THE MAXIMUM BOUND WATER CONTENT MEASUREMENT BY DIELECTRIC AND NMR TECHNIQUE

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1. INTRODUCTION

The relaxation processes in soils in UHF range are mainly accounted for by soil water. Therefore, it is significant to take into account dielectric properties of water when processing the remote sensing data. There a great many of models permittivity of moist soils, which consider the soil as a heterogeneous medium containing water alongside with mineral particles and air inclusions. The measurements on the dielectric properties of moist soils as a function of water content revealed different functional dependences of soil permittivity, with water content being less and greater regarding some critical moister value [1]. Specifically, complex dielectric constant was found to increase with moister more slowly, the soil moisture being below this point. It takes place because of electrostatic forces impact on water molecule dipoles adjacent to the surface of soil particles. To take in account this phenomenon J. Wang and T. Schmugge [1] proposed dielectric model of moist soils In accordance with this model, the critical moister point was named transition moister.

One more model where a moisture transition point is employed is the generalized refractive mixing dielectric model (GRMDM) proposed in [3]. In accordance with this model, soil water at moistures below transition point were considered as a bound water type, and transition point was designated as the maximum bound water content (MBWC). The soil water in excess of the MBWC is associated with unbound liquid water. Both the Schmugge model and GRMDM allow to derive MBWC as the result of regression analysis. At that, the values of transition points derived with the Schmugge model and GRMDM are different. In the present studies the MBWC was measured with the use of nuclear magnetic resonance (NMR) technique to be used as an independent source of data. The values of MBWS measured with the three independent approaches were compared to each other.[1]

2. DIELECTRIC MODELS

2.1. Schmugge model

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The expressions for the complex permittivity of a soil-water mixture according to the Schmugge model are given by

$$\varepsilon = W\varepsilon_x + (P-W)\varepsilon_a + (1-P)\varepsilon_r\,,\ W \le W_t\,, \text{ where } \varepsilon_x = \varepsilon_i + (\varepsilon_w - \varepsilon_i)\frac{W}{W_t}\gamma \tag{1}$$

and

$$\varepsilon = W_t\varepsilon_x + (W-W_t)\varepsilon_w + (P-W)\varepsilon_a + (1-P)\varepsilon_r\,,\ W > W_t\,, \text{ where } \varepsilon_x = \varepsilon_i + (\varepsilon_w - \varepsilon_i)\gamma\,. \tag{2}$$

Here $P = 1 - \rho_s/\rho_r$ is the porosity of the dry soil, where ρ_s and ρ_r are the density of the dry soil and the density of associated solid rock, respectively, W, W_t are moister of soil and transition moister. ε_a, ε_w, ε_r and ε_i, in sequential order, are the permittivity of air, water, rock, and ice. ε_x stands for the permittivity of the initially absorbed water. γ is a parameter which can be chosen to best fit (1) and (2) to the experimental data. So far as dielectric constant of water ε_w in Schmugge model is the same of pure water, this parameter can be given by dielectric models of pure water by Stogrin's empirical formulas for example [4].

2.2. Generalized refractive mixing dielectric model

According to the GRMDM the dependencies of complex refractive index (CRI) $n^* = n + i\kappa$ on moister is linear:

$$n_s(W,f,t) = \begin{cases} n_d^* + (n_b^*(f,t)-1)W, & W \le W_t \\ n_s^*(W_t,f,t) + (n_u^*(f,t)-1)(W-W_t), & W > W_t \end{cases} \tag{3}$$

where n is refractive index (RI) and κ is normalized attenuation coefficient (NAC), W, W_t are moister of soil and MBWC. The subscripts *s*, *d*, *b*, and *u* are related to moist soil, dry content of soil, bound water and unbound water in soil, respectively, t is the temperature value of the soil. Dielectric constant ε' and loss factor ε" are related to RI and NAC by

$$\varepsilon' = n^2 - \kappa^2\,,\ \varepsilon'' = 2n\kappa\,. \tag{4}$$

The dielectric constant and the loss factor for the components of bound water and unbound water are represented by the Debye relaxation expressions:

