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# Research of dielectric properties of oil dispersed systems depending on the ratio of asphalt-resinous substances

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The degree of influence of the electromagnetic field on oil dispersed systems depends on the dielectric properties of these systems, in particular oil. Dielectric properties of oil depend on the content of high molecular weight polar components: asphaltenes and resins. In this regard, a study was carried out of the dielectric properties of oil in the radio-frequency range, depending on the content of asphalt-resinous substances in it. The obtained results of experimental studies show the correlation of dielectric parameters with the ratio of the content of resins and asphaltenes in oil.

**Keywords:** petroleum dispersed systems, asphalt-resinous substances, dielectric properties, dielectric loss tangent, resonance frequency

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The last few years have seen an ongoing search for new techniques involving the use of physical fields for stimulation of production and improvement of the quality of extracted products in the oil industry. High-frequency electromagnetic fields may be the most convenient and efficient in this context.

Electromagnetic fields may be used for bottom-hole area heating in the process of oil extraction. Electromagnetic heating has an advantage in that electromagnetic waves have the capacity to penetrate deep into the formation. The formation is heated due to the loss of energy of the electromagnetic field in the process of propagation of electromagnetic waves. These energy losses depend on the wave parameters and the dielectric properties of oil and the oil-bearing rock in general [1–4].

High-frequency electromagnetic fields may be used efficiently for oil dehydration in the process of oil treatment. It is known that oil wells produce highly stable water-oil emulsions. Their stability is ensured by protective shells formed by polar oil molecules (asphaltenes) around water globules. The presence of polar oil molecules in emulsions opens up the opportunity to use high-frequency electromagnetic fields for efficient breakdown of emulsions [5,6].

Electromagnetic fields may also be used to control the formation of deposits in oil-field equipment and pipes in oil transportation [7,8].

The extent of interaction between the electromagnetic field and oil dispersed media (oil, oil-saturated media, water-oil emulsions) in all the above processes depends on the dielectric properties of these media that, in turn, depend on the concentration of asphalt-resinous substances in oil [9,10]. Depending on the oil grade, the asphaltene and/or resin content of oil may be as high as 20%. Thus, the examination of dependences of the dielectric properties of oil on the concentration of asphalt-resinous substances in it is highly topical. The aim of the present study is to investigate the dependences of the high-frequency dielectric properties of oil on the concentration of asphalt-resinous substances in it.

It was demonstrated in [9,10] that the dielectric properties of oil dispersed media (water-and-oil-saturated rocks and water-oil emulsions) are largely dependent on the oil grade. Therefore, natural oil samples with different concentrations of macromolecular substances were used in the present study (see the table).

Their dielectric properties were examined with a VM 560 quality-factor meter (frequency range: 0.05−35 MHz) [11]. The frequency dependences of the dielectric loss tangent ($\mathrm{tg}\,\delta$) of oil were studied in the frequency range of 0.1−35 MHz.

Figure 1 presents the $\mathrm{tg}\,\delta(f)$ curves for the studied oil grades. It can be seen that the $\mathrm{tg}\,\delta(f)$ curves are of a resonance nature with resonance frequency $f_{res}$ and the corresponding dielectric loss tangent $\mathrm{tg}\,\delta_m$. The width of the resonance curve corresponds to the region of polarization

Concentration of resins and asphaltenes and their ratio in the studied oil grades

| Oil grade | Asphaltenes, wt.% | Resins, wt.% | Resins/asphaltenes ($R/A$) |
|---|---|---|---|
| 1 | 2.3 | 18.4 | 8.0 |
| 2 | 2.6 | 15.2 | 5.8 |
| 3 | 1.19 | 16.6 | 13.9 |
| 4 | 3.2 | 11.4 | 3.6 |
| 5 | 2.32 | 12.00 | 5.2 |
| 6 | 10.71 | 3.26 | 0.3 |
| 7 | 0.92 | 10.6 | 11.5 |
| 8 | 0.67 | 6.2 | 9.3 |

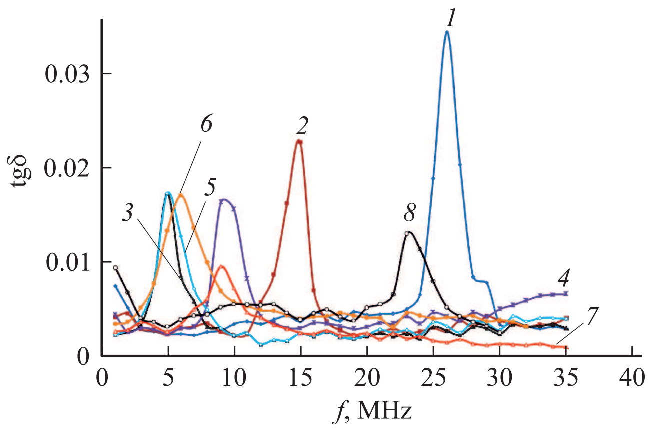


**Figure 1.** Dependences $\mathrm{tg}\,\delta(f)$ for the studied oil grades. The numbering of curves corresponds to the numbering of oil grades in the table.

of polar components of oil, which may occupy various frequency intervals. This suggests that different oil grades feature different relaxation times of dielectric polarization of polar components. According to the relation between the relaxation time and molecular constants formulated by Debye [12]:

$$f_{res} = \frac{kT}{4\pi\eta a^3}$$

(where $f_{res}$ is the resonance frequency corresponding to the maximum dielectric loss tangent $\mathrm{tg}\,\delta_m$, $k$ is the Boltzmann constant, $T$ is temperature, $\eta$ is the viscosity of liquid, and $a$ is the radius of a spherical molecule), molecules $1-2$ nm in size feature dielectric polarization at frequencies of $1-30$ MHz.

