Glow of a coal flame during exposure to microsecond laser pulses with different energy densities

Ya. V. Kraft¹, B. P. Aduev¹, D. R. Nurmukhametov¹ and Z. R. Ismagilov¹, ²

¹Federal Research Center of Coal and Coal Chemistry, Siberian Branch of Russian Academy of Sciences, 18 Sovetskiy Ave., 650000, Kemerovo, Russia
²Federal Research Center Boreskov Institute of Catalysis, Siberian Branch of Russian Academy of Sciences, 5 Akademik Lavrentiev Ave., Novosibirsk, 630090, Russia

E-mail: lesinko-iuxm@yandex.ru

Abstract. The kinetic characteristics of the glow of coal during exposure to microsecond laser pulses have been investigated. It is shown that the glow intensity increases from the moment of exposure to the laser pulse, the maximum glow intensity falls on ~ 110-120 μs, i.e. at the end of the laser pulse. In the submillisecond range, a decrease in the glow intensity is observed. The glow intensity of coals increases linearly with an increase in the energy density of the laser radiation.

1. Introduction

Investigation of the processes of initiation of thermochemical phenomena in fossil coals makes it possible to expand the understanding of the mechanisms of initiation of combustion of solid mineral fuels.

When studying the initial mechanisms of coal ignition, laser radiation can be used as an energy source of [1-5]. However, a detailed study of the initial mechanisms of coal ignition under laser action has practically not been carried out. We started such studies earlier. In our previous works, we carried out studies of laser ignition of coals in the series of metamorphism [6-8]. To ignite the coals, a YAG: Nd³⁺ laser operating in the free-running mode was used. Registration of fast processes was carried out using the electron-optical method [6, 7] and the method of spectroscopy with high time resolution [8]. By the nature of the registered kinetic dependences of the glow and the spectral characteristics of the glow, it was found that the process of ignition of coal particles by pulsed laser radiation is multistage. The ignition stages take place in different time intervals and have ignition thresholds with characteristic energy densities $H_{cr}$. The first stage of ignition, which occurs in the time interval of ~ 120-150 μs, is associated with heating the surface of coal particles and the ignition of microprotrusions on their surface. The second stage of ignition, which takes place in a millisecond time interval, is associated with the release and ignition of volatiles in the gas phase. The third stage of ignition, which takes place in the time interval of ~ 40-150 ms, is associated with the ignition of the non-volatile residue of coal particles. To understand the details of the ignition mechanism of coals, it is necessary to sequentially study the processes at different stages of ignition. Of particular interest are the processes occurring during the action of a laser pulse.

2. Objects and techniques
The objects of study were coals of the Kuznetsk coal basin of various stages of metamorphism: long-flame (LF), semi-lean caking (SLC), weakly caking (WC), lean (L), anthracite (A).

The results of technical analysis of coals are shown in Tables 1.

| №  | Sample, coal grade                              | Technical analysis |
|----|-------------------------------------------------|--------------------|
| 1  | Sample No. 72, grade LF, mine "Kamyshansky"    | Wa, %  7.6        |
|    | Severo-Taldinskoye deposit, seam 73            | Ad, %  6.2        |
|    |                                                 | Vdaf, %  44.5     |
| 2  | Sample No. 34, grade SLC, mine "Tomusinsky"    | Wa, %  0.1        |
|    |                                                 | Ad, %  6.7        |
|    |                                                 | Vdaf, %  19.8     |
| 3  | Sample No. 45, grade WC, mine "Bachatsky"      | Wa, %  1.3        |
|    |                                                 | Ad, %  4.7        |
|    |                                                 | Vdaf, %  19.0     |
| 4  | Sample No. 81, grade L, Kuznetskinveststroy JSC, seam 19a | Wa, %  0.5        |
|    |                                                 | Ad, %  6.2        |
|    |                                                 | Vdaf, %  14.4     |
| 5  | Sample number 33, grade A, mine "Bungurskiy"   | Wa, %  0.4        |
|    |                                                 | Ad, %  3.6        |
|    |                                                 | Vdaf, %  7.7      |

Wa is analytical moisture content; Ad is ash content; Vdaf is yield of volatiles.

The coals were ground in a ball mill. After grinding, a fraction of coal particles with a size of ≤ 63 μm was taken by sifting through a sieve. In the experiment, we used samples with a bulk density of 0.5 g/cm³ and a mass of 10 mg, which were placed in a copper capsule 5 mm in diameter and 2 mm deep.

A schematic of the experimental setup and a detailed description of the technique for studying the kinetic dependences of the glow of coal are given in [6]. The coals were ignited using single pulses of the first harmonic of a YAG: Nd³⁺ laser (λ = 1064 nm) operating in the free-running mode (τ₀ = 120 μs). The glow of a coal sample was converted into an electrical signal by a photomultiplier tube and recorded with an oscilloscope.

When measuring the kinetic dependences of the glow of a coal flame in the submillisecond range, filters were installed in front of the PM input screen, selectively cutting off laser radiation, and neutral light filters were also installed to attenuate the intensity of the light signal.

The illustrations on the ordinate axis show the real values of the luminescence intensity in volts (V), recorded on the oscilloscope screen and calculated using experimentally determined transmission coefficients of neutral light filters.

3. Experimental results

As an example, Figure 1 shows the kinetic dependences of the glow of a L grade coal flame during exposure to microsecond laser pulses in the energy density range from 1.0 to 8.9 J/cm².
Figure 1. Kinetic dependences of the luminescence of grade L coal during exposure to microsecond laser pulses in the energy density range from 1.0 to 8.9 J/cm².

Qualitatively similar kinetic dependences were obtained for all the studied coals.

Measurement of the kinetic dependences of the glow of coals during exposure to microsecond laser pulses showed that the intensity of the glow of coals increases linearly with an increase in the energy density of the laser radiation (Figure 2).

Figure 2. Dependence of the glow intensity of coal on laser pulse energy density

Figure 3 shows the dependence of the glow intensity of coals during exposure to a laser pulse with an energy density $H = 8.9$ J/cm² on the degree of coalification of the studied coals.
Figure 3. Dependence of the glow intensity of coals during exposure to a laser pulse with an energy density $H = 8.9 \text{ J/cm}^2$ on the degree of coalification of the studied coals.

Figure 1 shows that from the moment of exposure to the laser pulse, the glow intensity increases, the maximum glow intensity falls on ~ 110-120 μs, i.e. at the end of the laser pulse. In the submillisecond range, a decrease in the glow intensity is observed.

The damping law of flame glow is not elementary. The decay time to half the amplitude increases in the range $\Delta t = (2.9 \cdot 10^{-5} \ldots 1.3 \cdot 10^{-4}) \text{ s}$ with an increase in the energy density in the range $\Delta H = (1.0 \div 8.9) \text{ J/cm}^2$.

The observed dependence of the glow intensity on the energy density (Figure 2) indicates that during laser pulses in the used power range there are no processes associated with optical breakdown, chain reactions, etc., which would lead to a nonlinear dependence of the flame glow intensity on energy density.

For bituminous coals, the glow intensity increases with an increase in the degree of coalification (Figure 3). The glow intensity of anthracite is significantly lower than the glow intensity of highly metamorphosed coal and is close to the glow intensity of low-metamorphosed coal.

In further works, in order to refine the results and build a model of the coal ignition mechanism, the set of used coals will be expanded to a full series of metamorphism.

4. Conclusion

For all the studied coals, the glow intensity increases from the moment of exposure to the laser pulse. In the submillisecond range, a decrease in the glow intensity is observed.

The glow intensity of coals increases linearly with an increase in the energy density of laser radiation.

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