Investigation of the elemental and technical composition and thermophysical properties of coal samples from the Talovsky deposit of Siberia

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Abstract. The work is devoted to the study of thermophysical properties, elemental and technical composition of brown coal of the Talovskoe deposit in Siberia. This kind of coal can be used as power fuel for thermal power plants, boilers, etc. However, according to the preliminary analysis, this type of fuel requires additional processing, namely activation, drying, crushing, enrichment, removing toxic impurities, etc. From the available known methods of coal processing, one of the most promising and innovative technology may be exposure of coal to microwave radiation. With this treatment, intense drying of the material, grinding, yield of nitrogen, sulfur and other toxic components during processing takes place. This significantly increases the energy efficiency and environmental friendliness of the further use, of the final product processed in this way. Design and efficient engineering systems for heating, drying, grinding and using microwave energy requires a more in-depth information about the parameters of this type of coal and the changes in the course of technological processes. This work aims at finding and studying such regularities for brown coal of the Talovskoye field.

1. Introduction
Talovsky brown coal (grades B1, B2) deposit of Siberia is located in a south-east part of the Tomsk area in 25-50 km to the north of city of Tomsk and is estimated as large deposit with a predicted resource about 3.6 billion tons that is capable to provide a coal mining of 10-15 million tons per year [1,2]. In these brown coals, humidity ranges from 15 to 30%, ash content is 10-25%, and combustion heat is reaches up to 20 MJ / kg [3]. At present, the deposit is at the stage of incomplete geological development and the estimation of coal as an energy fuel will make it possible to evaluate the possible scales of its application for thermal power plants, heating boilers, etc. As shown by earlier studies [4], Talovsky coal in its original form is limitedly suitable for these purposes. Therefore, it is necessary to search for such modes of preliminary heat treatment, which contribute to improving its quality characteristics. Here, broad opportunities are associated with the methods of processing coal using microwave energy. The use of electromagnetic microwave radiation will increase the combustion heat, reduce humidity, ash content, and also reduce the content of mercury, chlorine, sulfur and other harmful components. In addition, microwave treatment will result in parallel to partial crushing of coal. As a result, low-grade coal exposed to microwave radiation becomes a more homogeneous, high-quality product. So, brown coal, ennobled with microwave energy, is close in terms of its characteristics to rock coal. During fuel combustion in the microwave field, the rate of combustion increases, and the process itself becomes stable, the ignition mode improves, environmental indicators improve, etc. Not enough widespread of microwave technologies in the coal power industry, to which the world today displays increased interest, is because of weak development of the scientific
foundations of interrelated, rather complicated electrophysical and thermophysical processes. Full advantage of the microwave effect on the qualitative preparation of coal and its drying, and also ecological combustion is possible only upon availability of modern mathematical models and means for their analysis, as well as an array of experimental data on the influence of microwave on coal properties. The use of brown coal exposed to microwave radiation will ensure the improvement of thermal power plant (TPP) operation in terms of the following: increasing overall efficiency; reducing operating costs; improving the environment; and expanding the possibilities of simultaneous use of different brands of coals. The most promising and effective processes of preliminary treatment of coal include the following: microwave heating, microwave activation, microwave drying, microwave enrichment, etc. Carrying out engineering calculations and selecting technology parameters require knowledge of fuel characteristics and their dependence on microwave exposure, as well as humidity, temperature, etc. In this paper, we investigated thermophysical characteristics of coal and its composition.

2. Research methods and instrumentation
The core sample of Talovsky coal extracted from well No. 40 at a depth of 25.1-26.6 meters was investigated. The sample was conditioned to an air-dry state and analyzed in accordance with Russian State Standard P 52911-2013 "Solid mineral fuel. Determination of total moisture", 55661-2013 "Solid mineral fuel. Determination of ash content", 55660-2013 "Solid mineral fuel. Determination of the yield of volatile substances".
The elemental composition of the test sample was determined using the Vario Micro Cube (Elementar, Germany). The content of trace elements (in particular mercury and chlorine) in the coal was studied using an EDX 720p energy dispersive X-ray fluorescence spectrometer (Shimadzu, Japan). Determination of thermophysical characteristics, such as thermal diffusivity, heat capacity, and thermal conductivity, was performed using the Discovery Flash DLF-1200 thermal diffusivity analyzer (TA Instruments, USA).
The chemical composition of the ash residue was investigated according to Russian State Standard 10538-87 "Solid fuel. Methods for determining the chemical composition of ash".

2.1. Element composition analysis
The measurements were carried out with the aid of the Vario Micro Cube element analyzer. It is an instrument designed for fully automatic quantitative analysis of the elemental composition of a solid substance (C, H, N, S, O).
The operating principle of the device is as follows. The analyzed sample is loaded into the automatic sample feeder, which rotates, after a certain time, moves the sample to the ball valve. From the tap, the sample enters the combustion tube, in which it burns. The products formed during combustion enter the recovery tube, then are directed into the drying tube to remove the water vapor present in the sample. Further, the reduced gas is sent to the adsorption column, where it is separated into different gas components, and enters the detector (which recognizes gas components by its thermal conductivity). The signal from the detector is transmitted to the computer and processed using calibration curves.
Also for additional analysis of the elemental composition, the X-ray fluorescence spectrometer EDX 720p was used, which is a device used to determine the elemental composition of a substance from sodium to uranium by X-ray fluorescence analysis.

