High-Speed Visualization of Coal Particles Ignition Process Stages in the Low-Temperature Oxidizer Flow

Dmitrii O. Glushkov*, Pavel A. Strizhak, Kseniya Yu. Vershinina, Olga V. Vysokomornaya

Laboratory of Heat and Mass Transfer Processes Simulation, National Research Tomsk Polytechnic University, Tomsk, Russian Federation
*corresponding author: dmitriyog@tpu.ru

Abstract Regularities of coal particles (typical fuel for thermal power plants) ignition in an air flow were investigated at the using optical techniques of gas-flow diagnostics. Developed experimental setup includes cross-correlation digital camera, double pulsed solid-state laser, personal computer, and synchronizer for a collaboration of these devices. The PIV and PTV methods application let us measure airflow velocity at a flow of coal particles. High-speed video fixation allowed establishing particles ignition delay time at a variety of temperature and velocity of airflow. Minimum oxidizer flow parameters sufficient for ignition of coal particles were defined. Ignition delay times of volatile gas-phase ignition and carbon heterogeneous ignition in "coal particle – air" system were determined.
Keywords: coal particle, air flow, ignition, heat and mass transfer, high-speed visualization, PIV, PTV

1 Introduction

The processes of ignition and combustion of coal particles are of great interest because of the wide range of applications (especially in the energy sector) [1, 2]. It is explained by the many results of theoretical [3, 4] and experimental [5, 6] studies of the ignition and combustion of single coal particles, carbon and coal dust. Well studied thermochemical processes at high temperature (more than 1200 K) heating of coal particles. Its ignition under conditions of moderate (less than 1000 K) heating is also quite a lot of interest. This phenomenon is much less studied and is often the cause of fires and explosions at thermal power stations. Analysis of the current coal particles burning theory shows that the mechanisms and characteristic times of heating and ignition of the solid fuel at ambient temperature changes in the range of 700 K to 2000 K are significantly different, and possibly required characteristics sufficiently significant refinement of these processes.
The purpose of this work is an experimental study of single coal particle ignition in the air flow.

2 Experimental setup

Fig. 1 shows the experimental setup, the main parts of which are an air fan *1* (air flow velocity from 1 to 4 m/s) and air heater *2* (temperature range from 300 to 900 K). In each experiment, air flow was heated to a pre-set temperature. A control panel *8* integrated with a thermocouple K was used to adjust the heating power in order to control air temperature. Once the temperature reached a stable value in heated air supply channel, it was released to the hollow glass cylinder *4* (length 1 m, diameter 0.1 m), where coal particle was placed into the symmetry axes. The ignition phenomenon was recorded with a high-speed camera Phantom v411 *5* (frame size of 1280×800 pixels at 2000 frames per second). The experimental data was saved in a computer *7*. The equal samples of coal particles in different experiments were weighed by an analytical balance (0.1 mg readability).
Additional equipment (based on PIV and PTV methods) was used for airflow velocity measurement: cross-correlation camera, impulse laser, synchronizer.

