Laser ignition of coal-petn mixtures composition

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Abstract. Laser ignition ($\lambda=1064$ nm, 120 $\mu$s) of the fraction of lignite particles $\leq 0.1$ mm in diameter, as well as lignite-petn mixtures, was studied. It was found that with an increase in the petn inclusions in the range from 0 to 50 wt. %, the ignition threshold of the mixtures decreases monotonically from 2.9 to 2 J/cm$^2$, and the combustion temperature increases from 1800°K to 2100°K. At an inclusions concentration of 50 to 90 wt. %, the ignition threshold is weakly dependent on the energy density of the laser radiation. With an increase in the inclusions concentration from 90 to 99.5%, a sharp increase in the ignition threshold is observed.

1. Introduction

The growing use of primary, blending and high explosives not only in the mining industry, construction, but also in other areas is a necessity of modern times [1]. The use of the most sensitive substance in the series of high explosives – pentaerythritol tetranitrate (petn), is of great interest. The methods of obtaining a photosensitive material based on a mixture of petn and metal nanoparticles are being intensively developed [2-6]. It was shown in [7] that inclusions of submicron particles of lignite and parabituminous coal in the petn at low concentrations (0.5 wt. %) for specimens with a density $\rho=1.7$ g/cm$^3$ under the influence of short laser pulses (14 ns, 1.064 $\mu$m) lead to explosive decomposition with a critical initiation energy (threshold) $\sim 1$ J/cm$^2$, which is comparable with the results on composite materials of petn-ultradispersed metals [8]. In this paper, low-density mixtures of lignite and petn ($\rho=0.5$ g/cm$^3$) are studied, which do not explode, but are effectively ignited by laser pulses. It should be noted the practical aspect of the problem. At present, furnace fuel oil is used to kindle fine-dyspersated coal fuel, which reduces economic indicators and causes environmental damage. The search is underway for other ways to kindle coal fuel without the use of furnace fuel oil. For this purpose, attempts are being made to use, for example, microwave radiation [9, 10]. From our point of view it is necessary to study the laser ignition of coal fuel.

2. Experimental setup and experiments

The lignite of the Kaychak field was used with the following characteristics: moisture content $W_a=8.3\%$, ash content $A_d=10.3\%$, volatile matter content $V_{daf}=48.3\%$. Coal was milled in a ball mill. After milling, the smallest fraction of the coal particle size of $\leq 0.1$ mm was selected. The petn powder was synthesized in the laboratory and had a narrow granulometric distribution with a distribution maximum of 1-2 $\mu$m. The mixtures were prepared as follows. On the analytical balances, the weights of coal and petn were made, and mechanically mixed in the required proportion. Mixtures was placed into hexane and stirred in an ultrasonic bath. Thus, we obtained a more uniform mixing of the mixture particles. Then the drying of the mixture was carried out and the charging of the experimental
specimens. The specimens with a bulk density $\rho = 0.5 \text{ g/cm}^3$ were a sample weighing 10 mg, placed in a copper cap with a diameter of 5 mm and a depth of 2 mm with a mass of 10 mg.

The scheme of the experimental setup is shown in figure 1.

![Figure 1](image.png)

Figure 1. The scheme of the experimental setup. 1 – pulsed Nd:YAG-laser; 2 – neutral light filters; 3 – beam-splitting plate; 4 – pyroelectric receiver; 5 – deflecting mirror; 6 – lens (25 cm); 7 – specimen; 8 – base; 9 – photoelectric multiplier; 10 – oscilloscope.

As a source of ignition of coal a YAG:Nd$^{3+}$-laser SOLAR Laser Systems LQ929 (1), operating in the free-running mode was used. The pulse duration was 120 $\mu$s, the maximum energy in the pulse was 0.5 J. The laser radiation energy was adjusted by means of neutral light filters (2). A part of the radiation (9% of the radiation energy) was diverted through a beam-splitting plate (3) onto a pyroelectric receiver Ophir® Photonics PE50BF–C (4). Pyroelectric receiver measured the laser radiation energy. The transverse distribution of the laser radiation intensity on the specimen surface was close to a rectangular with a characteristic beam diameter of 2.5 mm. The instability of the laser pulse energy did not exceed 3%.

Using a deflecting mirror (5), laser radiation was directed through a focusing lens (6) with a focal length of 25 cm to the specimen (7) located on the base (8).

