A laboratory setup based on porous burner for coal particles combustion investigation

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In this work, physicochemical features, thermal behaviour, and combustion properties of a coal dust of Pavlovskiy brown coal were studied. For investigations of kinetic properties of fine coal particles combustion, the laboratory-made setup was developed and constructed. An experimental research on the properties of fine coal particles was carried out. Additionally, thermophysical characteristics of coal dust, compositions of thermal decomposition products and particle size distribution were investigated.

1. Introduction
The study of effective combustion of fossil fuels is important for finding optimal regimes for burning coal particles in various domestic and industrial boilers and power plants [1, 2].

The investigation of the complex physicochemical process of coal dust burning in the combustion chamber is difficult. Experimental studies of the combustion of a single particle as an elementary component of a coal dust torch have found wide application [3-5].

According to the current models [6-8], it is known that the combustion of coal particles is a complex physicochemical process in which several stages of organic matter conversion during the heating of a coal particle are occurred such as an evaporation of moisture from the surface of a coal particle, a multi-stage yield and combustion of volatile components at thermal decomposition of organic mass, heterogeneous reactions of the char and oxidizer with the formation of complete and incompletely combustion products, and others.

The literature analysis [9, 10] revealed that the kinetic features of the thermal transformation and combustion of coal dust with particle sizes less than 150 μm have not been fully studied. Further investigations require special experiments and a more complex theoretical analysis using improved numerical models.

In this work, physicochemical features, thermal behavior, and combustion properties of a coal dust of Pavlovskiy brown coal were studied. For investigations of kinetic properties of fine coal particles combustion, the laboratory-made setup was constructed.

2. Experimental
A coal dust of Pavlovskiy brown coal was studied in present work. The particle sizes of coal dust were analyzed by Analysette 22 Nano Tec (Fritsch, Germany). Ash content was determined using standard method (GOST 11022-95). The lowest calorific value was measured by Calorimeter IKA C 6000
(IKA -Werke GmbH & Co, Germany) as an average value of three measurements. Thermogravimetric analysis was performed using TGA-HP150s equipment (TA Instruments, USA). IR specters of thermal decomposition gas products were recorded using the Nicolet iS10 FT-IR Spectrometer (Thermo Electron Corporation, USA). The experiments were carried out in a chamber at atmospheric pressure in the air. Samples were heated up to 800°C with a heating step of 5°C/min. Outlet gases came out into separate gas line heated up to 180°C connected to the spectrometer.

2.1. Laboratory-made setup

The scheme consists of several units (fig.1): a coal dust supply unit, a coal particles transporting line, a gas-air mixture feed unit, a porous burner, a cooling zone, a wet ash collector, and a decompression section. In the laboratory-made setup the thermal radiation used for coal particles decomposition and ignition was emitted by porous burner during propane/butane combustion. The porous cylindrical Ni-Al alloy burner prepared by self-propagating high-temperature synthesis was used as external heater. Such type of heater was chosen because of its high radiative and heat flux density.

![Diagram](image)

Fig. 1. The laboratory-made setup: a – scheme, b - photo.

Coal dust is poured into the "coal feeder". Under gravity and decompression the dust moves through a tube of 11 mm in diameter to the screw feeding unit that regulates the metering of coal dust. Then the dust gets into a transporting line that is a quartz tube with an internal diameter of 6 mm and a wall thickness of 2 mm. When the coal particles enter the zone of burner, they are heated up and ignited. The burning dust particles come out from the zone of the porous burner and move along the
quartz tube into the cooling zone. This zone is performed as a stainless steel tube with an internal diameter of 8 mm and a length of 150 mm. Then the residues of particles fall into the wet ash collector. The pressure in the particles transporting line is controlled by a draft gauge.

Thermocouples (K types), a gas analyzer, flowmeters (Bronkhorst) with a flow regulators, a thermal imager (NEC TH 9100), a video camera (Nicon), a high-speed camera (Photron), and a thermometer are used in the setup for research purposes. The recording of coal dust particles movements with a high-speed camera and/or a video camera can be carried out at two points: in front of the burner and after it.

