THE EFFECT OF CLAY AND ORGANIC MATTER CONTENT ON THE DIELECTRIC PERMITTIVITY OF SOILS AND GROUNDS AT THE FREQUENCY RANGE FROM 10 MHz TO 1 GHz

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1. INTRODUCTION

For the algorithms processing microwave radiometric and radar remote sensing of the Earth surface data, as well as for subsurface probing data, it is necessary to have dielectric models for the complex permittivity (CP or $\dot{\varepsilon}$) of moist soil which determine the dependence of CP on the temperature, moisture, wave frequency, particle-size distribution, mineral and organic matter contents. The basic contribution to the soil CP is invoked by soil water, which is present in the free and bound water forms [1], [2]. The experimental researches have shown, that CP of various soils depends on particle-size distribution and mineral contents [3]-[5]. So far, the CP at P-band (below 300 MHz) is less investigated. The frequency dependence analysis for the moist soils CP in this frequency range has revealed a noticeable increase of the real and imaginary parts of CP in the frequencies range below 50 MHz [5]. This growth is most noticeable for the soils having large clay percentage.

The presence of the organic matter also results in increase of the CDP. At the same time, in the frequency range situated above 1 GHz, the presence of organic matter increases the bound water fraction and thus reduces the CDP values in the whole range of moistures [6]. However, the dependence of the soil CDP on moisture, soil particle-size distribution, in the frequency range situated below 300 MHz has not been studied yet. In the present work, the results of CP studies for some moist artificial soil like mixes, having different particle-size distributions, are given.[1]

2. EXPERIMENT DESCRIPTION

To measure CP in the frequency range from 50 MHz to 1 GHz, the sample under investigation was placed in a segment of coaxial line with the cross section size of 7/3 mm. While for CP measurement in the range from 10

[1] This research was supported by the Siberian Branch of the Russian Academy of Sciences under Project No 10.4.6 and under interdisciplinary Project No 6.

MHz to 80 MHz, the sample was placed in a capacitor, inserted in a gap of the coaxial line. Dielectric measurements were made using a vector network analyzer, which measures the scattering matrix components of the coaxial segment and capacitor.

The bentonite (sample No. 13 in Table 1) and three types of quartz particles in the form of nearly spherical granules (samples NoNo. 1-3) were used to make soil like mixtures. The mixtures containing quartz granules and bentonite clay particles with varying percentages by mass (95 and 5, 70 and 30, 50 and50) for each type of granules were measured.

Also there were measure a number of natural soil samples having different organic matter contents. In total, 16 samples were manufactured and measured.

Table 1. The distribution of particle size in the studied samples.

No sample	The distribution of particle size in mm (in mass fractions)			
	1-0.25 mm	0.25-0.05 mm	0.05-0.01 mm	<0.01 mm
1	0.133	0.867	0	0
2	0	0.90	0.10	0
3	0	0.042	0.958	0
…	…	…	…	…
11	0.02	0.50	0.171	0.359
…	…	…	…	…
13	0.04	0	0.242	0.718

3. EXPERIMENT RESULTS AND DISCUSSION

In Fig. 1 the measured values of the real part of CP and dielectric loss tangent, tgδ, are show as functions of frequency and temperature for the two moist samples: 1) pure quartz sand grains with the size of 40-70 microns (sample No. 2); 2) bentonite (sample No. 13). In Fig. 2, the values of ε' and tgδ for the pure quartz sand grains mixed with bentonite clay (with all particle sizes < 0.01 mm) in different percentages are given. One can see that the temperature dependencies in the cases of only quartz grains or mixtures with bentonite clay are quite different. The real part of CP of moist grains decreases with the temperature increasing, which can be explained due to dielectric properties of water. The real part of CP of moist bentonite increases the temperature increasing, which may be caused by the interlayer polarization taking place near the solids surface. This kind of polarization is observed with the samples having a large specific surface of solids, particularly at lower frequencies.