2.2. Analysis of thermal diffusivity
The measurements were carried out using the Discovery Flash DLF-1200 analyzer, which is configured by connecting the radiation source modules and thermostats. The source module contains a xenon lamp with a reduced flash duration (HSXD) or laser, a registration system, and temperature controls.
The flash method used in the analyzer is the most common way to determine thermal diffusivity. The advantage of this method is the high measuring rate with good accuracy and reproducibility. The method consists in uniform irradiation of one plane of a small disc-like sample with a very short energy pulse (figure 1).

![Diagram of thermal diffusivity measurement by flash](image1)

**Figure 1.** Schematic representation of thermal diffusivity measurement by flash.

The temperature-time dependence on the lower surface is recorded by a solid-state optical sensor with an ultrafast response. The thermal diffusivity is determined on the basis of the obtained thermogram (figure 2). Based on the obtained value and the previously measured sample density, heat capacity, and thermal conductivity are calculated.

![Diagram of thermogram](image2)

**Figure 2.** The thermogram obtained by the Discovery Flash DLF-1200 analyzer.

The Discovery Flash DLF-1200 analyzer determines the thermal diffusivity within a wide temperature range (from -150°C to 1200°C).
3. Results
The heat engineering characteristics of the Talovsky coal sample are listed in table 1, the chemical composition of the ash residue is shown in table 2, while the thermal characteristics, depending on the temperature and humidity of the source fuel, are presented in table 3 and table 4, respectively.

**Table 1.** Thermal characteristics of the Talovsky Coal sample.

| Characteristic                       | Value (%) |
|--------------------------------------|-----------|
| Operating humidity, $W_1$            | 17.94     |
| Ash content in terms of dry weight, $A_d$ | 24.49     |
| $C_{daf}$                            | 61.29     |
| $H_{daf}$                            | 4.72      |
| $N_{daf}$                            | 0.40      |
| $S_{daf}$                            | 1.43      |
| $O_{daf}$ (by residue)               | 32.16     |
| Mercury content                      | Not detected |
| Chlorine content                     | Not detected |

**Table 2.** The composition of the ash residue obtained from coal ashing

| Chemical components of ash          | Value (%) |
|-------------------------------------|-----------|
| $SiO_2$                             | 54.0      |
| $CaO$                               | 4.7       |
| $MgO$                               | 1.9       |
| $SO_3$                              | 1.9       |
| $R_2O_3$+$TiO_2$                    | 35.6      |
| $Fe_2O_3$                           | 8.5       |
| Total                               | 98.1      |

**Table 3.** Thermophysical characteristics of Talovsky coal at different temperatures

| Temperature ($^\circ$C) | Thermal conductivity, W/(m · K) | Specific heat capacity, J/(kg · K) | Thermal diffusivity, cm²/s |
|-------------------------|---------------------------------|-----------------------------------|----------------------------|
| 25                      | 0.23                            | 1438.47                           | 0.0013                     |
| 50                      | 0.23                            | 1430.80                           | 0.0013                     |
| 80                      | 0.22                            | 1423.65                           | 0.0012                     |
| 110                     | 0.22                            | 1463.96                           | 0.0012                     |

**Table 4.** Thermophysical characteristics of Talovsky coal at different humidity

| Влажность (%) | Thermal conductivity, W/(m · K) | Specific heat capacity, J/(kg · K) | Thermal diffusivity, cm²/s |
|---------------|---------------------------------|-----------------------------------|----------------------------|
| 3.15          | 0.21                            | 1612.02                           | 0.0011                     |
| 6.37          | 0.25                            | 1619.15                           | 0.0013                     |
| 7.66-15.1     | 0.23                            | 1438.47                           | 0.0013                     |
| 23.33         | 0.27                            | 1383.83                           | 0.0016                     |

The measured values of the true heat capacity coincide with the results (figure 3) obtained by the dynamic c-calorimeter method using the IT-S-400 heat capacity meter [5].
Figure 3. Dependence of the heat capacity of Talovsky coal on temperature: Measurements obtained by 1 - dynamic c-calorimeter method using the IT-S-400 heat capacity meter; 2 - using the Discovery Flash DLF-1200 analyzer.

Convergence of the results obtained by different methods indicates their reliability.

4. Conclusion
During the implementation of these studies, elemental and thermophysical characteristics of the Talovsky brown coal have been determined, including moisture, ash content, element composition, mercury and chlorine content, chemical composition of ash, heat capacity, thermal conductivity, and thermal diffusivity. These properties were measured using certified Russian State Standard methods and a high-precision instrumentation.

The achieved results are in a good agreement with the measurement results reported by other authors that indicates the reliability of the obtained values. Above thermophysical characteristics, found depending on the temperature and humidity will be use as the basis for microwave heating and drying of coal from Talovsky coal deposits.

5. References
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