Effect of microwave radiation on the electrical parameters of soil

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The paper presents the study of the effect of microwave radiation on dry soil. For this, five different soil samples were collected from various geographical regions of India. The waveguide cell method was employed for the determination of the storage factor ($\varepsilon'$) and the loss factor ($\varepsilon''$) of the soils. In this paper the methodology of measurement of dielectric constant for unexposed and exposed soils to microwave radiation is given and the results obtained are discussed.

Keywords: Electrical parameter, Soil texture, Microwave radiation, Dielectric constant

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1 Introduction

The microwave remote sensing of moon calls for understanding of the variation of electrical parameters of the soil of moon which has been receiving microwave radiation for all these years and there could be an effect on the electrical parameters of soil. These parameters will manifest through the change of dielectric constant, emissivity and scattering coefficient. This work is initiated to understand the behaviour of microwaves absorbed by dry soil of moon, which could be different from that of the normal soil. Here the soils of different parts of the country have been subjected to the variable power level at microwave frequency. The dielectric constants of these soils have been measured and the effect of microwave radiations on the electrical parameters is presented.

Two of the most important electrical parameters of soil, i.e. scattering coefficient and emissivity depend upon the dielectric constant of the soil$^1$. In the present study the effect of microwave radiation on the dielectric constant of the dry soil for different power levels (90 W to 600 W) of microwave radiation and different times of exposure (from 20 min to 60 min) has been reported. Soils from five different geographical regions of India have been collected and are artificially exposed to various amount of microwave radiation at 2.45 GHz, and their effect on the storage factor and the loss factor of the soil has been studied by the waveguide cell method at 7.04 GHz in CJ- band. The calculation has been carried out using a C-programme.

2 Properties of the soil

Soils are composed of solids, liquids and gases mixed together in variable proportions$^{2,3}$. 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 pore space and its distribution in the soil. Soil texture is characterized by percentage of sand, silt and clay in it. Depending upon the percentage of constituents soils are classified into 12 types and they are arranged in a triangular form which is known as soil texture classification triangle$^{1,2}$. In the present study the five samples are used from the states of Orissa, Rajasthan, Gujarat and Himachal Pradesh, and their constituents are listed in Table 1.

3 Sample preparation for measurement

The samples of soil were first grinded and sieved to obtain fine particles. Then the samples were oven dried at 110°C for about two hours. Equal amounts of the oven-dried samples were taken for measurement. The dry soils were put in microwave oven and exposed for different power levels 90, 160, 360 and 600 watts for different time duration like 20, 40 and 60 min. Then the dielectric constant was measured using waveguide cell method for both exposed and
unexposed soil samples at different power levels and for different exposure times.

4 Measurement of dielectric constant

The methods of measurement of dielectric constant of the soil at microwave frequencies have been described elsewhere. Here, the waveguide cell method has been used for the measurement of the dielectric constant of different soil samples. The dielectric constant is obtained by using standing wave ratio of the soil and the shift in minima of the standing wave pattern formed inside a slotted section of rectangular waveguide. This shift takes place due to the change in guide wavelength when dielectric material is introduced in the waveguide.

The measurements of guide wavelength and standing wave ratio of soil are carried out at 7.04 GHz in CJ-band. The relevant equation used for determining the relative dielectric constant ($\varepsilon_r = \varepsilon' + j\varepsilon''$) is given as

\[
\varepsilon = \frac{V_e + \left(\frac{\lambda_s}{2a}\right)^2}{1 + \left(\frac{\lambda_s}{2a}\right)^2}
\]

where, $V_e$ is the characteristic admittance of the sample which is given by

\[
V_e = G_e + j B_e
\]

Hence, Eq. (1) becomes:

\[
\varepsilon' = \frac{G_e + \left(\frac{\lambda_s}{2a}\right)^2}{1 + \left(\frac{\lambda_s}{2a}\right)^2}
\]

\[
\varepsilon'' = \frac{B_e}{1 + \left(\frac{\lambda_s}{2a}\right)^2}
\]

The admittance $V_e$ is obtained from:

\[
V_e = \left(\frac{T}{kL_s}\right)^2 \angle 2(\tau - 90^\circ)
\]

where, $G_e$ = Conductance offered by the sample

$B_e$ = Susceptance offered by the sample.

$\lambda_s$ = Guide wavelength in air-filled waveguide.

$a$ = Width of the waveguide.

The solution for $T$ and $\tau$ are obtained from the following Eqs (6) and (7).

\[
\tanh(T\angle\tau) = C \angle -\psi
\]

where the complex number is calculated by the equation:

\[
C \angle -\psi = \frac{1}{jkL_s} \times \frac{1 - |\Gamma|e^{j\phi}}{1 + |\Gamma|e^{j\phi}}
\]

Here

$k = 2\pi/\lambda_s$, $\phi = 2k \left(D - D_s - L_s\right)$

$D_s$ = Distance of the minima without the dielectric

$D$ = Distance of the minima with dielectric

$L_s$ = Length of the dielectric introduced in the guide

$|\Gamma|$ = Reflection coefficient = $(r - 1)/(r + 1)$

$r$ = Voltage standing wave ratio

Each soil sample was divided into three parts which were heated in a microwave oven for 20, 40 and 60 minutes, respectively and four sets of power level of the oven, i.e. 90, 160, 360 and 600 watts were used.

