Studying dielectric properties of oil shale

R R Zinnatullin and R F Sultanguzhin
Department of Applied Physics, Bashkir State University, Z. Validi st. 32, 450076, Ufa, Russia
E-mail: rasulz@yandex.ru

Abstract. The paper describes the methodology, equipment and results of studying the features of dielectric properties of oil shale in the frequency range for values from 0.05 to 300 MHz and temperatures for values from 20 to 200°C. It is shown that the dielectric parameters for the studied shale samples are an order of magnitude higher than for terrigenous rocks, and along the layers they are about 1.5 - 4 times higher than across the layers. The dielectric properties of the studied shale are found to undergo dispersion in the range for values from 50 to 125 MHz and have nonlinear temperature dependence.

1. Introduction
Combustible (oil) shales are minerals containing kerogen. Their volumes are an order of magnitude greater than open oil reserves. When shale is heated without air access, kerogen forms liquid and gaseous hydrocarbons (20-70% of the initial mass) [1].

The study of dielectric properties of shales in a wide range of frequencies and temperatures is of particular interest for two reasons. First, information on many processes and phenomena occurring in these rocks under changing conditions can be obtained from the frequency-temperature dependences of the dielectric properties of shales. When shale is heated from 200 to 400°C and kept at these temperatures for a certain period of time, a pyrolysis process occurs and results in generation of oil and gas from kerogen [2]. In this case, thermoelastic stresses can occur in the rock, leading to crack formation, softening and destruction of the rock [3]. Secondly, one of the methods for producing shale oil may be the electromagnetic heating method. And the degree of interaction of the electromagnetic field on dielectric materials depends on the dielectric properties of these materials. Depending on the dielectric properties of the shale, electromagnetic fields of different frequency ranges can affect the rock with varying degrees [4]. Modeling of the dynamics of saturated porous media heating by electromagnetic radiation during the manifestation of nonlinear effects due to the temperature dependence of the dielectric parameters of the media was considered in [5]. It is shown that due to changes in dielectric parameters depending on temperature, the heating process can be significantly accelerated. As you know, oil shales consist of a set of different minerals: quartz, feldspar, mica, which behave differently in electromagnetic fields due to the difference in their dielectric properties, which determines the uneven heating of the rock, leading to thermal expansion. Therefore, the key point is the choice of the effective frequency and power of electromagnetic radiation as applied to a specific target.

In the case of RF and microwave exposure, there is an intense heating of the oil-water emulsion. In the case of HF electromagnetic action, heating occurs due to polarization of the polar components of...
the oil. With microwave exposure it is due to the polarization of water molecules. In addition, in the case of two-phase liquids, surface polarization is manifested at the interface [2–4].

Thus, the destruction of oil-water emulsions in electromagnetic fields depends on many factors: the content and concentration of high-molecular compounds, the amount of water, the dielectric properties of oil-water emulsions, the frequency and intensity of the electromagnetic field, the time of exposure. Therefore, an urgent task in the development of electromagnetic methods for dehydration of oils is to study the characteristics of the effects of electromagnetic fields on oil-water emulsions with different physicochemical properties under certain parameters of the electromagnetic field and to identify patterns of behaviour of oil-water emulsions in the electromagnetic field.

2. Material and methods

The most important electrophysical parameters of media, determining the nature of the interaction between emulsions and electromagnetic fields, are relative permittivity and dielectric loss tangent. To determine frequency dependences of these electrophysical parameters the experimental setup based on quality factor measurer Tesla BM 560 (for values of frequency from 50 kHz to 35 MHz) is implemented. The experimental setup provides measurement accuracy up to 5% for relative permittivity and up to 10% for loss tangent.

The loss tangent characterizes dissipation of electromagnetic energy in medium when electromagnetic wave propagates through it. The greater the loss tangent value is, the greater part of the electromagnetic energy is converted into heat and the more the medium heats up.

The main measuring part of the installation is the Q factor meter. To simulate the necessary temperature conditions, the cell is placed in a furnace [6].

For the study, samples of oil shale were selected, cut parallel to (sample No. 1) and along (sample No. 2) layering. The rock samples are cylindrical in size 30 (diameter) x 10 (height). In the process of research, the samples were placed in a sealed cylindrical cell made of radiolucent material (fluoroplastic). The frequency dependences of the dielectric properties were studied at temperatures of 25, 75, 110, 130, 150, 200°C.

3. Results

Figure 1 shows the frequency dependences of the dielectric loss tangent for the samples under study in the frequency range for values from 0.05 to 300 MHz at a temperature of 75°C.

