzed graphically to study the variation of emissivity and scattering coefficient as a function of soil moisture and angle of incident for both horizontal and vertical polarizations.

RESULTS AND DISCUSSION

Results of our experimental measurements on dielectric constant of black soil for various percentage gravimetric moisture contents at 5.3 GHz frequency are given in Table 2. It shows strong dependence of dielectric constant of soil on MC (%).

Table 3: Dielectric constant of black soil at various percentage gravimetric moisture contents

MC (%)	Dielectric Constant (Є')
0	3.94
10	8.82
20	20.45

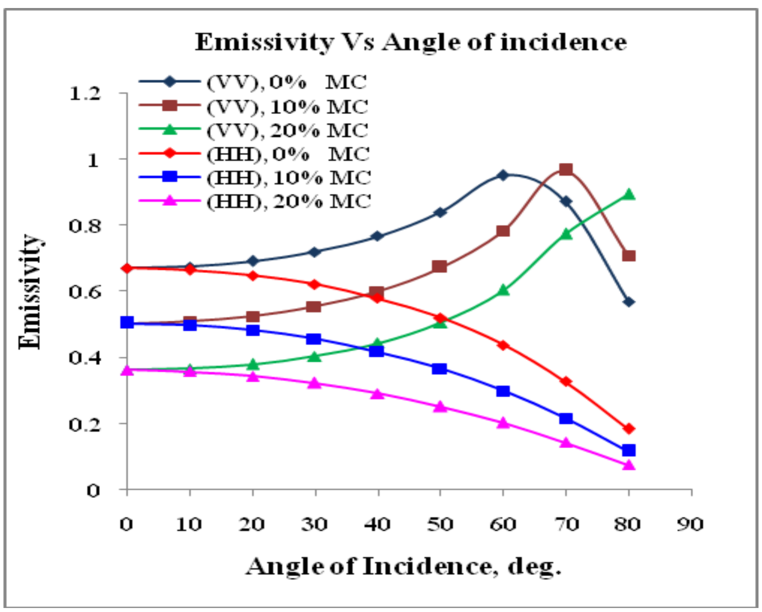

Figure 2: Variation of Emissivity of Dry and Wet Black Soil for Vertical and Horizontal Polarizations with Angle of Incidence

Dielectric constant of black soil increases with increase in the MC (%). This is due to resonance absorption of microwave energy by water molecules over the range of frequency used and hence our results are in close agreement with the results of quoted by earlier investigators (Calla *et al*., 2004; Calla and Kalita, 2004; Calla *et al*., 2005; Fung *et al*., 1992; Gupta and Jangid, 2011; Ulaby, 1974). These values of dielectric constants of black soil sample having different MC (%), are used to estimate the emissivity and scattering coefficient for this soil sample.

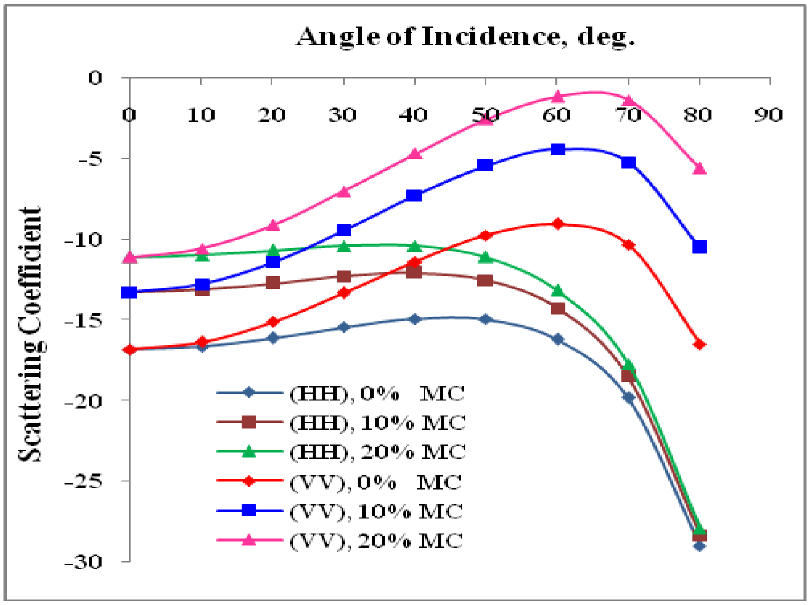

Figure 3: Variation of Scattering Coefficient of Dry and Wet Black Soil for Vertical and Horizontal Polarizations with Angle of Incidence

Figure 2 show the variation of emissivity, $e_p(\theta)$ for black soil sample with MC (%) at different angle of incidence for horizontal and vertical polarizations, 5.3 GHz frequency. It is observed that at constant value of MC, emissivity of soil sample increases with increase in the incident angle for vertical polarization, and this increase continues up to a certain look angle referred to as 'Brewster's angle', at which it reaches maximum value equal to unity; and beyond this particular angle, emissivity decreases sharply. Further, for vertical polarization, at constant value of incident angle, emissivity of soil sample is found to decrease significantly with increase in the values of its MC (%). As an example, at 0° incident angle, the emissivity values are 0.67 and 0.36 for soil sample having 0 % and 20 % MC respectively.

