Laboratory setup for microwave drying of brown moisture carbon

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Abstract. A setup has been created to study the drying of wet coals by microwave radiation with a frequency of 2.45 GHz. Time dependences of humidity and surface temperature of brown coal samples from the Talovskoye deposit in Siberia are measured at an absorbed energy density of about 30 W g\textsuperscript{-1}. The analysis of the data obtained is carried out and the mechanisms of possible processes that explain the observed patterns are considered.

1. Introduction

Under current conditions, coal (40%) makes the main contribution to world electricity production, followed by gas (19%) and then nuclear and hydropower (16% each). The need to increase the efficiency of coal-fired TPPs and the implementation of toughened environmental requirements forces the development of new technologies for the use of coal, as a rule, of low-quality. Great opportunities are predicted for coal processing methods involving microwave energy [1,2]. The use of electromagnetic radiation will increase the calorific value, reduce humidity, ash content, as well as lower the content of mercury, chlorine, sulfur and other harmful components. In addition, partial crushing of coal takes place in parallel [3,4]. As a result, low-grade coal subjected to microwave irradiation becomes a more homogeneous, high-quality product.

At the previous stages of the work, modeling of heating and drying processes was carried out and an array of experimental data was collected. At this stage, a microwave setup is designed and assembled to study the change in temperature and humidity of coal during microwave processing. The brown coals of new large and little-studied Talovskoye field of Siberia with a forecasted resource of about 3.6 billion tons and a production volume of 10-15 million tons per year are selected as the object of study. In these brown coals, humidity is from 15 to 30\%, ash content is 10-25\%, and calorific value is from 25 to 27 MJ kg\textsuperscript{-1}.

Other researchers have already performed a number of experimental studies on microwave processing of coal [1,4]. However, to confirm the correctness of the heating and drying model and the previously measured electrophysical and thermophysical characteristics of coal from the Talovskoye deposit, it is necessary to measure the change in temperature and humidity during microwave processing, which has not been done earlier for this type of coal.

2. Research Methods and Instrument Base

When measuring the electrophysical parameters of coal at the previous stage of work, a power of the order of 1 mW was supplied to the resonator. This power is sufficient for measurements, but it does not heat the sample itself (which has a positive effect if only measurements are required) [5]. However, this
power can be enhanced using a system of two amplifiers (figure 1.). The microwave power at the output (up to 20 W) goes further into a cylindrical resonator, in which a coal sample is heated. The transmitted power is supplied to the attenuator and measured; on the measuring result the degree of energy absorption by coal inside the resonator may be estimated. During the heating and drying of coal, the degree of power absorption and the consistency of the entire circuit can significantly change, which can lead to high values of the power reflected from the resonator and the failure of the amplifiers. To prevent this situation, a microwave valve is added to the circuit - a device transmitting power in one direction and capable of absorbing the reflected power even in the event of a complete mismatch (20 W).

![Diagram](image)

**Figure 1.** Final scheme of the setup for microwave heating of coal samples.

The temperature change is recorded using a pyrometer located above the hole in the cavity in which the sample with coal is located.

### 3. Coal sample preparation

A brown coal sample highly absorbs the incident microwave power. It is necessary to select the optimal mass of the sample at which the reflected power from the resonator would be minimal. For this, we use an Agilent Technologies network analyzer, which supplies power at a certain frequency (2.45 GHz) to the resonator, while measuring the standing wave coefficient (SWR). When the SWR is close to 1, the reflected power tends to a minimum, and most of the incident power falls into the resonator with coal. In this case, the sample mass is selected for the SWR to be 1.01-1.05. The mass of the sample is about 0.16 g. Scales Cubis 524S with 1 class of accuracy according to GOST OIML R76-1-2011 are used to take into account the loss of mass of the sample during microwave processing. Analyzer also measures the electrophysical parameters of a coal sample to further evaluate the effect of microwave processing on these parameters. Seven samples are made with identical masses and moisture content in the range of 17.9–18% for further comparison of the rate of temperature increase and moisture loss. To prevent coal from spilling into the cavity, the sample is placed in a low-loss quartz flask (figure 2).
Figure 2. Cylindrical resonator. 1 – quartz flask, 2, 3 – holes for input/output of microwave energy, 4 – resonator wall, 5 – sample of coal in the form of a cylinder, 6 – sample surface on which the temperature is measured.