Figure 3 shows the dependence of the real part of the refractive index $\dot{n} = n + j\kappa = \sqrt{\dot{\varepsilon}}$ on the volumetric moisture W of two samples – pure quartz sand grains (sample No. 2) and the same sand mixed with bentonite (sample No. 11) at two frequencies of 300 MHz and 1 GHz. One can see that the regression lines slope angles for the pure quartz sand grains and grains with bentonite in the values of the free soil water (for the sand it is the entire range of moisture, but for a mixture of sand grains with bentonite it is the value of moisture in excess of 0.18 cm^3/cm^3) differ significantly.

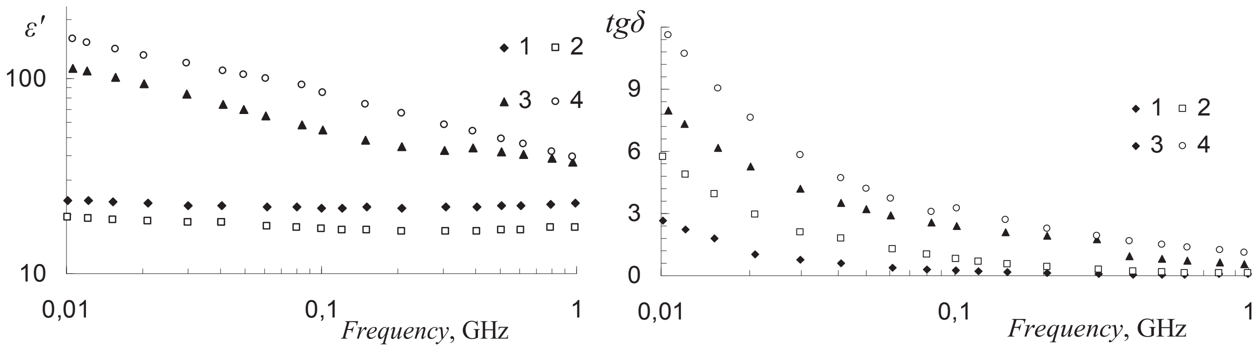

Fig. 1. Frequency dependence of real part of the CP (ε ') and the dielectric loss tangent (tgδ) of the moist samples. 1,2 is sample No. 2 with a moisture of 0.30 cm^3/cm^3; 3,4 is sample No. 13 with a moisture of 0.62 cm^3/cm^3; 1,3 is temperature of 25ºC; 2,4 is temperature of 85ºC.

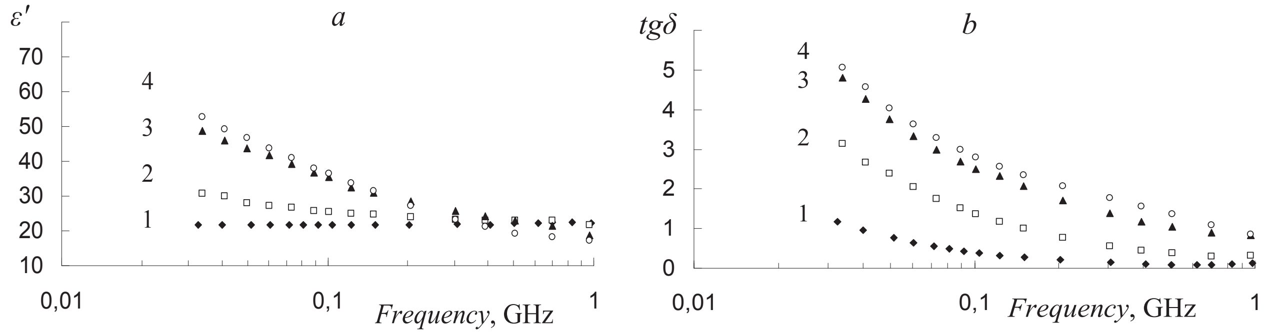

Fig. 2. Frequency dependence of ε ' and tgδ of the sample No 2 (curve 1) and mixtures with a different clay content at the temperature of 25ºC; clay content of 3.6 %, moisture of 0.32 cm^3/cm^3 (curve 2); clay content of 21.5 %, moisture of 0.34 cm^3/cm^3 (curve 3); clay content of 36 %, moisture of 0.35 cm^3/cm^3 (curve 4).