This is the size of individual asphaltene molecules. Resins are an order of magnitude smaller in size and stabilize individual asphaltene molecules by adsorbing on their surface. If resins are lacking, asphaltenes combine into nanoaggregates, clusters, and agglomerates [13–15].

It follows from the results of comparative analysis of $\mathrm{tg}\,\delta_m$ values for different oil grades with different concentrations of macromolecular compounds (asphaltenes, resins, paraffins) that $\mathrm{tg}\,\delta_m$ is correlated with the ratio of resins and asphaltenes in oil. Figure 2 presents the dependences of $\mathrm{tg}\,\delta_m$ values on the ratio of concentrations of resins and asphaltenes in oil ($R/A$).

It can be seen that the maximum of the dependence of $\mathrm{tg}\,\delta_m$ on $R/A$ corresponds to $R/A = 8/1$. This is indicative of the fact that asphaltenes are completely peptized and stabilized by resins (i.e., asphaltenes cease to exist in the form of agglomerates and become more mobile and prone to participation in polarization processes) at this $R/A$ ratio. When $R/A$ grows above 8/1, the values of $\mathrm{tg}\,\delta_m$ go down (the polarity of oil decreases). It is possible that resin molecules present in excess quantities adsorb on asphaltene molecules and form protective shells consisting of several layers, thus isolating and enlarging asphaltenes.

A similar dependence on $R/A$ was plotted for the resonance frequency (Fig. 3).

It can be seen from Fig. 3 that resonance frequency $f_{res}$ and, consequently, the region of polarization of asphaltene molecules shift toward higher frequencies (i.e., the dielectric relaxation time decreases) as ratio $R/A$ increases to 8/1. This is also attributable to the breakdown of asphaltene agglomerates by resins. At higher $R/A$ ratios, the resonance frequency shifts into the low-frequency region. This is indicative of enlargement of polar molecules involved in the process of polarization.

The results of experiments revealed that the dielectric loss tangent corresponding to the resonance dipole polarization of asphaltene molecules increases with the ratio of concentrations of resins and asphaltenes in oil. It was also found that the resonance polarization frequency of asphaltene molecules and, consequently, the region of their polarization shift toward higher frequencies (i.e., the dielectric relaxation time decreases) as the mentioned ratio increases. This is attributable to the breakdown of asphaltene agglomerates by resins at higher $R/A$ values.

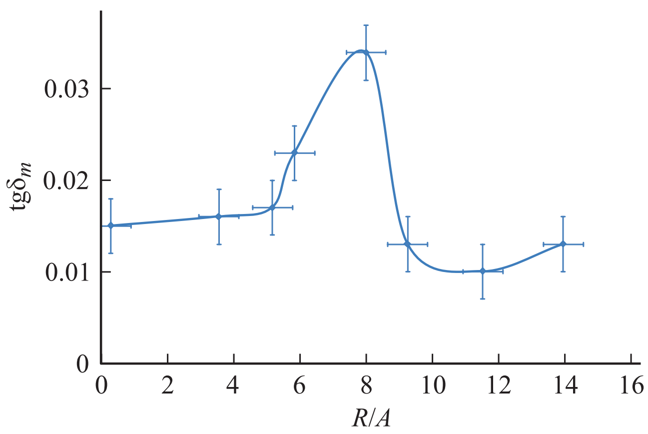


**Figure 2.** Dependence of $\mathrm{tg}\,\delta_m$ on the ratio of concentrations of resins and asphaltenes in oil ($R/A$).

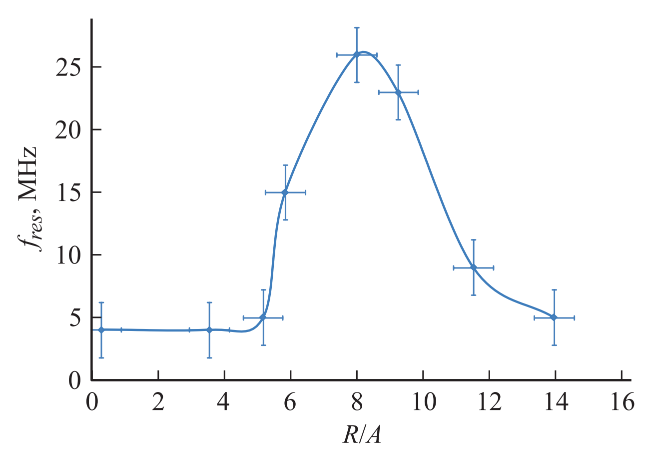


**Figure 3.** Dependence of the resonance frequency on the ratio of concentrations of resins and asphaltenes in oil ($R/A$).

The obtained results should help formulate guidelines for industrial application of high-frequency electromagnetic treatment of oil dispersed systems such as oil-filled formations and water-oil emulsions.

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### Conflict of interest

The authors declare that they have no conflict of interest.

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