The glow that occurs when a radiation pulse is affected to a specimen is fixed by a photoelectronic multiplier Hamamatsu H10721-01 (9), converted to an electric signal, and recorded by an oscilloscope LeCroy WY332A (10).

3. Results and discussion

The glow kinetics and the ignition threshold of mixtures of lignite with the petn particles inclusions in the range from 0 to 99.5 wt. %. Ten specimens were successively irradiated with a single laser pulse of definite energy, the glow kinetics was recorded with a photomultiplier. The mixture ignition probability $p$ was taken to be the ratio of the recorded signals of the photomultiplier (flares) to the total number of specimens. Further, the laser pulse energy was increased and the experiment was repeated. Thus, the appearance probability of the flare was measured as a function of the laser energy density (the frequency curve). The experiments were repeated for various compositions of energy mixtures. For the ignition threshold, we took the energy density $H_{cr}$, corresponding to a 50% probability of a flare. The ignition thresholds, depending on the composition of the mixture, are presented in figure 2.

We note that coal powder without the petn inclusions is ignited at $H_{cr} = 2.9 \text{ J/cm}^2$. Petn powder without coal inclusions does not ignite at the maximum possible used energies 20 J/cm$^2$. A distinct decrease in the ignition threshold is observed with an increase in the petn content from 0 to 50 wt. %. At an inclusions concentration from 50 to 90 wt. %, the ignition threshold is weakly dependent on the
energy density of the laser radiation. With an increase in the inclusions concentration from 90 to 99.5%, a sharp increase in the ignition threshold is observed.

![Figure 2. Dependence of the threshold energy of mixture ignition on the petn content concentration.](image)

The obtained results can be interpreted as follows. It is known that the pure petn powder is practically transparent to a wavelength of 1064 nm [11]. Accordingly, in the coal-petn mixture, the laser radiation is absorbed by the coal particles. Heating of the coal particles to a petn flashpoint temperature $T\approx215^\circ C$ [12] leads to the ignition of the petn particles and ignition of coal particles surrounding the petn. This leads to a decrease in the ignition threshold of the mixture in the range from 0 to 50 wt. % of the petn content. With a further increase in the petn content, due to a decrease in the content of the absorbing coal particles, $H_{cr}$ at first depends weakly on the composition, and when the content of the absorbing coal particles is <10 wt. % begins to increase sharply. Some glow kinetics that result from the combustion of a mixture are represented in figure 3.

![Figure 3. Kinetics of the glow intensity that occurs when laser ignition of mixtures with different petn contents in coal.](image)

The flare duration is non monotonically dependent on the composition of the mixture. For visibility, figure 4 shows the time dependence corresponding to the maximum flare intensity from the composition of the mixture.

Comparison of figure 2 and 4 shows that the flare duration decreases with decreasing $H_{cr}$ and sharply increases with a petn content above 90%.
Using the spectral pyrometry method [13], the flame temperature was measured. The dependence of the flame temperature on the petn inclusions concentration in lignite is shown in figure 5.

**Figure 4.** Time dependence corresponding to the maximum flare intensity from the composition of the mixture.

**Figure 5.** Dependence of the lignite combustion temperature and mixtures on the petn inclusions concentration in lignite.

Figure 5 shows that the addition of the energy material (petn) inclusions into lignite in the range from 0 to 50 wt. % leads to an increase in the combustion temperature from 1800 to 2100°K.

4. **Conclusion**
1. The laser is an effective tool for ignition of coals.
2. The energy material (petn) inclusions into lignite results in a monotonic decrease in the laser ignition threshold from 2.9 J/cm$^2$ to 2 J/cm$^2$ at an increase in the inclusion concentration from 0 to 50 wt. %. At an inclusions concentration from 50 to 90 wt. %, the ignition threshold is weakly dependent on the energy density of the laser radiation. With an increase in the inclusions concentration from 90 to 99.5%, a sharp increase in the ignition threshold is observed.
3. The energy material (petn) inclusions into lignite results in a monotonic decrease in the duration of the flare at an increase in the inclusions concentration from 0 to 50 wt. %.
4. The energy material (petn) inclusions into lignite in the range of 0 to 50 wt. % leads to an increase in the combustion temperature from 1800 to 2100 °K.

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