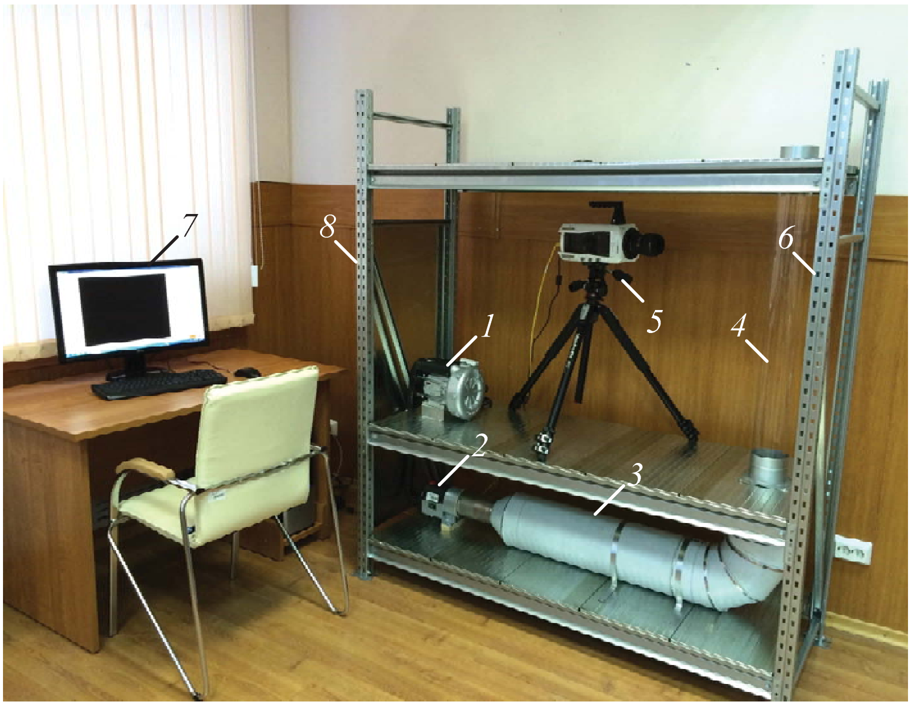
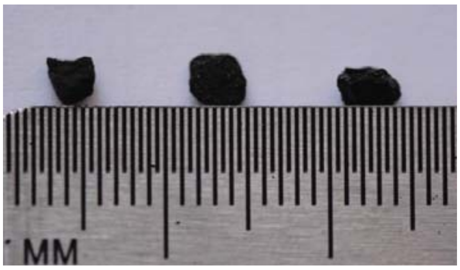
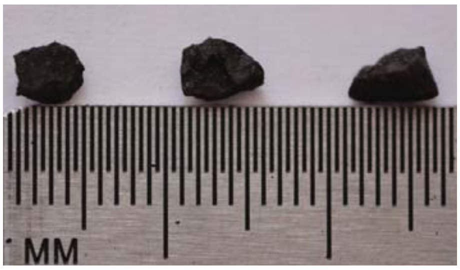


Fig. 1 Experimental setup: *1* – air fan; *2* – air heater; *3* – heated air supply channel; *4* – hollow glass cylinder; *5* – high speed video camera; *6* – yardstick; *7* – computer; *8* – control panel

Three different samples were used in the experiments: coal particles with dimensions r=2·10^{-3} m, r=2.5·10^{-3} m, r=3·10^{-3} m (Fig. 2).



(a)



(b)

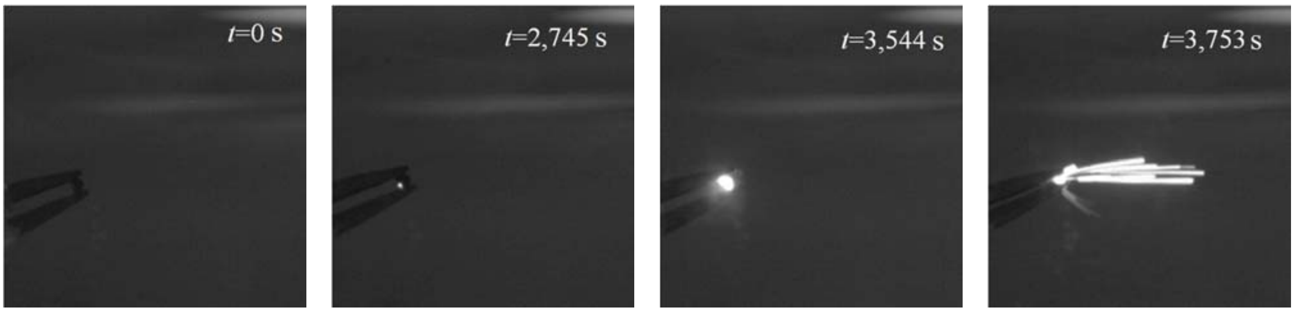
(c)

Fig. 2 Experimental samples: r=2·10^{-3} m (a), r=2.5·10^{-3} m (b), r=3·10^{-3} m (c)

The obtained results were classified as two types: “no ignition” or “flaming ignition”. Flaming ignition means the presence of a visible flame that persisted for more than 1 s after the initiation of combustion process. According to experimental conditions, no more 10 repeating runs were performed to calculate the main characteristic – ignition time delay (t_d) under the same conditions to provide valid results.

