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РЕСПУБЛИКИ КАЗАХСТАН

АО «ИНСТИТУТ ТОПЛИВА, КАТАЛИЗА И
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♦
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Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Химия және технология сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Химия және технология сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді химиялық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия химии и технологий» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по химическим наукам для нашего сообщества.

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DIELECTRIC PROPERTIES OF THE COALS OF MAYKUBEN AND EKIBASTUZ BASINS

Abstract. The paper describes the measurement of the frequency dependences of electrical conductivity, permittivity and loss factor in the frequency range from 25 Hz to 1 MHz for coals of Maykuben and Ekibastuz basins. Measurements were made on plates 2-4 mm thick in a two-electrode measuring system. The technique of preparation of samples and results of measurements are described. From the point of view of electrophysical characteristics fossil fuels refer to weakly conducting materials with heterogeneous structure. The frequency dependences of their dielectric properties are mainly investigated for the development of high-frequency heating technologies. Thus, the heat release under the action of the applied field depends on the electrical conductivity (resistive losses) and the loss tangent (dielectric losses). In addition, the process of electric discharge phenomena in such materials also depends on the dielectric properties.

Key words: coal, dielectric properties, permittivity, conductivity, loss factor.

Introduction

Fossil fuels are the most valuable raw material for energy production and chemical synthesis. Effective technologies for their processing can allow receiving products with high added value without damage to the environment. A number of such technologies can be based on pyrolytic processing. These include aboveground and underground pyrolytic conversion and gasification. Aboveground gasification of coal has a long history with periods of rapid development and recessions [1, 2]. To date, apart from traditional and industrially developed technologies, more promising ones have been developed, such as plasma, catalytic, layer gasification with reversed blowing [3, 4].

Underground conversion is realized by heating of the coal bed in situ and taking of pyrolysis products through the wells. This way of the coal deposits development looks the most promising and environmentally safe [5]. Access to the formation in this case organizes via wells. Heating can be realized by incomplete oxidation of the coal [6], heat-conducting heating [7, 8], electric heating [9, 10, 11], etc. In our opinion, one of the effective methods for coal heating is electrophysical heating, based on the action of an electromagnetic field of high voltage [12, 13].

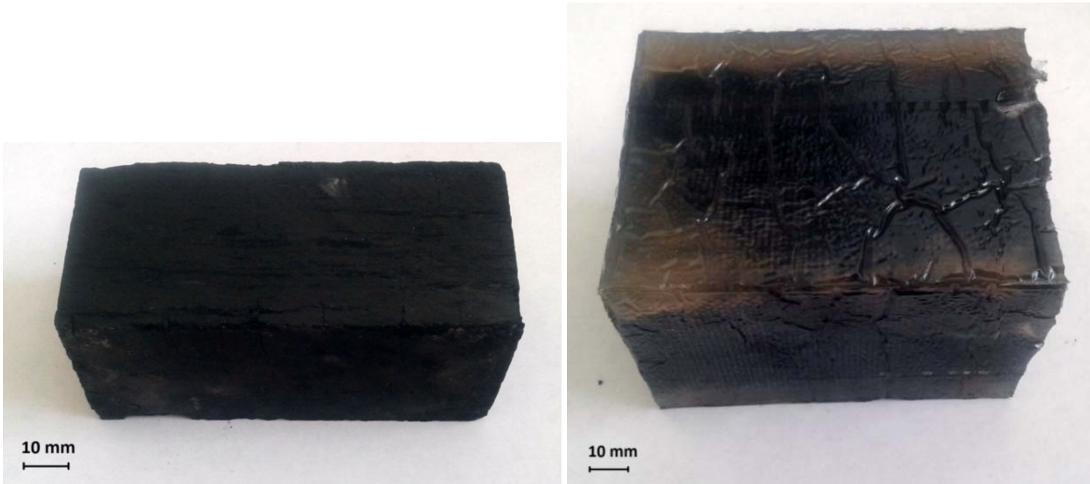
From the point of view of electrophysical characteristics fossil fuels refer to weakly conducting materials with heterogeneous structure. The frequency dependences of their dielectric properties are mainly investigated for the development of high-frequency heating technologies [14-17].Thus, the heat release under the action of the applied field depends on the electrical conductivity (resistive losses) and the loss tangent (dielectric losses). In addition, the process of electric discharge phenomena in such materials also depends on the dielectric properties. For example, the maximum electric fieldstrength on the gas pores is determined by the relative permittivity [18]. Therefore, the dielectric properties will affect the heat release, the electrical discharge phenomena (partial discharges, triaging) and, as a consequence, the technical characteristics of the equipment necessary for heating.

