Investigation of electrophysical properties of coal samples from Talovskoy deposit in Siberia

V V Salomatov¹, Y D Chernousov², and V A Karelin¹

¹ Institute of Thermophysics of SB RAS, Novosibirsk, Russia.
² Institute of Chemical Kinetics and Combustion SB RAS, Novosibirsk, Russia

E-mail: vad2hen@mail.ru

Abstract. The work is devoted to the study of the electrophysical properties of brown coal at the Talovskoy deposit in Siberia. This type of coal can be successfully used as an energy fuel for thermal power plants, boiler houses and other industries. However, experiments show that like other low-quality coals, it needs additional treatment: drying, removing of toxic impurities, crushing, etc. Due to this, the search for the most optimal methods of its processing is constantly conducted. One of the promising methods is the treatment with microwave radiation. This leads to intensive drying, removing of sulfur, nitrogen, mercury, chlorine and other undesirable impurities, grinding the fraction, which generally positively affects the quality of the fuel being prepared for use [1]. However, for the most effective use of microwave technologies, knowledge of the coal properties and their changes during processing is necessary. In particular, the dielectric properties of coal are responsible for the efficiency of microwave energy absorption. And due to changes in the humidity and temperature of the coal during microwave heating and drying, the efficiency of the process will always change. This work is devoted to the measurement of electrophysical properties and their dependencies.

1. Introduction

The processes of drying wet materials, including coal, are among the most energy intensive. From the classification of existing methods of drying the following can be identified: introduction of heat through the surface (conductive), introduction of heat directly into the volume (electromagnetic waves), and combined [2]. At the same time, for each material and for certain purposes of its use, you should choose the most effective method. The object of the study in this paper is the control samples of brown coal from the little-developed Talovskoy deposit in Siberia. Talovskoy brown coal (marks B1, B2) deposit is located in a southeast part of the Tomsk area in 25-50 km to the north of the city of Tomsk and is estimated as a large one with a predicted resource of about 3,6 billion tons that is capable to provide a coal mining of 10-15 million tons per year [3]. In these brown coals, the moisture content ranges from 15 to 30%, the ash content is 10-25%. The paper examines the core sample of coal from the Talovskoy field extracted from well No. 40 at a depth of 25.1-26.6 meters. The main tasks of drying: reducing the humidity to 10-12% required by the technology, creating the optimal gradients of temperature, pressure and humidity to reduce the time and energy consumption for drying. One of the popular approaches is the use of microwave radiation. Coal is a moist porous material, which contributes to intense volumetric absorption of microwave radiation. The use of electromagnetic microwave radiation will increase the heat of combustion, reduce humidity, ash content, and also
reduce the content of mercury, chlorine, sulfur and other harmful components [1]. In addition, there is parallel partial crushing of coal. As a result, low-grade coal exposed to microwave radiation becomes a more homogeneous, high-quality product.

To find a rational method of microwave heating and drying, it is necessary first of all to create the processes models, which will take into account the parameters of the installation and the sample. It is required to control the change in humidity, temperature, pressure and structure of the coal sample, which affect the drying efficiency and must be taken into account. In this case, the use of microwaves can induce the heating of a dielectric material in two ways: dielectric losses due to relaxation polarization and heating by conduction current in places with increased conductivity. The mechanism of the electromagnetic waves energy absorption by coal is possible only under the conditions of completeness of knowledge about electrophysical parameters such as dielectric permittivity, tangent of the dielectric loss angle, conductivity, etc. This work is devoted to measurement of these characteristics and analysis of the obtained regularities during heating and drying.

2. Methods of research and instrumentation
To measure electrophysical parameters, in particular dielectric permittivity and the tangent of the dielectric loss angle, a resonance method was used. The main idea of this method consists in observing the resonance curves of the oscillatory circuit as the sample is inserted into it. The change in the quality factor of the circuit and the shift in the resonant frequency of the resonator make it possible to determine the real and imaginary part of the dielectric constant of the sample. The relationship between the parameters of the resonator and the sample under study as a function of frequency is obtained from the solutions of the Maxwell or Kirchhoff equations.