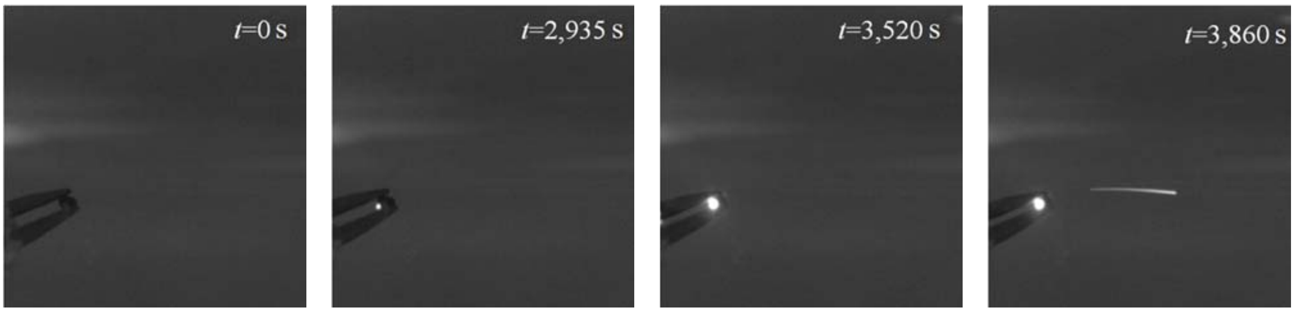
3 Experimental investigation results

Figs. 3–5 shows coal particle ignition stages at air temperature 850 K. It was established that T=750 K is the minimal temperature of air flow when ignition takes place.



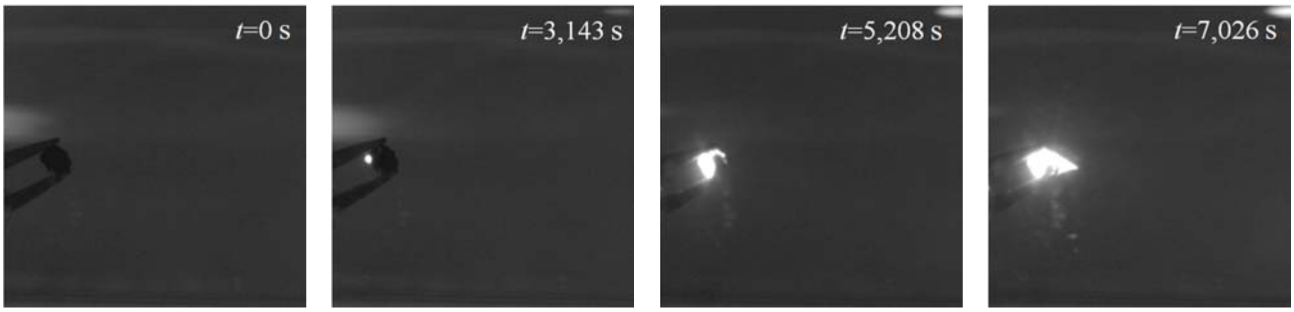
Heating Ignition Combustion Destruction

Fig. 3 Coal particle ignition stages (r=2·10^{-3} m)



Heating Ignition Combustion Destruction

Fig. 4 Coal particle ignition stages (r=2.5·10^{-3} m)



Heating Ignition Combustion Destruction

Fig. 5 Coal particle ignition stages (r=3·10^{-3} m)

In case of convective heating of solid fuel particles by air flow with velocity higher 5 m/s, stages of ignition and flame combustion of volatiles do not happen. Coke combustion is initiated as a result of coal particle heating. Emitted volatiles during thermal decomposition products of coal entrained by gas stream and their concentration in the vicinity of the particle are insufficient for the combustion.

4 Conclusion

The study was conducted experimentally on heat and mass transfer controling the ignition of coal particles by hot air flow. Ignition time delays of coal were measured and compared for three different particles.

Experiments were carried out with high-speed camera, cross-correlation camera, impulse laser, synchronizer, air fan, air heater, and software for automatic calculation of ignition time delay.

Experimental data lead to the following conclusions:

- high probability of ignition due to interaction between a coal particle and heated air flow exists even at short-time period t<5 s;
- an exponential increase of the coal ignition time delay is demonstrated when the temperature of the air is decreased from 1000 K to 700 K and the dimension of particle is increased from $r=2\cdot10^{-3}$ m to $r=3\cdot10^{-3}$ m;
- limit parameters describing the heat source (temperature higher 750 K, velocity lower 5 m/s) beyond which stable ignition starts for coal particle were measured.

The obtained results can be useful in investigation of heat and mass transfer processes at the solid fuel particle heating by air flow when low heat capacity may be a limiting factor for development of physical or chemical processes.

Acknowledgements

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