The paper describes the technique and results of measuring of frequency dependences of the specific electric conductivity, relative permittivity and loss tangent, measured in the coals taken from the Maykuben, Bogatyr and Saryadyr strip mines (Kazakhstan).

Research methodology

Measurement of dielectric properties requires the samples in the form of plates with a thickness of no more than 5 mm [19, 20]. Samples were cut from solid fragments of coal by a stone cutting machine with an abrasive-cutdiamond-coated disc.

It is impossible to cut the plates directly from the coal fragment because of the cracks and low mechanical strength. To avoid the destruction, the samples were prepared as follows. A bar with dimensions 55 × 55 × 100 mm was cut out from the initial fragment of coals (Figure 1,a). Then the bar was wrapped in a polyethylene film and poured into a solid ificated polyester resin (Figure 1,b).



a) b)

Figure 1 – Preparation of samples for dielectric properties measurement:
a) coal bar; b) bar, filled in polyester resin

Polyester resin gives the workpiece a mechanical strength and retains the coal during cutting. In this case, the layer of polyethylene film does not allow the resin to penetrate into the sample and further affect to the measurement results.

Then the resulting workpiece was cut into plates using an abrasive-cut diamond-coated disc (Fig. 2).

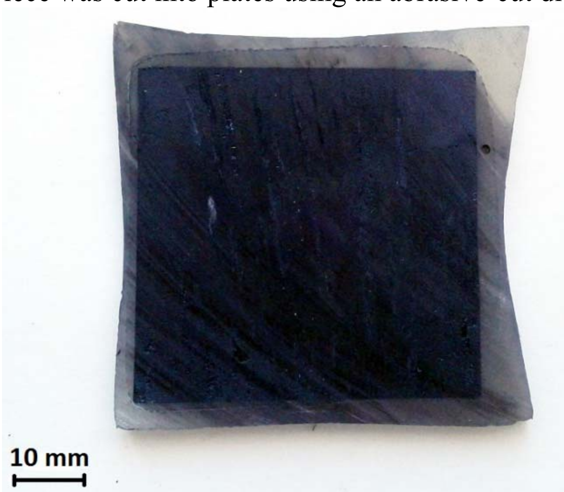
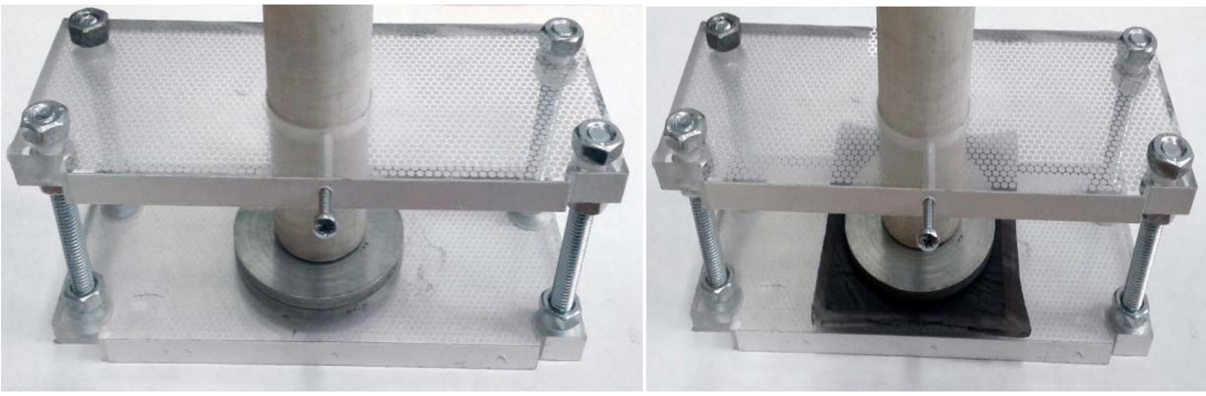


