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Investigation of the dependence of the process of spontaneous combustion on the particle size of brown coal processing products

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Abstract. The paper presents the results of a study of the process of spontaneous combustion of partially carbonized lignite and sorbent from coal, depending on the particle size. To determine the critical conditions of spontaneous combustion and the effective kinetic parameters of the process proceeding along the thermal mechanism, a special experimental setup was used. The results of the study indicate the influence of particle size on the time of spontaneous combustion and on the rate of oxidation of coal matter. A mathematical model of spontaneous combustion of coal matter is developed. The model uses the spatial nonstationary heat conduction equation, in which the heat release in the process of coal oxidation is taken into account by setting a heat source based on the experimentally obtained kinetic parameters of the spontaneous combustion process - effective activation energy and the pre-exponential factor.

1. Introduction

Since the appearance of the first coal mines, there is a worldwide problem of spontaneous combustion of coal fuel. It is known that coal fuel and its processing products have the ability to sorb oxygen from the air. The oxidative processes developing at the same time lead to its spontaneous combustion. Fires resulting from spontaneous combustion of coal create dangerous conditions for humans and lead to large economic losses. For example, in China, the annual loss of coal resources as a result of spontaneous combustion accounts for about a seventh of the annual production, and in addition to direct economic damage is fraught with serious environmental consequences.

The storage risk of thermal power facilities is due primarily to the using of brown coal and coal dust [1-3]. The spontaneous combustion is the main cause of fires in fuel storages and coal supply routes (50-60%), for this reason, every sixth fire occurs at CHP plants and boilers. The number of fires at these sites in regions where brown coal is used as fuel is 1.5-2 times more than in other regions. According to expert estimates, 90% of fires and explosions of pulverizing installation occur due to spontaneous combustion [3, 4]. Thus, in the region of Siberia and the Far East, about 30% of man-made fires in industrial plants and 50% of fires in thermal power plants occur due to spontaneous combustion [2].

One of the promising areas for the development of the coal industry is the introduction of modern technologies for the enrichment and deep processing of coal. On the basis of processing of brown coals, there are such demanded products as partially carbonized lignite and briquetted products for metallurgy and domestic use. For the prediction and prevention of fire during transportation and storage of brown coal processing products, it is necessary to study the reaction characteristics of the spontaneous combustion process for these substances.

The aim of this work is to study the dependence of the process of spontaneous combustion on the particle size of the partially carbonized lignite and sorbent from coal, as well as testing the mathematical model of these processes.

2. Experimental setup

To determine the kinetic parameters and critical conditions of spontaneous combustion processes proceeding along the thermal mechanism, an experimental setup was used, the scheme of which is shown in Fig. 1 [5]. The basis of the installation is a special dry-bulb thermometer allowing to maintain the temperature in the range from 50 to 300 ° C with an accuracy of 0.5 ° C and a reaction vessel in which the test sample of solid fuel is filled, in the form of a cylinder is from a thin brass net. During the experiments, the temperature of the test sample is recorded at no less than three points (at the center, near the wall and at the boundary of the reaction vessel). The temperature in the thermostat is monitored to maintain constant conditions. To calculate the effective activation energy and the pre-exponential factor, the thermograms obtained during the experiment are processed and recalculated in Arrhenius coordinates.

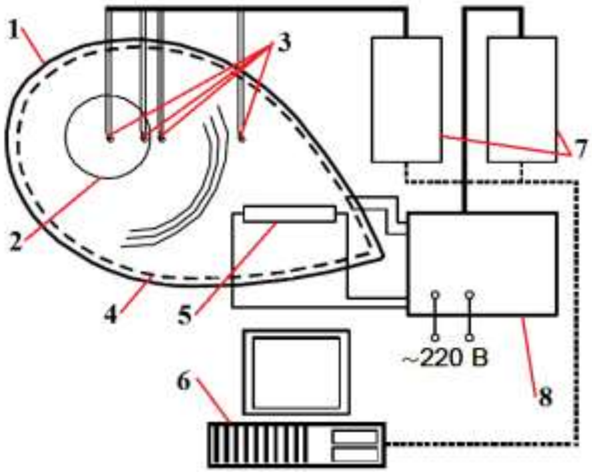

Figure 1. The installation for the definition of parameters of spontaneous combustion [5]: 1 – thermostat housing; 2 – reaction vessel; 3 – thermocouples; 4 – basic heater; 5 – additional heater; 6 – electronic data processing; 7 – data acquisition and management modules; 8 – power supply and control module.

