The Electrical Characteristics of the Rocks with Different Texture

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Abstract— The results of measuring the frequency characteristics of the complex relative permittivity (CRP) of the artificial clay-sand mixtures having different porosity and specific surface saturable deionized water and emulsion brine-oil are given. It is shown that at the frequency of 1 GHz the real part of the CRP of the water-saturated samples increases almost linearly with increasing porosity, and at 50 MHz it increases almost linearly with increasing specific surface area. Frequency dispersion is described based on the relaxation model of Cole-Cole. It is shown that the relaxation time increases with a decrease of the specific surface area of the samples saturated with deionized water. When the sample was saturated with brine-oil emulsion the relaxation time decreases with increasing of concentration of the solution and also with decreasing oil fraction.

1. INTRODUCTION

The measurements of the complex relative permittivity (CRP) in the wide frequency band allow to study the different polarization effects in clayey porous rocks. Because of the CPR sensitivity to rock texture and fluid saturation, wide-band electromagnetic measurements exhibit frequency dispersion of CPR that are influenced by a variety of petrophysical properties, including porosity, pore morphology, clay amounts, specific surface area and fluid saturation.

Many measurements have been done to study the dielectric spectra of porous saturated media saturated with fluids in different frequency ranges from 10 MHz to 40 GHz [1–7]. Usually samples are measured in narrow frequency bands because of the absence of broadband measurement methods. It does not allow continuous spectra of CPR and acquisition of full information about the frequency dispersion of CPR. Due to our method [8], we can measure the dielectric properties of the same sample in a wide frequency range.

In this paper, we focus on the dependence of the CPR frequency dispersion on the specific surface of artificial mixtures at saturation by deionized water and fluid containing oil and brine.

2. EXPERIMENT DESCRIPTION

The river sand with particle sizes of 200 to 400 microns and a specific surface area of 0.05 m^2/g, or spherical quartz granules with particle sizes from 45 to 65 microm and a specific surface area of 0.08 m^2/g was the sand fraction of the mixture. There were also 4 types of clay used in making mixture: bentonite (B1), Ca — bentonite (B2), Na — bentonite (B3) and kaoline (K). The areas of a specific surface were measured by a method of adsorption of nitrogen and were found to be 140 m^2/g and 60 m^2/g to 70 m^2/g and 17 m^2/g, respectively.

Samples were saturated either with deionized water or brine-oil emulsion. NaCl brine was used at a concentration of 4 g/l or 20 g/l.

We performed the dielectric measurements in the frequency range from 1 MHz to 4–8.5 GHz at 25°C. The samples after fluid saturation were kept overnight in a closed container. Samples No. 1–7 and No. 10–20 were formed into a cylinder coaxial hole with the size of the measuring cell using a press under a pressure of 10 kPa. The use of the press allows us to reduce porosity and increase the density of the sample, as well as to remove almost all the air in it. Samples number 8, 9 were not pressed.

After the measurements, the samples were dried at a temperature of 105°C for calculating the porosity P, and the water saturation level $K_W = W/P$, where W — the volume fraction of water in the sample. The specific surface area S was calculated from the amount and type of clay in the sample. Physical characteristics of the samples are given in the table.

For the dieletric measurements, coaxial line of length from 2 to 5 cm was used and the diameters of the outer and inner conductors were 16 mm and 6.96 mm, respectively. The measurement method is described in [8].

Due to the high losses of electromagnetic energy in the samples the real measurement error of the CRP ε' ranged from 3% to 10% in the investigated frequency band. Measurement error of the imaginary part of the CRP ε'' was no more than 3%.

Table 1: Physical properties of the samples.

No	Type of clay	Type of sand	K_W	Sand/clay ratio	Saturating fluid	Porosity, P	τ, nsec	S, m^2/g
1	B1	rives sand	0.1	50-50	brine 4 g/l-oil	0.365	58.89	23.03
2			0.33	50-50		0.469	55.68	23.03
3			0.66	50-50		0.469	49.47	23.03
4			0.1	50-50	brine 20 g/l-oil	0.428	52.75	23.03
5			0.33	50-50		0.481	47.60	23.03
6			0.66	50-50		0.372	37.05	23.03
7			0.9	50-50		0.482	29.15	23.03
8		quartz granules	1	50-50	deoinized water	0.445	4.57	70.0
9			1	70-30		0.454	7.73	42.0
10	B2 (Ca-Bentonite)	river sand	0.99	0-100		0.67	4.1	60.0
11			1.00	30-70		0.59	14.3	42.0
12			1.00	50-50		0.47	19.8	30.0
13			0.73	70-30		0.30	43.2	18.0
14	B3 (Na-Bentonite)		0.80	0-100		0.64	4.2	70.0
15			0.99	30-70		0.52	7.5	49.0
16			1.00	50-50		0.45	15.7	35.0
17			0.96	70-30		0.36	26.6	21.0
18	K (kaoline)		0.97	0-100		0.46	373	17
19			0.95	50-50		0.28	63.9	8.5
20			0.93	70-30		0.23	79.6	5.1