Figure 2 − Sample in the form of a plate for dielectric properties measurement

Since sedimentary rocks, including coal, have a layered structure, anisotropy of their dielectric properties is possible. If the applied electric field is oriented in the same direction as the layers in the coal, the value of the measured quantity can differ from the measurement, in which the applied field is oriented perpendicularly to the layers. Since in the developed technology of in-situ gasification the voltage applied to the electrodes will be oriented predominantly along the bedding layers of coals, the samples for measurement were made in such a way that the field of the measuring device was oriented along the layers of the sample.

Measurement of dielectric properties was carried out by the immittance meter E7-20 (MNIPI, Minsk, Belarus). The device generates a sinusoidal voltage of a specified frequency, applied to the measuring electrodes, and measures the electromagnetic response of the object. The meter has a PC-compatible interface RS-232C and can work under the control of a computer. Since measurements for the entire frequency range required the registration of a large number of measured values, software for controlling the instrument was designed to simplify the procedure.

In accordance with standard [19], measurements were made by the use of disk electrodes. Tool setis shown in Figure 3.



a) b)

Figure 3 − Tool set for the measurement ofdielectric properties:
a) without a sample, b) with an installed sample

The sample in the clamp is clamped between two disk aluminum electrodes with a diameter of 50 mm and a thickness of 3 mm. The thickness of the sample to ensure the necessary measurement accuracy should not exceed 5 mm.

The electrodes are connected to the immittance meter, and the measured values are recorded. The directly measured values are the loss tangent, the sample capacitance and the sample resistance. The specific permittivityε is then calculated as the ratio of the measured capacitance of sample C and the capacitance of a similar air capacitorC_0:

$$\varepsilon = \frac{C}{C_0}$$

The capacitance C_0 was measured in the absence of a sample and with inter electrode distance equal to the thickness of the sample. Specific electrical conductivity σ of the coal is defined as the ratio of the sample thickness h to the electrode area S and the measured resistance of the sample R:

$$\sigma = \frac{h}{S \cdot R}$$

For each of the investigated deposits, measurements were taken on 5 samples, after which the results of the measurements were averaged.

Results and discussion

Electric conductivity

The electrical conductivity σ characterizes the ability of a material to conduct an electric current. From the point of view of pyrolytic conversion technologies, the electrical conductivity along with the field strength E determines the heat energy P that will be released in the material from the flowing current:

$$P = \sigma \cdot E^2$$

Heating of materials having a low electrical conductivity value requires so high intensity of the applied field that industrial equipment for such heating is technologically unfeasible.

The measured frequency dependence of the electrical conductivity of investigated coals is shown in Figure 4.