5 Approximate solution for the complex transcendental equation to find $T$ and $\tau$

The solution of the transcendental equation when the dielectric loss is very small, i.e. for the range

<table>
<thead>
<tr>
<th>Soils</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Sand (%)</th>
<th>Fine sand (%)</th>
<th>Coarse sand (%)</th>
<th>$\varepsilon'$</th>
<th>$\varepsilon''$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample E (Orissa)</td>
<td>20.7</td>
<td>23.8</td>
<td>55.5</td>
<td>40</td>
<td>15.5</td>
<td>2.2383</td>
<td>0.4693</td>
</tr>
<tr>
<td>Sample F (Orissa)</td>
<td>8.3</td>
<td>12.6</td>
<td>79.1</td>
<td>78.8</td>
<td>3</td>
<td>2.0177</td>
<td>0.301</td>
</tr>
<tr>
<td>Sample G (Himchal Pradesh)</td>
<td>29.1</td>
<td>17.7</td>
<td>52.6</td>
<td>43.6</td>
<td>9</td>
<td>1.9133</td>
<td>0.2084</td>
</tr>
<tr>
<td>Sample H (Gujarat)</td>
<td>4.7</td>
<td>5.3</td>
<td>82.1</td>
<td>40.4</td>
<td>41.7</td>
<td>2.009</td>
<td>0.2628</td>
</tr>
<tr>
<td>Sample I (Rajasthan)</td>
<td>4.2</td>
<td>3.7</td>
<td>86.5</td>
<td>42.2</td>
<td>44.3</td>
<td>2.6672</td>
<td>0.2838</td>
</tr>
</tbody>
</table>
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where \( \tau \) is nearly 90\(^\circ\), can be accomplished to good accuracy by employing the following procedure, assuming that \( k, \tau, |\Gamma| \) and \( \phi \) have been calculated already. The constant \( K \) and \( A \) are found out from the equations

\[
K = \frac{-2|\Gamma|\sin \phi}{kL_e(1 + |\Gamma|^2 + 2|\Gamma|\cos \phi)} \quad \ldots(8)
\]

\[
A = \frac{|\Gamma|^2 - 1}{kL_e(1 + |\Gamma|^2 + 2|\Gamma|\cos \phi)} \quad \ldots(9)
\]

The value of \( X \) is obtained from

\[
\tan \frac{X}{X} = \tan \left[ \frac{k(L_e + D_k - D)}{kL_e} \right] \quad \ldots(10)
\]

Now, the constant \( R \) is found out as follows

\[
R = \frac{AX^2}{\tan X - \tau (1 + \tan^2 X)} \quad \ldots(11)
\]

and \( K' \) is computed as:

\[
K' = \frac{R\tanh R(1 + \tan^2 X) + X\tan X(1 - \tanh^2 R)}{(R^2 + X^2)(1 + \tanh^2 R\tan^2 X)} \quad \ldots(12)
\]

If \( K \) and \( K' \) are identical, the calculated values of \( X \) and \( R \) are acceptable. One can find \( T \) and \( \tau \) from

\[
T = \sqrt{R^2 + X^2} \quad \ldots(13)
\]

and

\[
\tau = \tan^{-1} \left( \frac{X}{R} \right), \quad 45^\circ < \tau < 90^\circ \quad \ldots(14)
\]

6 Results and discussion

In order to determine the variability of dielectric constant of different soil samples which were exposed for varying amounts of microwave radiation, five samples of different soils were taken and exposed to microwave radiation (using a microwave-oven operating at 2.45 GHz) at different power levels and for different time duration.

The variations in the dielectric constant (\( \varepsilon' \) and \( \varepsilon'' \)) for five soils with the different time exposure at 90 W and 600 W amount of microwave energy absorbed are presented in Figs 1 and 2, respectively. It is observed that the dielectric constants of soil samples at microwave power of 600 W is less than the dielectric constants of soil samples at microwave power of 90 W. Hence the values of dielectric constant decrease with the increase of radiated microwave power. Figure 3 shows the trend for the variation in the dielectric constant (\( \varepsilon' \) and \( \varepsilon'' \)) for all the soil samples with different microwave power for the 20 min exposure time. Figures 1-3 show that the dielectric constant (both \( \varepsilon' \) and \( \varepsilon'' \)) for soils decreases with the increase in microwave energy.

The variability in \( \varepsilon' \) and \( \varepsilon'' \) with constituents, i.e. sand, silt and clay are shown in Figs 4-6. The trend lines of the variation of the dielectric constant with the percentage of each constituent are drawn for different durations of exposure to microwave radiations for each power level (i.e. 90 W, 160 W, 360 W and 600 W).
Fig. 3 — Variation of $\varepsilon'$ and $\varepsilon''$ for five soil samples with different radiated microwave power for an exposure of 20 min

Fig. 4 — Variation of $\varepsilon'$ and $\varepsilon''$ with the percentage of sand at different microwave power exposed for 20 min

Fig. 5 — Same as Fig. 4, but for silt

Fig. 6 — Same as Fig. 4, but for clay

The above phenomenon are due to compactness of the constituents and texture size. The variability of dielectric constant with constituents of soil has been discussed in detail where the dependences of dielectric constant on sand, silt and clay are shown. There is a possibility that the above mentioned characteristics are due to the absorption of microwaves. The absorption of microwave energy depends upon the particle size and the way they are arranged.

7 Conclusions

From the study of the variation in dielectric constant of different soil samples, which are exposed to microwave radiation with variable intensity in terms of power and duration, it is evident that the value of dielectric constant decreases with more and more radiation on soil. Linear trends of variation are obtained as shown Figs 1-3. The variation of dielectric constant for different soils suggests that this effect depends on the physical composition of soil. The variation in $\varepsilon'$ and $\varepsilon''$ for the soils having nearly the same constituents is almost the same. The study reveals that there is a slight decrease in $\varepsilon'$ with increasing of sand percentages, whereas this value slightly increases with the increase in silt and clay content. The results are unique because the varied types of soils have been considered in this study. It has been observed that $\varepsilon'$ and $\varepsilon''$ are function of constituents of exposed as well as of unexposed soil.

References