3. Results and Discussion

The distribution of measured particle sizes is illustrated on figure 1.

![Particle size distribution](image)

**Fig. 2.** The particles size distribution of coal dust.

The results of particle size measurements show that the sizes of coal dust particles are less than 120 µm. Ash content measured is about 24.5%. It was found that the lowest calorific value is higher for fine coal particles (3914 kcal/kg) than for a raw coal of the same rank (3250 kcal/kg) in according to our previous investigations [13].

FTIR spectroscopy of fine coal particles during thermal transformation in air show that the trace of CO has already detected at 200°C. On the spectra recorded at 300°C the trace of methane was appeared. Absorbance peak maximums of CO and CH₄ were detected at about 400°C and 450°C, respectively. At the same time TG curve demonstrates two well-defined step-like zones that are from 35 to 110°C and from 190 to 550°C. In the first zone the rapid decrease in weight with rate of about 4.8 mg/°C is observed. The rate of weight decreasing in the second zone is about 1 mg/°C. The rest of diagram (from 550 to 800°C) is characterized by the weight-loss rate less than 0.3 mg/°C [14].

After the laboratory setup (fig. 1) was constructed the combustion of coal particles under different conditions were investigated.

| Flow gas rate, l/min | Flow air rate, ml/s | Fuel–air ratio, Φ | Heat release*, kW/m² | Outer temperature, °C | Inner temperature, °C |
|----------------------|---------------------|-------------------|-----------------------|------------------------|------------------------|
| 1.5                  | 750                 | 0.8               | 395                   | 906                    | 915                    |
| 1.7                  | 850                 | 0.8               | 448                   | 915                    | 955                    |
| 1.8                  | 900                 | 0.8               | 475                   | 924                    | 1000                   |
| 2                    | 1000                | 0.8               | 528                   | 965                    | 1058                   |
| 2.5                  | 1250                | 0.8               | 660                   | 1066                   | 1129                   |
| 4                    | 2000                | 0.8               | 1052                  | 1211                   | 1283                   |

* - the heat release of the internal surface of the burner
Temperatures on the surface of porous burner and in the middle of quartz tube (coal particles transporting line) were measured using the thermal imager and the thermocouple. The obtained results in dependence of burner power are presented in table 1. In the table 1 maximum temperatures are pointed out. Additionally, temperatures of zones near burner were investigated. It was determined that the temperature before and after the burner decreases slightly during the transition from a decompression pressure $P = -2$ hPa to $P = -5$ hPa. The temperature is reduced by 10-15% but cooling in the cooling zone is slower and temperatures are higher at 2-4%.

The mass flow rate of coal dust was determined at different level of decompression, for instance at -2.5 hPa the mass flow rate is 205 mg/min.

Fig. 3. Images of ignited coal particles recorded by the high-speed camera in the outlet of porous burner in dependence of radiant flux density: a – 395 kW/m$^2$, b – 475 kW/m$^2$, c – 1052 kW/m$^2$. (the decompression in transporting line is -2 hPa)

To study the flow rate of coal particles, a high-speed camera was used. During experiments the camera mode was selected which was 20,000 frames per second. Laser illumination was also used to better display the coal particles. The measured speed of coal particles at -2 hPa was 3 m/s before the burner and 11.6 m/s after it. Figure 3 shows the ignited coal particles recorded in the outlet of porous burner. As can be seen in the images, the linear dimensions of the particles decrease with increasing of burner power. At the same time, it was found that the number of outlet particles are initially increased and then rapidly decreased. Such behaviour could be explained by the fragmentation process [15, 16].

4. Concluding Remarks
Experimental results such as coal properties, decomposition rates (temperature dependencies of mass loss), and product distributions, coal particle size analysis were obtained in our work.

The scheme of the laboratory setup was developed and constructed. When developing the scheme of the laboratory setup, the concept of practicality and multifunctionality was adhered to. Combustion of coal dust of Pavlovskiy brown coal was investigated using the laboratory-made setup.

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