3. Problem statement and research methods

As samples for the study, was chosen a sorbent from the Itat deposit coal and the partially carbonized lignite from the Balakhta deposit (Table 1). The temperature of the thermostat during the experiments with the sorbent was 235 ° C, and for the partially carbonized lignite - 285 ° C. The reaction vessel in which the sample was placed was a cylindrical shape 4 cm high and 3 cm in diameter.

Table 1 Technical analysis of brown coal processing products

Products	**W_r,%**	**A_d,%**	**V_{daf},%**	**Adsorption, %**
Sorbent. Itat-7	0,85	37,0	22,1	55,2

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Sorbent. Itat-8	0,90	42,2	22,2	70,6
Partially carbonized lignite. Balakhta	1,92	19,0	9,8	69,2

The process of heating a sample of coal substance in a thermostat is written in the form.

$$\frac{dT}{d\tau} = \frac{m}{C_m}\left(\dot{Q}_m + \dot{Q}_d + \dot{Q}_o\right) \qquad (1)$$

where $\dot{Q}_m$ – thermal power due to thermal conductivity, W;

$\dot{Q}_o$ – power of heat release during coal oxidation, W;

C_m – heat capacity of coal substance, J/(kgK).

$$Q_m = \alpha S\left(T - T_0\right) \qquad (2)$$

where α – heat transfer coefficient, W/(m^{2}K); S – surface area of heat transfer, m^2.

Heat release during coal oxidation is taken into account by setting the source in the form:

$$C_p \rho \frac{dT}{dt} = C_p \rho k_{cb} C \exp\left(-\frac{E}{RT}\right) \qquad (3)$$

where C – the rate constant of the chemical reaction; E – activation energy of the oxidation reaction, J/mol; k_{cb} – coefficient characterizing the specificity of coal burnout.

At the boundaries, the heat transfer coefficient, corresponding to the formulation of the problem. The obtained mathematical model allows calculating the dynamics of heating (heat generation) of coal substance in the process of spontaneous combustion, depending on the properties of coal matter and external factors.

4. Results and discussion

Figs. 2-3 show the results of an experimental study in the form of a graph of the temperature change of the sample in the center of the reaction vessel when it is heated and oxidized for different particle sizes. It can be seen that for the Itatsky-7 the spontaneous combustion rate decreases with increasing particle size (Fig. 2). This is due to the change in the active surface of the coal backfill at different particle sizes [6]. For Itatsky-8, this dependence is not so pronounced (Fig. 3).

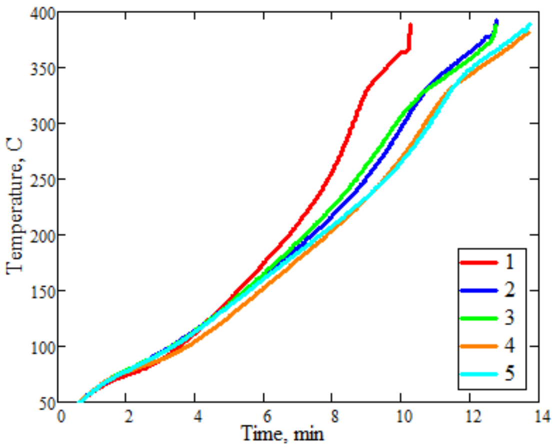

Figure 2. The temperature in the center of the sample (Itatsky-7): 1 – 0.05-0.1 mm; 2 – 0.16-0.2 mm; 3 – 0.2-0.25 mm; 4 – 0.25-0.315 mm; 5 – 0.315-0.35 mm.

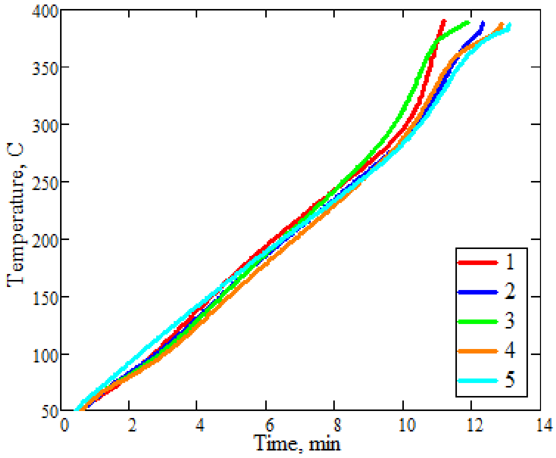

Figure 3. The temperature in the center of the sample (Itatsky-8): 1 – 0.05-0.1 mm; 2 – 0.16-0.2 mm; 3 – 0.2-0.25 mm; 4 – 0.25-0.315 mm; 5 – 0.315-0.35 mm.

