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ESTIMATION OF COMPLEX DIELECTRIC CONSTANT OF SOLID PARTICLES FROM BULK MEASUREMENT

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ABSTRACT

A theoretical investigation has been carried out to evaluate the complex dielectric constant of solid soil particles from bulk measurement data. For this purpose various expressions suggested by different authors have been utilized and from extrapolation the value of complex dielectric constant of solid soil particles has been obtained. It has been found that the value obtained from the extrapolation has good agreement with the reported value of the dielectric constant of moist solid soil particles. Further, using same suggested formula the complex dielectric constant of moist solid soil particles has also been calculated. It has been observed that the value of complex dielectric constant of solid soil particles increases with increasing percentage of moisture content for each sample.

Key words : Complex dielectric constant, Solid soil particles

INTRODUCTION

The main constituents of soil are sand, silt and clay. These constituents have got important role in the area of soil physics and soil chemistry. It may be mentioned that it is the dielectric constant of solid soil particles, which is used to estimate the various physical and chemical phenomena related to soil samples. Therefore, it is important to calculate the dielectric constant of soil particles from the bulk measurement. For this, many correlations are used to obtain the dielectric constant of the solid soil particles from bulk measurement data. The details of which are given in the following sections.

Correlations for extrapolation

Rayleigh formula : As per Rayleigh, if the volume fraction is very small then the permittivity of medium containing spherical soil particles of permittivity $\in_s$ embedded in a medium of permittivity $\in_m$ can give as[1]

$$\in_b = \in_m [1 + 2v (\in_s - \in_m) / (\in_s - 2\in_m)] \quad ...(1)$$

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where

$\in_b$ = Bulk permitivity

$\in_s$ = Permitivity of solid particle, and

v = Volume fraction

Substituting the complex values of $\in_b$ and $\in_s$ in equation (1), one gets

$$(\in_{1b} - J \in_{2b} - \in_{m)} / (\in_{1b} - j \in_{2b} + 2\in_m) = v (\in_{1s} - j \in_{2s} - \in_m) / (\in_{1s} - j\in_{2s} - 2\in_m) \quad ...(2)$$

Nor for $\in_m = 1$ that is for air, the equation (2) is modified as

$$(\in_{1b} - J \in_{2b} - 1) / (\in_{1b} - j \in_{2b} + 2) = v (\in_{1s} - j \in_{2s} - 1) / (\in_{1s} - j\in_{2s} - 2) \quad ...(3)$$

Solving equation (3) and equating real and imaginary parts, one has

$$\varepsilon 1s = [\in_{1b} (v + 2) + 2(v-1)] [\in_{1b} (v-1) + (2v + 1)] + [\in 2_{2b} (v + 2) (v-1)/ [\in_{1b} (v-1) + 2(v + 1)]^2 + [\in_{2b} (v-1)]^2 \quad ...(4)$$

and

$$\in_{2s} = [\in_{1b} (v + 2) + 2(v-1)] [\in_{2b} (v-1) - [\in_{1b} (v-1) + (2v + 1)] [\in_{2b} (v+2)] / [\in_{1b}(v-1) + (2v+1)]^2 + [\in_{2b} (v-1)]^2 \quad ...(5)$$

Neglecting the higher powers of $\in_{2b}$ in equations (4) and (5), we have

$$\in_{1s} = [2(v-1) + \in_{1b} (v+2)] / [(2v+1)] + \in_{1b} (v-1)] \quad ...(6)$$

$$\in_{2s} = -(v+2) / [(2v+1) + \in_{1b} (v-1)] + (v-1) [2(v-1) + \in_{1b} (v+2)] / [(2v+1) + \in_{1b} (v-1)]^2 \quad ...(7)$$

Bruggeman Formula

In this approach, initially low concentration is gradually increased by infinitesimal addition of dispersed particles so that corresponding permittivity of medium around the solid soil particles changes from $\in_m$ to $\in_b$. Thus Bruggeman suggested the following correlation :

$$(\in_s - \in_b) / (\in_s - \in_m) = 1 - v [\in_b / \in_m]1/3 \quad ...(8)$$

For air as background medium $\in_m = 1$ and therefore, equation (8) is modified as

$$(\in_s - \in_b) / (\in_s - 1) = 1 - v (\in_b)^{1/3}$$

Thus the value of $\in_s$ can be obtained as

$$\in_s = (\in_b - (1-v) \in^{1/3}) / (1 - (1-v) \in_b 1/3) \quad ...(9)$$

Bottcher Formula

The Bottcher formula utilizes the concept of Lorentz equation according to which the value obtained by averaging the interval fields over all the points of dielectric, is given as

$E_{inc.} = (\in_s + 2)/3)E_1$

Let us consider a spherical solid particle embedded in the air dielectric medium ($\in_m$) of the environment of the spherical particles are continuous dielectric, then one has

$$v = (\in_b - \in_m)(2 \in_b + \in_s) / 3 \in_b (\in_s - \in_m) \qquad ...(10)$$

where

$\in_b$ = Permittivity of bulk,

$\in_s$ = Permittivity of solid,

$\in_m$ = Permittivity of air, and

v = Volume fraction of solid particle.