4. Preparation of a setup for microwave heating and drying of coal and experiment

After tuning the resonator with the sample, it was included in the circuit. At the initial stage, it was necessary to measure the power coming directly into the cavity. The power at the output of the last amplifier could differ significantly from the power supplied to the resonator, due to losses inside the coaxial cables and the microwave valve. Therefore, a power meter was in advance installed in place of the resonator to measure the input power; during measurements it was installed after the resonator to measure the transmitted power and in front of the resonator to the valve to measure the reflected power. With a sufficiently large power, almost instantaneous heating of the coal sample could occur. However, at low powers (1 W or less), coal heating was very weak. Therefore, it was also necessary to select the power at which it was possible to obtain a detailed time dependence of the surface temperature of the coal sample. The power selected from the above considerations was 5 watts.

Since the measuring equipment could not be placed inside the microwave camera because of its influence on the field distribution and the influence of the electromagnetic wave on the measurement readings, a pyrometric method was used to measure the surface temperature of coal. A BENETECH GM320 pyrometer was used (with a ratio of the distance to the diameter of the measured surface spot of 12:1). This pyrometer was directed to the surface of a coal sample through an opening inside the resonator. Thus, the dependence of the surface temperature of coal on the processing time was measured.

5. The results

During the beginning of the experiments and the selection of the required power, it was found that during microwave processing the steam leaving the coal settles on the walls of the flask itself, which, along with a significant increase in temperature, indicated that the values of necessary power for microwave heating and drying were achieved.

Therefore, after the experiment with each sample, it was necessary to clear the tube from the remaining moisture. During microwave processing, due to heating and moisture loss, the power not
absorbed by coal (reflected and passed through resonator) varied within 5 - 20 mW. Which, at an input power of 5 W was a fairly small value and indicated an almost complete absorption of microwave power by coal.

The dependence of temperature on time obtained after experiments with three samples is shown in Figure 3. The accuracy of the pyrometer is ± 1.5 ° C. As you can see, in the first 50 seconds there is intense heating to temperatures of about 90 degrees, then the heating rate decreases, which may be due to internal redistribution of moisture and intense heat dissipation. After 180 s the temperature begins to fall, and, based on measurements of the output power from the resonator, the bulb with coal still absorbs the incident power very intensely. This effect can be explained by the fact that water released from coal and deposited on the walls still absorbs microwave power, but coal itself, losing moisture, absorbs heat less efficiently. The temperature remains at 60 degrees for the next few minutes, which can be associated with the absorption of power due to the mineral part of coal, as well as bound water inside the coal sample.

![Coal surface temperature during microwave heating](image)

**Figure 3.** Change in the surface temperature of a coal sample by heating time. Sample weight is 0.162 g, initial moisture content is 18%, input power is 5 W, microwave frequency 2.45 GHz.

Moisture measurement was carried out by removing the sample flask from the resonator and weighing a coal sample every 30 seconds during the experiment. Since the temperature regime took place at temperatures of about 110 degrees and below, no chemical reactions affecting the mass of coal occurred, except for the evaporation of water. The working humidity of the samples at the initial stage was 17.9 – 18%. On average, after the completion of the experiment (540 s), this humidity was 13.3 – 13.5%. Moreover, after 300 s, as shown by measurements, the humidity practically ceased to change (the supplied microwave power was not enough to dry the rest of the moisture). The moisture loss rate averaged 0.024 mg s\(^{-1}\) or 0.9 % min\(^{-1}\).

In modeling, the imaginary part of the dielectric constant is the most important parameter determining the efficiency of converting the energy of an electromagnetic wave into heat as well as the dissipation of microwave energy into heat. Using the measured values of the frequency shift and the Q factor of the circuit, we determine changes in this parameter with a drop in humidity, which on average show a decrease from 0.3 to 0.2 during this experiment. This is consistent with experiments on
determining the dependences of electrophysical parameters on humidity performed at the previous stage of the work.

**Conclusions**

A technique has been developed and a setup has been created for studying the processes of moisture evaporation from coals when exposed to microwave radiation. Radiation parameters have been optimized to ensure maximum absorption of microwave energy by the samples. The rate of water evaporation from the coals of the Talovskoye deposit in Siberia in the performed experiments is shown to be about 1% min\(^{-1}\). The measurement results of the sample heating rate are explained by a possible change in the mechanisms of radiation absorption. The data obtained for the first time on the rate of microwave heating and moisture yield provide the necessary information for testing models of microwave drying for this class of coals.

**References**

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