![Figure 1](image.png)

**Figure 1.** Frequency dependences of the dielectric loss tangent for the samples under study at a temperature of 75°C. (Designations: I – sample No. 1, II – sample No. 2).
It can be seen from the figure that in the range for values from 50 to 125 MHz the $\tan \delta$ value experiences a dispersion in the form of a resonance curve, that is, polarization of polar components in kerogen occurs in the indicated range. At lower temperatures, the dispersion is weakly expressed. With increasing temperature, the dispersion region remains in the same ranges, but $\tan \delta$ values take on different values.

Figures 2 and 3 show the temperature dependences $\varepsilon'$, $\tan \delta$ for the samples under study at a frequency of 85 MHz close to the resonance one. It can be seen from the presented results that with an increase in temperature to 130°C, the values $\varepsilon'$ and $\tan \delta$ for the samples under study increase, and at 150°C they noticeably decrease.

![Figure 2](image2.png)

**Figure 2.** Temperature dependences of the relative dielectric constant $\varepsilon'$ at a frequency of 85 MHz (Designations: I – sample No. 1, II – sample No. 2).

![Figure 3](image3.png)

**Figure 3.** Temperature dependences of the dielectric loss tangent $\tan \delta$ at frequency of 85 MHz (Designations: I – sample No. 1, II – sample No. 2).

All these phenomena are explained by several reasons. First, with increasing rock temperature, the relaxation time of dielectric polarization decreases. This contributes to an increase in dielectric constant with temperature. Secondly, the magnitude of the dipole orientational polarization in solids depends on the bonds between the particles, on the one hand, and on the thermal motion on the other...
hand. With increasing temperature, the bond strengths in the rock decrease, which contributes to an increase in the number of polarizable particles. The latter leads to an increase in dielectric parameters, and a further increase in temperature leads to disorientation of polar molecules due to thermal motion and, accordingly, to a decrease in dielectric parameters. Thirdly, at temperatures close to 150°C in the rock, phase transformations of kerogen into oil and gas can begin, which leads to a sharp decrease in dielectric parameters. Fourth, when shale is heated to a temperature of 150°C, micro cracks appear in it [6, 7].

In addition, it can be seen from the above results that the values ε' of the dielectric constant and the dielectric loss tangent along the layers are approximately 1.5 to 4 times higher than across the layers at higher temperatures. This is especially noticeable for the dielectric loss tangent.

Conclusions
As a result of the research, it has been found that:
1. The values ε' for the studied samples of shale are an order of magnitude higher than for terrigenous rocks. This fact provides good prerequisites for further research on the possible use of the electromagnetic field in the development of shale deposits.
2. The frequency dependences of tgδ for the samples under study have pronounced maxima in the range for values from 50 to 125 MHz at temperatures of 75°C and above. With an increase in temperature, a shift of the tgδ maxima in frequency is not observed; therefore, a generator of a fixed permissible frequency from the indicated range can be recommended for influencing the samples of shale under study.
3. With an increase in temperature to 130°C, the values ε' and tgδ for the samples under study increase, and at 150°C they noticeably decrease, which is explained by a number of phase transformations in shale rock upon heating in the studied temperature range.
4. The values ε' and tgδ along the layers are approximately 1.5–4 times higher than across the layers.

These results can be useful in choosing the directivity of the electromagnetic field to influence shale deposits.

The obtained results will be used in mathematical modeling of the phase transformations of oil and gas generated by kerogen as a result of the influence of an electromagnetic field on kerogen-containing samples, and will also be useful in developing recommendations for the industrial use of high-frequency electromagnetic effects on oil shale.

The results will be useful in developing recommendations for the industrial use of RF electromagnetic effects on oil reservoirs.

Acknowledges
The research was supported by the grant of the Russian Foundation for Basic Research (project no. № 20-05-00535 A).

References
[1] Strizhakova Y 2019 Fine Chemical Technologies 1(4) 76–85 (In Russ.)
[2] Martemyanov S 2013Simulation of Underground Heating of Oil Shale (Tomsk: TPU press) (In Russ.)
[3] Menzhulin M 2000 Mining informational and analytical bulletin 8 229–33 (In Russ.)
[4] Zinnatullin R and Kovaleva L 2019 High Temperature 57(1) 127–9
[5] Khabibullin I and Nazmutdinov F 2014 High Temperature 52(1) 697–702
[6] Kovaleva L 2019 Bulletin of Bashkir University 24(1) 43–8 (In Russ.)
[7] Sultanguzhin R2019 Radio Frequency and Microwave Impact on Source Rock (Radiation and Scattering of Electromagnetic Waves (Divnomorskoe: IEEE)