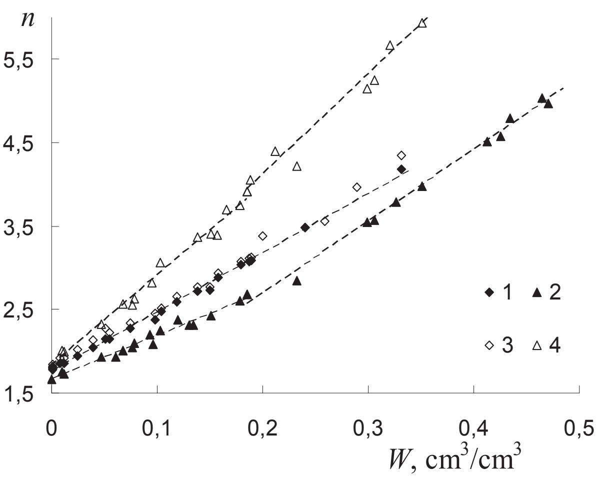

Fig. 3. The real part of the refractive index vs. moisture of samples No. 2 (curve 1,3) and No. 11 (curve 2,4) at 1 GHz (1,2) and 300 MHz (3,4).

As seen from Fig. 3, the inclination angle tangent of the regression line corresponding to the free soil water present in the mixture of sand and bentonite clay is considerably higher than it is in the case of pure sand.

This difference becomes larger with the frequency decreasing. For instance, in case of sample No. 2 the refractive index of free water does not practically depend on frequency. While in the case of sample No. 11 the refractive index of free water noticeably increases with the frequency decreasing.

Similar variations for the free water refractive index with the frequency decreasing were also observed in the case of samples having different organic matter contents.

4. CONCLUSION

The complex permittivity measurement for 16 moist soil like samples were carried out as functions of frequency and moisture. It was shown that the greatest variations with the frequency increasing were observed in the case of samples containing large clay and organic matter percentages.

5. REFERENCES

[1] V.L. Mironov, L.G. Kosolapova, and S.V. Fomin, "Physically and Mineralogically Based Spectroscopic Dielectric Model for Moist Soils," *IEEE Trans. Geosci. Remote Sensing*, vol. 47, no. 7, pp. 2059-2070, 2009

[2] N. R. Peplinski , F. T. Ulaby and M. C. Dobson, "Dielectric Properties of Soils in the 0.3-1.3-GHz Range," *IEEE Trans. Geosci. Remote Sensing*, vol. 33, no. 3, pp. 803 – 807, May 1995.

[3] J. O. Curtis, "Moisture Effects on the Dielectric Properties of Soils," *IEEE Trans. Geosci. Remote Sensing*, vol. 39, no. 1, pp. 125 – 128, January 2001.

[4] J. E. Campbell , "Dielectric Properties and Influence of Conductivity in Soils at One to Fifty Megahertz," *Soil Sci. Soc. Am. J.* vol. 54, pp.:332-341, 1990.

[5] J.E. Hipp "Soil Electromagnetic Parameters as Function of Frequency, Soil Density, and Soil Moisture" *Proceedings of the IEEE*. vol. 62. no 1. pp. 98-103, January 1974.

[6] V.L. Mironov, P.P. Bobrov, O.A. Ivchenko, S.V. Krivaltsevitsh and A.S. Jaschenko, "Dynamic Radiobrightness for Drying Soils as a Function of Humus Content," *Proc. of IGARSS'2005*, Seoul, Korea, vol. II, pp. 1127-1130, 2005.