In case of horizontal polarization, the value of emissivity for black soil sample remains constant for incident angles about 10-15° and then starts decreasing slowly. Beyond 40°, it decreases significantly with increase in the incident angle and at about 80°, it reaches to values near 0.3 for 0 % MC and 0.2 for 20 % MC. Thus, in general, for horizontal polarization, emissivity decreases with the increase in incident angle. It is further observed that the magnitudes of emissivity of soils at same incident angle are greater for vertical polarization rather than for horizontal polarization. Further, for horizontal polarization, at constant value of incident angle, emissivity of soil sample is also found to decrease significantly with increase in the values of its MC (%) from 0 % and 20 % MC, similar to vertical polarization. However, in this case, the magnitude of decrease in emissivity with increase in the values of its MC (%) of soil sample gradually reduces upon increasing for incident angles from 0-80°. Thus, results presented here show fairly good agreement with the experimental results and theoretical predictions of earlier investigators (Calla *et al*., 2004; Calla and Kalita, 2004; Calla *et al*., 2005; Fung *et al*., 1992; Gupta and Jangid, 2011; Li *et al.*, 2008; Ulaby, 1974).

Figures 3 show the variation scattering coefficient of black soil sample at 5.3 GHz frequency with incidence angle and having three different MC (0%, 10 % and 20 %) for vertical and horizontal polarizations. It is observed that at constant value of MC, scattering coefficient of soil sample increases

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with increase in the incident angle for vertical polarization, and this increase continues up to angles between 60^o to 70^o, at which it reaches maximum value and beyond this particular angle, scattering coefficient decreases sharply. Value of this angle is found slightly more for higher MC. Further, for vertical polarization, at constant value of incident angle, scattering coefficient of soil sample is found to increase significantly with increase in the values of its MC (%).

In case of horizontal polarization, the value of scattering coefficient for black soil sample almost remains constant for incident angles about 30-40° and then starts decreasing slowly. Beyond 40°, it decreases significantly with increase in the incident angle and at about 70-80°, thereafter values of scattering coefficient becomes equal for all three MC. Thus, in general, for horizontal polarization, scattering coefficient decreases with the increase in incident angle. It is further observed that the magnitudes of scattering coefficient of soils at same incident angle are greater for vertical polarization rather than for horizontal polarization.

Further, for horizontal polarization, at constant value of incident angle, scattering coefficient of soil sample is also found to increase significantly with increase in the values of its MC (%) from 0 % and 20 % MC, similar to vertical polarization.

Thus, results presented here show fairly good agreement with the experimental results and theoretical predictions of earlier investigators (Calla *et al*., 2004; Calla and Kalita, 2004; Calla *et al*., 2005; Fung *et al*., 1992; Gupta and Jangid, 2011; Li *et al.*, 2008; Ulaby, 1974).

The results presented on emissivity and scattering coefficient for dry and wet black soil at different incidence angles are quite useful in designing passive and active sensors respectively. Such sensors are very much needed for the study and interpretation of data on black soils obtained by remote sensing satellites.

CONCLUSIONS

Dielectric constant of black soil increases with increase in its MC (%).

At constant value of MC, emissivity of soil sample increases with increase in the incident angle for vertical polarization, and this increase continues up to a certain look angle referred to as ‘Brewster’s angle’, at which it reaches maximum value equal to unity.

For vertical polarization, at constant value of incident angle, emissivity of soil sample is found to decrease significantly with increase in the values of its MC (%) from 0 % and 20 % MC.

At constant value of MC, scattering coefficient of soil sample increases with increase in the incident angle for vertical polarization, and this increase continues up to angles between 60^o to 70^o, at which it reaches maximum value and beyond this particular angle, scattering coefficient decreases sharply.

For vertical polarization, at constant value of incident angle, scattering coefficient of soil sample is found to increase significantly with increase in the values of its MC (%).

In general, for horizontal polarization, scattering coefficient decreases with the increase in incident angle.

For horizontal polarization, at constant value of incident angle, scattering coefficient of soil sample is found to increase significantly with increase in the values of its MC (%) from 0 % and 20 % MC.

The magnitudes of scattering coefficient of soils at same incident angle are greater for vertical polarization rather than for horizontal polarization.

ACKNOWLEDGEMENTS

The authors are very much grateful to the Principal, Z. B. Patil College Dhule, for providing research facilities and also very much thankful to Prof. OPN Calla, ICRS, Jodhpur, for his kind suggestions during this study.

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