Samples of Talovsky brown coal at a frequency of 2.45 GHz were investigated in this paper. At this frequency the absorption of the microwave energy by the moisture becomes quite effective. In the region of centimeter wavelengths, the method of small perturbations is applied [4]. A resonator of a cylindrical type was used in the work. For this configuration it was possible to solve the equations of the electromagnetic field and take into account the influence of the introduced sample on these fields. Knowing the relationship between changes in Q, resonance frequency and electrophysical parameters for a sample of a cylindrical cavity placed in the center with oscillations of the E010 mode, it is possible to calculate the values of the real, imaginary parts of the dielectric constant, as well as the tangent of the dielectric loss angle:

\[
\epsilon' = 1 - 0.539 \left( \frac{a}{b} \right)^2 \frac{l}{h} \frac{f_1 - f_0}{f_0} 
\]

\[
tg\delta = \frac{0.269}{\epsilon'} \left( \frac{a}{b} \right)^2 \left( \frac{1}{Q_1} - \frac{1}{Q_0} \right) 
\]

Where \(\epsilon'\) is the real part of the dielectric constant; \(a, l\) is radius and height of the resonator, respectively (m); \(b, h\) are radius and height of the inserted sample, respectively (m); \(f_0, f_1\) are frequencies of the empty resonator and the resonator with the introduced sample, respectively (Hz); \(Q_0, Q_1\) are quality factors of the empty resonator and the resonator with the introduced sample, respectively; \(tg\delta\) is dielectric loss tangent.

We used a microwave analyzer of chains from Agilent Technologies model N5230A. This device is a standard measuring equipment that is able to measure accurately the main parameters of an electrical circuit and provide all the information about the object being diagnosed in a convenient form. This device is capable of generating microwaves at a frequency of 2.45 GHz, entering through a coaxial cable inside a cylindrical resonator, simultaneously measuring the quality factor and the resonance frequency of the resulting circuit (figure 1).
Figure 1. Agilent Technologies company model N5230A network analyzer and a cylindrical resonator.

Figure 2. A hole inside the resonator with a quartz tube for placing coal inside the sample.

2.1 Measuring and preparing a sample of coal from the Talovsky deposit
A sample of coal was processed in the form of a cylinder with a mass of 200-500 (mg). At the same time, due to the flowability of the coal, the sample was placed in a quartz flask to avoid the ingress of coal into the cavity. In this case, the Q-factor and the resonance frequency were measured before the sample was introduced into the quartz tube and after (figure 2).
Further, on the basis of the calculated formulas, the dielectric constant and the dielectric loss angle were determined. However, during the microwave heating and drying of coal, the temperature and humidity of the sample can vary substantially, which invariably leads to changes in the dielectric parameters. Therefore, it was necessary to prepare a stand that would allow measurements of the dependences on humidity and temperature.

2.2 Measurement of the electrophysical parameters dependencies on humidity and temperature

Due to the impossibility of introducing heating/measuring equipment inside the resonator, a heating tube was developed, located above the quartz tube of the resonator (figure 3). This tube allows the sample to be heated to 100-150 °C. After heating, the sample was placed inside the resonator and, as cooling was completed, the values of the resonant frequency and Q of the circuit were taken. Heating was carried out to various temperatures and the cooling time of the sample to room temperature was measured, which made it possible to recalculate the dependence of the frequency and Q of the circuit on temperature. After each measurement, the weight of the sample was measured, the initial moisture content of the material was recalculated.

After a series of measurements with the same sample, the temperature dependence was compared, indicating that free moisture leaves the sample.