$$\varepsilon'_{b,u} = \varepsilon_\infty + \frac{\varepsilon_{0b,0u} - \varepsilon_{\infty b,\infty u}}{1+\left(2\pi f \tau_{b,u}\right)^2}\,,\ \varepsilon''_{b,u} = \frac{\varepsilon_{0b,0u} - \varepsilon_{\infty b,\infty u}}{1+\left(2\pi f\tau_{b,u}\right)^2}2\pi f\tau_{b,u} + \frac{\sigma_{b,u}}{2\pi\varepsilon_r f} \tag{5}$$

where f is the frequency value of the electromagnetic field and $\sigma_{b,u}$, $\tau_{b,u}$, $\varepsilon_{0b,0u}$, and $\varepsilon_{\infty b,\infty u}$ denote conductivity, relaxation time, extreme low-frequency and high-frequency dielectric permittivity of bound and free water. Spectroscopic parameters of bound water and unbound water in (5) are derived by fitting procedure according to the concept of this model and vary with the type of soil.

3. RESULTS

The measurements of dielectric constant of the bentonite clay sample was conducted in the range of frequency from 0.5 GHz to 15 GHz. The measurement technique applied was similar to that used in [4].

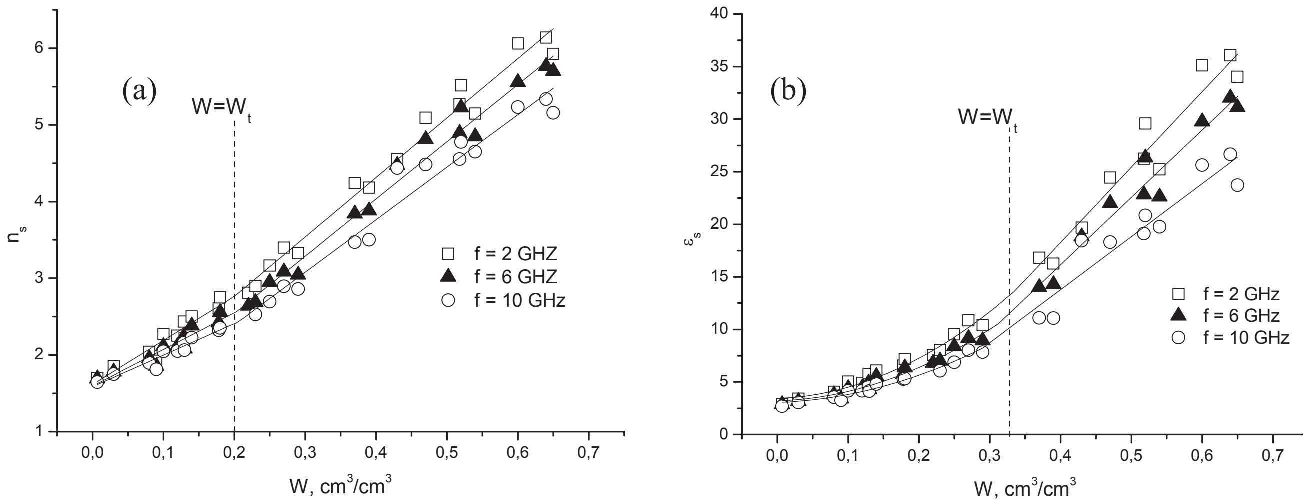

Fig.1. Measured refractive index (a) and dielectric constant (b) as a function of moisture content at the temperature of 20 ºC.

The measured dielectric constant ε_s and refractive index n_s of the bentonite clay as measured at the frequencies of 2 GHz, 6 GHz, 10 GHz and the temperature 20 ºC are shown as a function of moisture in Fig. 1. Using regression analysis with the Schmugge formulas (1)-(2) and GRMDM ones (3)-(5), the values of MBWC were found to be 0.20±0.05 cm^3/cm^3 and 0.33±0.07 cm^3/cm^3 respectively. It is easy to see that the MBWCs obtained with the use of the Schmugge model and GRMDM are different. This difference of obtained values is a result of employing different dielectric models. Therefore, a question arises which one can be considered as a true amount of soil water having specific macrophysics characteristics.