3. EXPERIMENT RESULTS AND DISCUSSION

The real and imaginary parts of the CRP of the samples with the same content for various types of clay are given in Fig. 1. Evidently, at frequencies below 0.5–1 GHz it is observed the increase of the real and imaginary parts of the CRP, caused by interfacial polarization. Low increase for the sample with kaolin clay is due to the low specific surface of kaolin. Similar dependence was observed for all samples containing various types of clay. The results of measurements of mixtures with different sizes of sand granules showed that the grain size has very little effect on the CRP of the mixtures.

Research has shown that in sandstones [1] and in the samples containing 70% of clay saturated with water there is an almost linear dependence of the real part of CRP ε' at 1 GHz on the porosity P (Fig. 2(a)). The higher the porosity, the greater the water content in the sample W, and hence

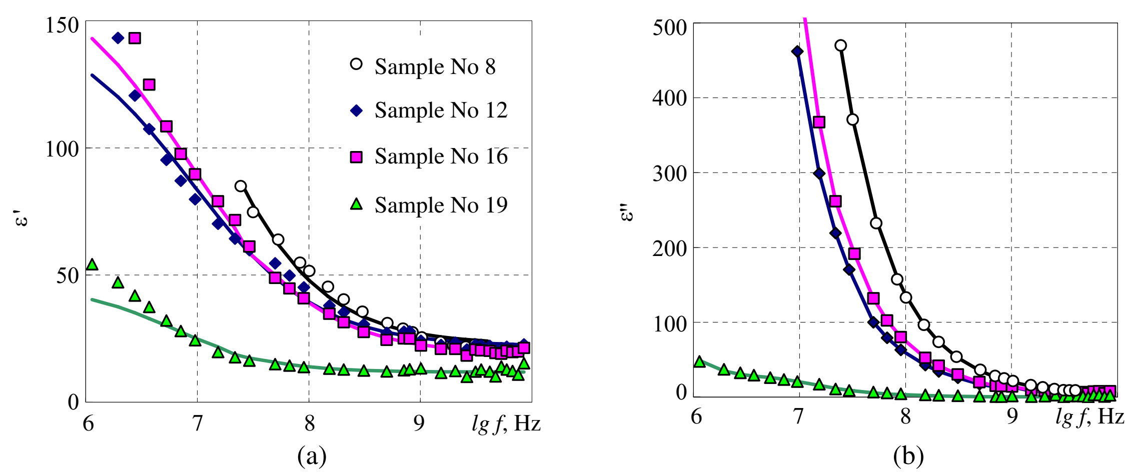

Figure 1: CRP frequency dependencies of samples No. 8, 12, 16 and 19. (a) Real and (b) imaginary parts. The solid lines are the calculation results.

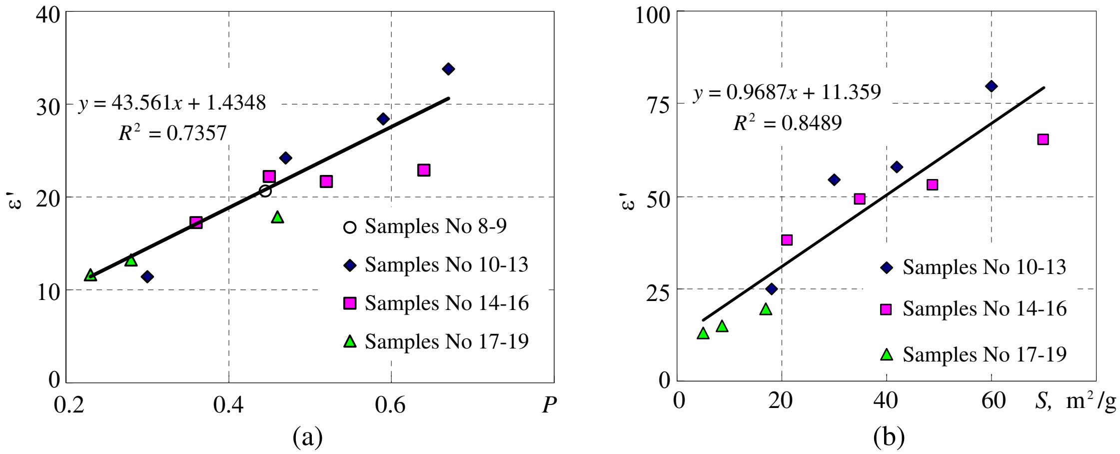

Figure 2: The dependence of the real part of CRP of the samples No 8–20 (a) on the porosity P at 1 GHz and (b) on the specific surface area S at 50 MHz.