Now from equation (10) the value of solid permittivity $\in_s$ can be obtained as

$$\in_s = (3v \in_m + 2 \in_b - 2 \in_m) / (3v + (\in_m / \in_b) - 1) \qquad ...(11)$$

Putting the complex value of permittivity for $\in_b$ and $\in_s$ and solving, one has

$$\in_{1s} = (2\in_{1b} + 3v - 2) \in_{1b} / [(3v + 1) \in_{1b} + 1]^2 \qquad ...(12)$$

and

$$\in_{2s} = \in_{2b} [2(3v - 1) \in_{1b2} + (3v - 2) + 4\in_{1b}] / [(3v - 1) \in_{1b} + 1]^2 \qquad ...(13)$$

Wagner Formula

If the separation between two spherical particles is large compared to their radii, then the permittivity of the bulk can be calculated using the Wagner formula. Thus

$$\in_b = \in_m [1 + 3v (\in_s - \in_m) / (\in_s + \in_m)] \qquad ...(14)$$

and

$$\in_s = \in_{1s} - j\in_{2s}$$

Then equation (4) can be modified as

$$\in_{1b} - j\in_{2b} = 1 + 3v (\in_{1s} - j\in_{2s} - j\in_{2s} - 1) / (\in_{1s} - j\in_{2s} + 2)$$
$$\in_{1s} - j\in_{2s} = (2 - 3v - 2 (\in_{1b} - j\in_{2b}) / (\in_{1b} - j\in_{2s} - 3v - 1) \qquad ...(15)$$

Solving equation (15) as equating the real and imaginary parts of equation (15), one has

$$\in_{1s} = \{(3v + 2\in_{1b} - 2)(3v + 1 - \in_{1b}) - 2\in_{2s2}\} / \{(3v + 1 - \in_{1b})^2 + \in_{2s2}) \qquad ...(16)$$

$$\in_{2s} = 9v \in_{2b} / (3v + 1 - \in_{1b})^2 + \in_{2b2}) \qquad ...(17)$$

RESULTS AND DISCUSSION

In order to obtain the real and imaginary parts of the complex permittivity of solid soil particles from bulk measurement data, the computational work has been done and the data thus obtained one shown in the Tables 1, 2 and 3. The value of $\in_{1s}$ and $\in_{2s}$ obtained from Wagner formula has good agreement with the reported value. However the same value obtained from Rayleigh formula has excellent agreement with reported values. These well documented correlation are further utilized to obtain the value of moist solid particles and it has been found that the value of $\in_{1s}$ and $\in_{2s}$ increase with increasing percentage of moist content, i.e. like bulk permittivity. The permittivity of solid soil particles depends heavily on the moisture content. The value of $\in_{1s}$ and $\in_{2s}$ for sand silt and clayey silt has large value than reported value. This is due to fact that in case of bulk measurement, the value of bulk permittivity varies due to different packing lengths. Due to variation in the bulk measurement data, the variation in the value of $\in_{1s}$ and $\in_{2s}$ for sand, silt and clayey silt occurs obviously. It may be, therefore concluded that the extrapolated value of solid permittivity obtained from these correlations for sand, silt and clay has excellent agreement with reported values. Hence, these correlations are very much suitable for these samples.

Table 1. Calculated values of $\in_{1s}$ for dry sandy sample

Volume fraction	Wagner	Rayleigh	Bruggeman	Bottcher
0.81	33.30	4.21	4.1	3.97
0.85	18.42	3.6	3.9	3.66
0.91	16.6	3.2	3.5	3.21
0.96	14.9	2.99	3.1	2.96

Table 2. Calculated values of $\in_{1s}$ for dry silty sample

Volume fraction	Wagner	Rayleigh	Bruggeman	Bottcher
0.80	27.36	4.13	4.01	3.96
0.83	27.04	4.05	3.96	3.92
0.86	26.6	3.99	3.92	3.85

Table 3. Calculated values of $\in_{1s}$ for dry clayey sample

Volume fraction	Wagner	Rayleigh	Bruggeman	Bottcher
0.76	37.08	4.6	4.27	3.90
0.82	41.85	4.2	4.20	3.95
0.86	48.87	4.4	4.32	3.97
0.88	71.70	4.5	4.18	4.07

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REFERENCES

1. D. A. C. Bruggeman, "Berechnug Verschiedner Physikalischer Konstanten Von Heterogenen Substanzen". Ann. Phys. Vol. 24, 636 (1935).
2. C. J. F. Bottcher, "Theory of Dielectric Polarization", Elsevier, Amsterdam (1952) p.419.
3. J. A. Goldhirsh, "Parameter Review and Assessment of Attenuation and Back Scattering Properties Associated with Dust Storms over Desert Regions in the Frequency Range of 1–10 GHz", IEEE Trans., Vol. AP 30, (1982) pp. 1121–1127.
4. S. M. Sharief and S. I. Ghobrial, "X–Band Measurement of the Dielectric Constant of Dust", VRSI Commission F. Symposium, Luvain–la–Neuve, Belgium E.S.A. Publication, SP–194 (1983) pp. 143–147.
5. S. J. Al Badar and M. M. Dawoud, Measurements of the Complex Refractive Index of Soils and Airborne Particles", Proc. V.R.S.I. Commission F. Symposium, Louvain–la-Neuve, Belgium, E.S.A. Publication, S.P. 194 (1983), pp 149–152.
6. H. T. Al Hafid, B. R. Vishvakarma and Al–Rizzo, "Coupler Dielectric Constant of Sand and Dust Particles at 11 GHz as a Function of Moisture Content". Indian J. Radio Space Phys., **14**, 21 (1984).
7. L. P. Bayvel and A. K. Jones, "Electromagnetic scattering and its Applications". Applied Science Publishers, London and New Jersey, 1981, p.19.

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