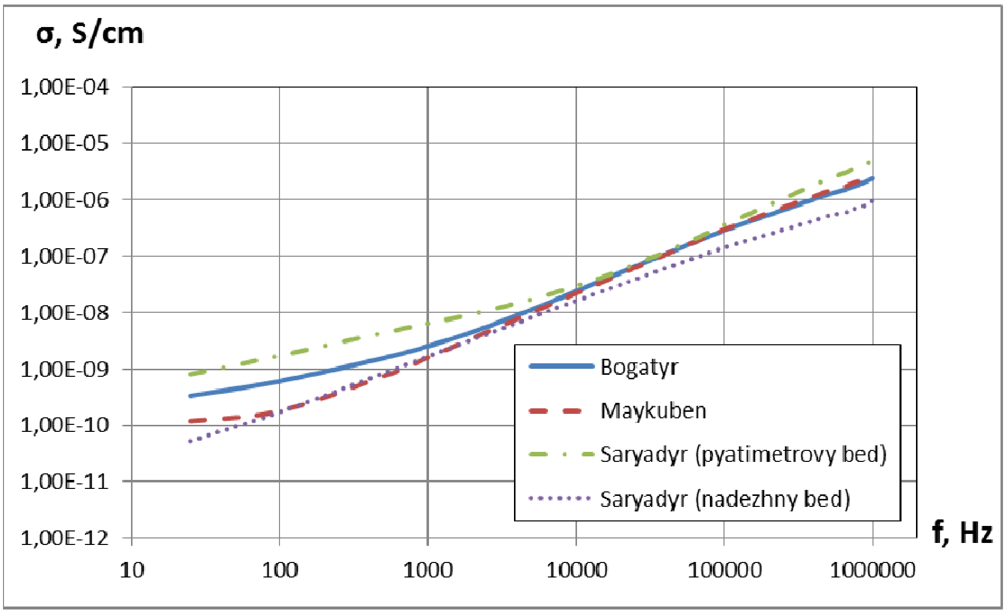


Figure 4 – Electric conductivity

In terms of the electrical conductivity, the coals are located on the boundary between semiconductors and dielectrics and belong to weakly conducting materials. Unlike materials with a homogeneous composition, coals tend to have a significant increase in electrical conductivity (by 3-4 orders of magnitude) with a frequency increasing from 25 Hz to 1 MHz. Presumably, this is connected with their mixed structure and the inclusion of a large number of crystallites and molecular clusters. At the boundaries of these macroscopic elements the energy structure of the electron shells of atoms and molecules is distorted, which is why free charge carriers with limited mobility and lifetime can arise in these places. The higher the frequency, the more such charge carriers can participate in conducting an electric current.

Since the electrical conductivity is very low at a low frequency, direct resistive heating of the investigated coals is possible only at high field strengths. Thus, by an electrical conductivity of 10^{-9} S/cm, field strength of 10^6 V/cm should be created to release the 1 kW of thermal energy.

Permittivity

The permittivity ε is an indicator of the polarization ability of the material. The higher its value, the greater the capacitive current can circulate through the material under the action of an alternating voltage. The results of measurements of the relative permittivity of the investigated coals are shown in Figure 5.

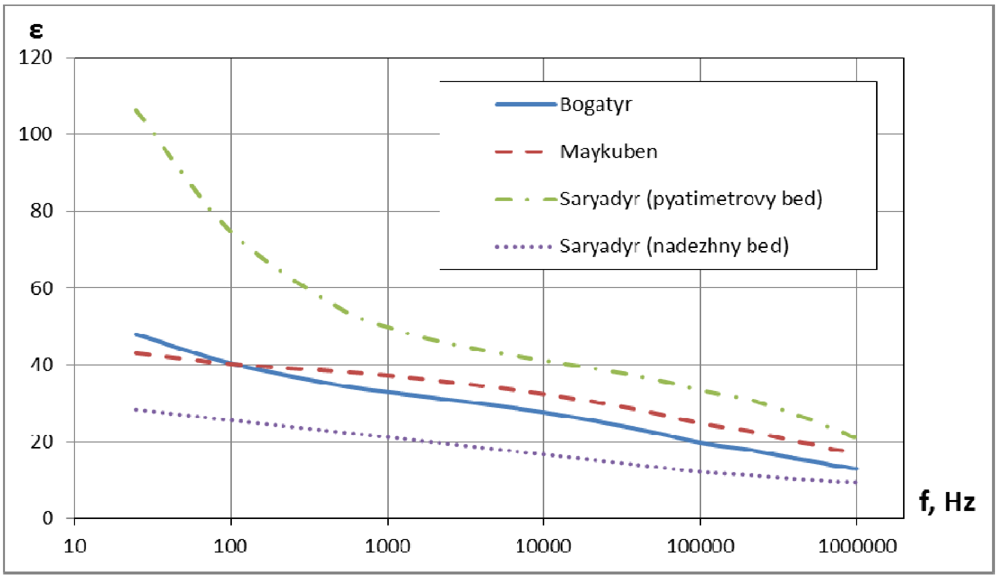


Figure 5 – Relative permittivity

As for most heterogeneous materials, the permittivity of coals decreases with an increasing of frequency from 25 Hz to 1 MHz in 3-5 times. For most mineral rocks in this frequency range *ε* is 3-10. For the coals in considered frequency range, the *ε* amounts to several tens, which indicates a very high polarization ability of the constituent components. Such components with high polarizability are water (sorbed, ion-bonded), OH groups, carboxyl groups, pyrite and other sulfur compounds.