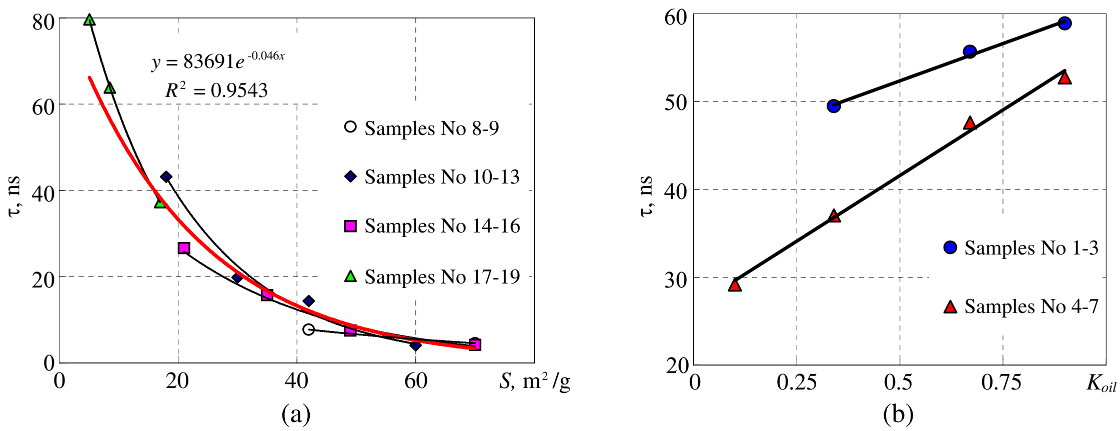

Figure 3: The dependence of the relaxation time (a) on the specific surface area for samples No. 8–20 and (b) on the oil saturation level K_{oil} for samples No. 1–7.

the higher value of ε'. Interfacial polarization occurs only at frequencies below 1 GHz. Its influence is stronger for greater specific surface area. You can choose the frequency at which the dependence of $\varepsilon'(S)$ is the closest to a linear relationship. Fig. 2(b) shows such dependence at frequency of 50 MHz.

For the CRP dispersion modeling, we used the relaxation model of Cole-Cole:

$$\dot{\varepsilon} = \varepsilon_\infty + \frac{\varepsilon_S - \varepsilon_\infty}{1 + (j\omega\tau)^{1-\alpha}} - j\frac{\sigma}{\omega\varepsilon_0}, \tag{1}$$

where ε_∞ is high-frequency dielectric constant; ε_S is static dielectric constant; ω is the angular frequency; ε_0 is permittivity of free space, τ is relaxation time; σ is ionic conductivity; j is imaginary unit; α is the coefficient of distribution of relaxation times, which can vary from 0 to 1.

The constants of the Cole-Cole were chosen by minimizing the difference between the experimental and calculated data by the method of least squares. While selection of the model parameters, we used the Newton method. Depending on the initial values of the constants of the Cole-Cole model their values after solving the problem of minimizing were different. We took the solution in which the value of the relaxation time and the static dielectric constant were the lowest.

The relaxation times in different water-saturated samples, obtained from Formula (1) decrease exponentially with the increase of the specific surface area.

The solid lines in Fig. 3(a) shows the approximation of the values of the relaxation times of all the samples. The dependences for different types of clay are shown separately. It is observed that the relaxation time in the samples containing Ca-bentonite changes more rapidly at the surface changes than that in the samples containing clay of other forms.

Relaxation time in the samples with the same specific surface area depends on the proportion of oil and brine concentrations in the saturating fluid (Fig. 3(b)). The relaxation time increases with increasing proportion of oil and decreases with increasing concentration of brine.

4. CONCLUSION

As a result of the research work, the dependencies of the CDP of the sand-clay mixtures on the specific surface, porosity and properties of the saturating fluid are determined. The obtained results could be used to interpret dielectric logging, induction-based electromagnetic methods, and ground penetrating radar data to characterize the soils of vadose zone and reservoir rocks.

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