The absorbed power from the microwaves is associated with the dielectric losses and losses on the electrical conductivity and can be calculated by the formula:

$$P = 2\pi \left| E_0 \right| f \varepsilon_0 \varepsilon''_{\text{eff}}$$  \hspace{1cm} (3)

where $\varepsilon''_{\text{eff}}$ is the effective imaginary part of the permittivity, responsible for the relaxation polarization and ionic conductivity, $E_0$ is module of electric field strength (V/m), $\varepsilon_0$ is dielectric constant, approximately equal to 8.85 $10^{-12}$ (m$^3$ kg$^{-1}$ s$^4$ A$^{-2}$), $P$ is power (W/m$^3$), $\sigma$ is conductivity (ohm$^{-1}$ m$^{-1}$). To determine the effect of heating by conduction current, it was also required to measure the conductivity of a given coal.

Figure 3. Stand for preheating the coal sample to temperatures of 100-150 °C.
2.3 Measurement of Coal Conductivity of the Talovsky Field

A coal sample was prepared in the form of a rectangular parallelepiped. For the qualitative contact with the electrodes on the coal, foil was applied. Coal resistance was measured at different voltages (figure 4). The measured conductivity was 4.7 \times 10^{-3} (\text{Ohm}^{-1} \text{m}^{-1}).

3. Results

With other constant magnitudes, the imaginary part of the dielectric constant exerts the greatest influence on microwave heating. Below is one of their experimentally obtained dependences of the change in the imaginary part of the coal permittivity as it cools down (figure 5). "0" on the horizontal axis - the beginning of cooling, corresponding to a temperature of 150 (°C), "***" - the moment of reaching room temperature (this time was when the Q-switching and resonant frequency of the circuit stopped). On the right are the moisture values of the sample being measured.

As can be seen from the graph at large temperatures, the imaginary part of the permittivity increases, which has a positive effect on the absorption of microwave energy and optimally affects the heating. On the other hand, at high temperatures there is a significant reduction in the moisture content of the coal, which reduces the absorption efficiency. In the course of experiments with different samples, an array of data was obtained, which makes it possible to find approximate dependences of the electrophysical parameters on humidity and temperature, which was first done for coal of Talovsky deposit.

4. Conclusion

The effectiveness of the absorption of microwave radiation by a dielectric material depends on a number of factors. They include the electric field strength, frequency, and imaginary part of the dielectric constant. If in the course of microwave heating it is possible to control the field strength and frequency, then the permittivity of coal can vary greatly as temperature increases and humidity changes. Conductivity measurements also showed that microwave heating is carried out by means of two inseparable mechanisms: relaxation polarization and heating by conduction current. In the course of these studies, the electrophysical parameters of brown coal from the Talovsky deposit were measured using a resonance method. A technique was developed to determine the dependencies of these parameters on humidity and temperature. The obtained data made it possible to express the temperature-humidity dependences, which in future will be used as a basis for the mathematical model, which makes it possible to calculate the microwave heating and drying of this type of coal.
Figure 5. The change in the imaginary part of the dielectric constant as the sample cools from 150 °C to room temperature for different levels of coals humidity (7.1%, 3.8%, 3.3%).

Acknowledgements
This study was supported by the Russian Foundation for Basic Research (№ 17-08-00752 a).

References
[1] Khaidurova A A 2010 Improvement of the qualitative characteristics of solid fuel by the action of microwave energy during its preparation for combustion Dissertation, Irkutsk
[2] Zlobina I V 2015 Microwave heat treatment of heterogeneous structures and electrophysical characteristics of compositions of organic materials Dissertation for the degree of candidate of technical sciences, Saratov
[3] Kazakova O A Study of the composition of the mineral part of coal Talovsky field of the Tomsk region as an energy fuel: The dissertation author's abstract on competition of a scientific degree of the candidate of technical sciences http://earchive.tpu.ru/handle/11683/6301
[4] Brandt A A 1963 Investigation of dielectrics at ultrahigh frequencies (State Publishing House of Physical and Mathematical Literature, Moscow)