Fig. 4 shows the results of the experiment for the Balakhtinsky partially carbonized lignite at different particle sizes. For a given coal matter, as for Itatsky-7, the rate of spontaneous combustion decreases with increasing particle size. The smallest with a size of 0 to 0.05 mm did not catch fire under the given conditions. Perhaps this is due to the increased share of minerals in small particles of coal fuel [7, 8]. Also, the increase in the proportion of minerals occurs after coal processing, since the probability of burnout of the organic part in fine particles is higher.

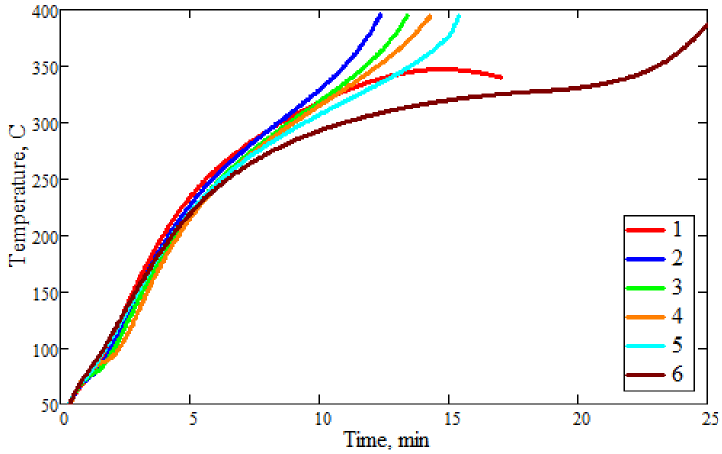

Figure 4. Temperature in the center of the sample (Balakhtinsky): 1 – 0.0-0.05 mm; 2 – 0.05-0.1 mm; 3 – 0.16-0.2 mm; 4 – 0.2-0.25 mm; 5 – 0.315-0.35 mm; 6 – 0.35-3.5 mm.

Table 2 shows the effective kinetic constants of the process of spontaneous combustion of coal matter for sorbents and the partially carbonized lignite at different particle sizes. It is known that organic materials, as a rule, at spontaneous combustion are not characterized by constant kinetic parameters. However, it is established that the parameters E and C do not change chaotically, but strictly according to a certain regularity [5, 9]. Figure 5 shows the linear dependence of the activation energy on the logarithm of the pre-exponential factor for sorbents and partially carbonized lignite. It is seen that the effective kinetic constants for different particle sizes for the Itatsky Sorbent in a given coordinate system lie on one line. It is the same for the Balakhtinsky partially carbonized lignite. Thus, it can be concluded that the particle size does not influence the kinetics of heat release during spontaneous combustion of coal substance, since the change in the activation energy is compensated by an increase or a decrease in the pre-exponential factor.

Table 2 Effective kinetic constants

The size	**Itatsky-7**		**Itatsky-8**		**Balakhtinsky**	
	C. m/s	E. J/mol	C. m/s	E. J/mol	C. m/s	E. J/mol
0.05-0.1 mm	51.2	18103.9	7903.0	45408.2	1562.9	43330.7
0.16-0.2 mm	18.5	14958.0	480.3	32307.8	3359.8	48212.5
0.2-0.25 mm	8.9	11634.0	32.8	17869.0	540.6	39424.2
0.25-0.315 mm	17.3	14938.0	167.0	26653.3	-	-
0.315-0.35 mm	31.9	18099.2	268.4	29539.1	144569.1	69618.1
0.35-3.5 mm	-	-	-	-	3.8e15	195924.2