Keeping in mind that both the Schmugge and GRMDM values for the transition point W_t were derived using the dielectric measurements, that is, measurement of the state of soil water polarization, one should expect for these values to be equal to each other within the limits of measurement error. But the values derived, namely, 0.20±0.05 cm^3/cm^3 and 0.33±0.07 cm^3/cm^3 are seen to be different ones. To ascertain which one is more likely to divide a total amount of soil water into two parts having different macrophysics properties, we validated these values, using the value of transition point W_t measured by an independent physical experiment. For this purpose we applied the NMR spectra measured for moist samples containing varying amount of water. This method has been chosen as it is widely used for studying aggregation state of water in very different media, such as crystals, gels and biological objects.

NMR spectrum of ^{1}H of bentonitic clay were measured by pulse spectrometer AVANCE 300 by “Bruker” at frequency 300.14 MHz and temperature 20 ºC. The standardized technique of Fourier spectroscopy has been used for spectrum registration. The duration of 90-degree radiofrequency pulse was equal to about 10 µsec. After Fourier processing of the collected data, the width of spectrum was measured at a half of its amplitude, hereinafter referred to as a half-width. The measured half-width of NMR spectrum versus moisture at 20 ºC is shown in Fig. 2. The dots represent measured values, while the solid lines are the two different polynomial fits of the second order to the measured half-widths . The point of interception W_{ft} = 0.25±0.01 cm^3/cm^3 ot the two fitting polynomials was considered to divide the soil water by their macrophysics states, in terms of half-width of their NMR spectra. From Fig. 2, one can see that that mobility of soil water protons at the moistures lower then W_{ft} is less then that at the moister greater then W_{ft}. Therefore, we accepted the soil water at moister $W<W_{ft}$ and $W>W_{ft}$ to belong to the bound and unbound (free) water types, with W_{ft} being equal to the MBWC.

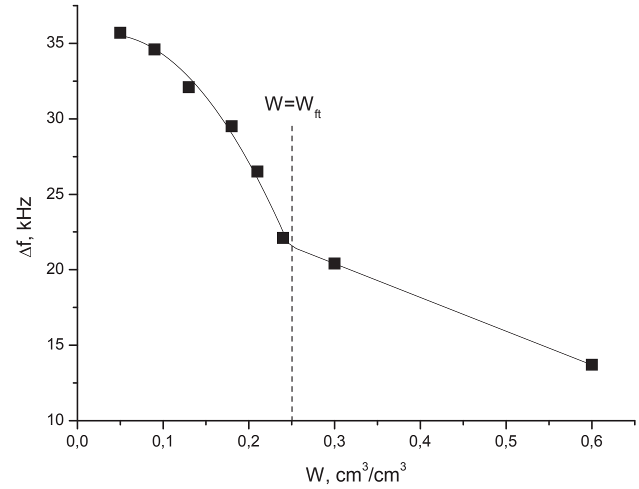

Fig. 2. The dependence of half-width of NMR spectrum against soil moister at the temperature 20 ºC.

4. CONCLUSION

The results of MBWC measurement by the two dielectric and NMR techniques were attained as independent assessments for the MBWC. The MBWCs obtained with the use of the dielectric measurement but derived using different dielectric models, that is, the Schmugge model and GRMDM, were found to be of 0.20±0.05 cm^3/cm^3 and 0.33±0.07 cm^3/cm^3, respectively, clearly demonstrating the quantitative differece. At the same time, the MBWCs measured by the NMR technique was found to be of 0.25±0.01 cm^3/cm^3. This value is closer to the one measured with the use of the GRMDM approach. Though, it is clear that these two values should not be rigorously equal to each other, because they were determined using different parameters of the microphysical state of soil water.

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