In addition to the large value of the capacitive current, a high value of *ε* leads to an uneven distribution of the applied external voltage. As a result, significant field strength caused by the Maxwell-Wagner effect is concentrated in the pores and gaseous inclusions. In accordance with this phenomenon, a charge accumulates at the boundaries between the solid and gaseous phases, the value of which is proportional to the ratio of the permittivities. Thus, because of the high *ε* value of the coals, when the external electromagnetic field is applied to the coal, the significant part of the field will fall on the pores, causing partial discharges by a relatively low value of the voltage.

Loss tangent

The loss tangent *tan(δ)* shows the ratio of active power to reactive power when applying an alternating voltage to a fragment of a dielectric material. Active power, which is the power of dielectric losses, arises as a result of the displacement of polar atomic groups under the action of an external field. For the most of dielectric materials the value of *tan(δ)* decreases with increasing of frequency having a resonance maximum at some frequency. At this frequency the rate of change of the external field and the velocity of the free mobility of the dipoles of matter coincide. For materials with the mixed structure the frequency dependence of the loss tangent will be the envelope of the resonant peaks of the various components (Figure 6).

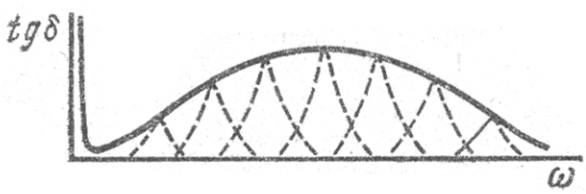


Figure 6 – Typical form of the curve *tan(δ) = f (ω)* for dielectric materials with the mixed structure [21]

This property is used in methods of high-frequency material heating, as, for example, by heating a subterranean oil reservoir, described in [22,23]. The measured frequency dependencies of *tan(δ)* are shown in Figure 7.