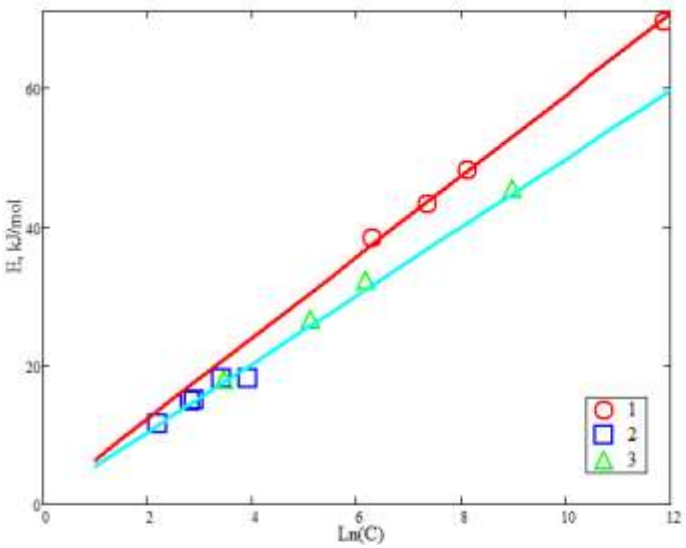

Figure 5. The linear dependence of the activation energy on the logarithm of the pre-exponential factor: 1 – Balakhtinsky; 2 – Itatsky-7; 3 – Itatian-8.

Figs. 6, 7 show the results of a comparison of the calculation with the experimental temperature data at the center of the sample. It can be seen from the figures that the proposed model and methodology for calculating the process of spontaneous combustion of products of brown coal processing, based on the preliminary obtaining of the reaction properties of coal from the experimental studies described above, makes it possible to predict the process of spontaneous combustion of coal matter, including during its transportation and storage.

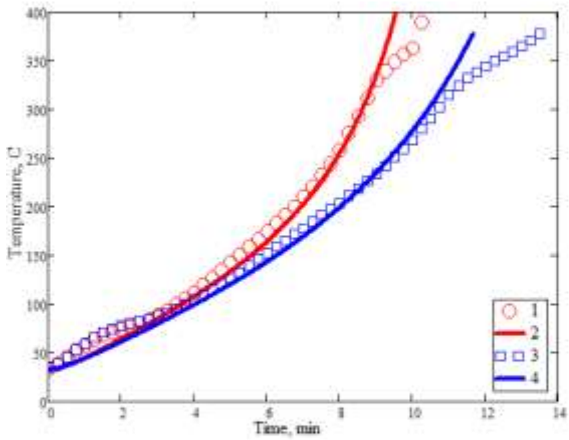

Figure 6. Temperature at the center of the sample (Itatsky-7): 1 – Experiment (0.05-0.1 mm); 2 – Calculation (0.05-0.1 mm); 3 – Experiment (0.315-0.35 mm); 4 – Calculation (0.315-0.35 mm).

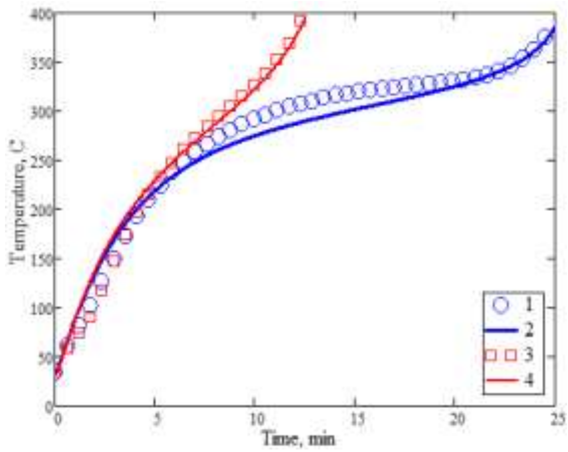

Figure 7. Temperature in the center of the sample (Balakhtinsky): 1 – Experiment (0.05-0.1 mm); 2 – Calculation (0.05-0.1 mm); 3 – Experiment (0.35-3.5 mm); 4 – Calculation (0.35-3.5 mm).

5. Conclusion

A study was conducted to reveal the dependence of the process of spontaneous combustion on the particle size of the partially carbonized lignite and sorbent from coal. The results indicate the influence of particle size on the time of spontaneous combustion and on the rate of oxidation of coal substance due to the change in the active surface of the backfilling of coal substance. It was shown that the particle size does not affect the kinetics of heat release during spontaneous combustion of coal substance. We have performed verification of the three-dimensional mathematical model of the process of spontaneous combustion of coal substance in a sample. Using the proposed methodology, it is possible to investigate the factors that affect the increase in the risk of spontaneous combustion of coal substance, when it is transported by rail and road transport, and also when stored in temporary stores. To justify and develop the constructions of specialized containers that meet the requirements for spontaneous combustion of coal, as well as coal processing products under non-standard conditions.

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