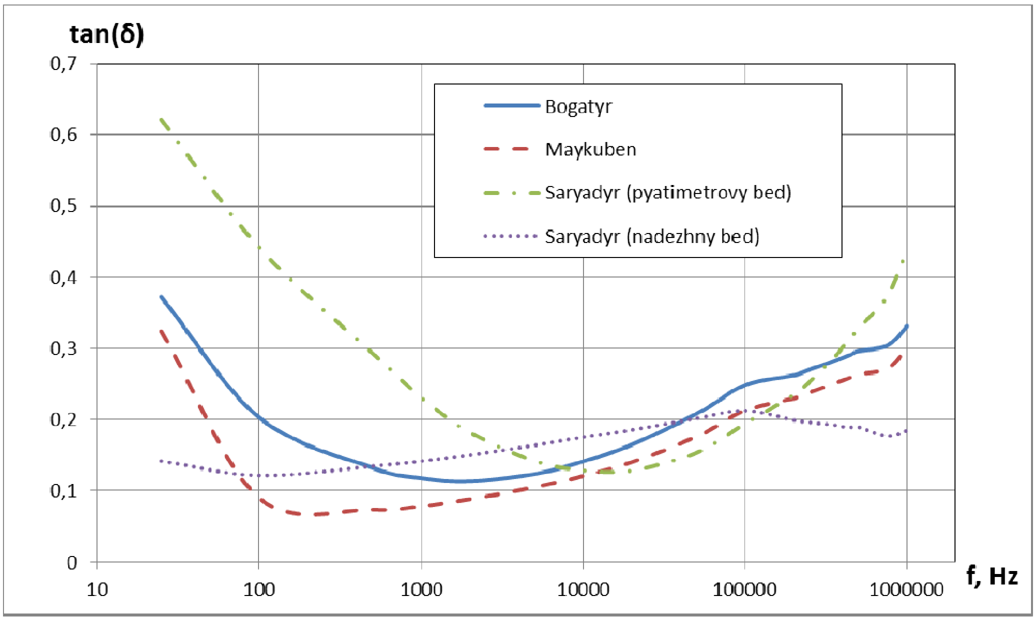


Figure 7 – Dielectric loss tangent

The measured dependencies shows that the peak values of *tan(δ)* for the coals are outside the range of the considered frequencies. Therefore, the heating of these coals only due to dielectric losses needs to use the electromagnetic field of the frequency range > 1 MHz. The cost of powerful equipment operating at such frequencies is quite high. Thus, it can be assumed that the heating of the coals due to the dielectric losses of the high-frequency electromagnetic field is unlikely to be advisable. If we try to produce dielectric heating in the frequency range of <1 MHz, a very large area of the electrodes will be required to provide heat release sufficient for heating.

Conclusions

The reaction of a substance to an electromagnetic field depends on the dielectric properties. For coals of different deposits, the dielectric properties can vary considerably. The described measurement results can be useful in the development of coals processing technologies which uses electromagnetic action, such as heating, enrichment, or electric discharge destruction. The described technic of samples making can be useful in carrying out similar measurements on solid fuels of other deposits.

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МАЙҚҰБЫ ЖӘНЕ ЭКІБАСТҰЗ КӨМІР БАССЕЙНДЕРІНІҢ ДИЭЛЕКТРИКАЛЫҚ ҚАСИЕТТЕРІ

Аннотация. Мақалада Майкүбен және Екібастұз бассейндерінің көмірлері үшін 25 Гц-ден 1 МГц жиілік диапазонында электр өткізгіштігінің, диэлектрлік өтімділігінің және тангенс жоғалу бұрышының жиілік тәуелділігін өлшеу сипатталады. Екі электродты өлшеу жүйесінде қалыңдығы 2-4 мм пластинкаларда өлшеу жүргізілді. Үлгілерді дайындау әдістемесі және жүргізілген өлшемдердің нәтижелері сипатталған.

Қазба отыны электрофизикалық сипаттамалар тұрғысынан гетерофазды құрылымды әлсіз өткізгіш материалдарға жатады. Диэлектрлік қасиеттерінің жиіліктік тәуелділігі, негізінен, жоғары жиілікті жылу технологияларын әзірлеу мақсатында зерттеледі. Осылайша, берілген өрістің әсерінен жылу бөлу электр өткізгіштігіне (резистивті шығындар) және диэлектрлік шығынның тангенс бұрышына (диэлектрлік шығындар) байланысты. Мұндай материалдардағы электр пиролизінің ағымы жылуды өндіру үрдістеріне әсер ететін диэлектрлік қасиеттерге, электр разрядты құбылыстардың ағынына (ішінара разрядтар, қисық сызық) аса тәуелді.

Түйін сөздер: көмір, диэлектрикалық шығындар, диэлектрикалық өтімділігі, электр өткізгіштік, шығын коэффициенті

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ДИЭЛЕКТРИЧЕСКИЕ СВОЙСТВА УГЛЕЙ МАЙКУБЕНСКОГО И ЭКИБАСТУЗСКОГО БАССЕЙНОВ

Аннотация. В статье описано измерение частотных зависимостей электропроводности, диэлектрической проницаемости и тангенса угла потерь в частотном диапазоне от 25 Гц до 1 МГц для углей Майкубенского и Экибастузского бассейнов. Измерения проведены на пластинках толщиной

2-4 мм в двухэлектродной измерительной системе. Описана методика подготовки образцов и результаты проведенных измерений. Ископаемые угли с точки зрения электрофизических характеристик относятся к слабопроводящим материалам гетерофазного строения. Частотные зависимости их диэлектрических свойств исследуются, в основном, с целью разработки технологий высокочастотного нагрева . Так, выделение тепла под действием приложенного поля зависит от электропроводности (резистивные потери) и тангенса угла диэлектрических потерь (диэлектрические потери). Протекание электропиролиза в таких материалах сильно зависит от диэлектрических свойств, которые влияют на процессы выделение тепла, протекание электроразрядных явлений (частичные разряды, трiинг).

Ключевые слова: уголь, диэлектрические потери, диэлектрическая проницаемость, электропроводность, коэффициент потерь

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