

Pyrolysis of High Volatile C Bituminous Coal under the Action of Nanosecond Laser Radiation

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Abstract

The effect of pulsed nanosecond laser radiation (wavelength 532 nm, pulse duration 14 ns, pulse repetition frequency 6 Hz, the density of laser radiation power 0.2–0.6 J/cm²) on the tableted samples of high volatile C bituminous coal in argon medium is investigated. Among the gaseous products of pyrolysis, H₂, CH₄, C₂H₂, CO and CO₂ are detected. The volume fractions of gaseous products from sample pyrolysis depending on the laser radiation power density is established. Within the laser radiation power density range 0.2–0.4 J/cm², the volume of the formed combustible gases per unit mass of the reacted sample increases, and remains almost unchanged with further increase in power density. The volume fraction of combustible gases in the mixture of gaseous pyrolysis products are only slightly dependent on the laser radiation power density. The action of nanosecond laser radiation with a power density of more than 0.4 J/cm² causes intense ablation of the tableted sample containing 0.005 wt.% polyvinyl alcohol. A tableted sample containing no binding material is destroyed under the action of nanosecond laser radiation with a power density of more than 0.2 J/cm².

1. Introduction

Fossil fuel is an available and widespread source of energy. At the same time, the use of coal to produce energy causes a negative effect on the environment. By 2040, the total consumption of energy in the world will increase by 28% [1], while the world consumption of coal will increase by ~ 35% [2]. Despite the growing coal consumption, the fraction for coal in power generation will decrease [2]. A comprehensive understanding of the processes of thermal decomposition for coal is necessary for the development of ecologically clean technologies of coal processing.

Pyrolytic methods allow us to study the processes involved in the thermal decomposition of the organic mass of coal. A substantial amount of information on the studies of coal pyrolysis has been accumulated, for example, in the works [3–8]. Most of the studies were carried out under the

conditions of low- and medium-rate coal heating. It is known that the thermal decomposition of coal is sensitive to the heating rate [9]. Investigation of coal pyrolysis under high-rate heating is of great interest. At the high coal heating rate, the energy of vibrational motion of initial molecules increases substantially, which leads to detachment of the groupings of atoms that are unstable from the viewpoint of energy under these conditions. Reactive radicals formed in this process interact with each other to form pyrolysis products. The high-rate coal heating may be caused by laser radiation [10–16]. For example, it has been demonstrated in [10, 12] that the laser pyrolysis of coal leads mainly to the formation of low-molecular gases: H₂, CO and CH₄. It is determined in [11] that the volume of the formed gaseous products of laser pyrolysis increases with a decrease in the size of coal particles. The authors of [15] demonstrate that the volume of gaseous products formed in laser pyrolysis of coal increases both with an increase in hydrogen content in the organic mass of coal and with an increase in the yield of volatile matter.

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In our previous works, we studied the fast thermochemical processes of coal particle ignition within the time range from microseconds to several hundred milliseconds [17–20]. Microsecond laser radiation was used as the igniting source. Three stages of coal particle ignition with characteristic times and characteristic energy thresholds were discovered by means of temporal spectroscopy. The radiation spectra of the flares on the coal particle surface and the flames have been measured. It is established that the emission spectra of flares on coal particle surface under the action of microsecond laser pulses depend on the radiation power density. At the laser radiation power density corresponding to the first stage of ignition, the flame glow of CO and excited H_2^* and H_2O^* molecules were detected. The described glow is due to the oxidation products of coal particles and excited molecules of volatile matter that are formed during thermal transformations of micro-asperities on the surface of coal particles. When the laser radiation power density reaches the value corresponding to the second stage of ignition, the entire volume of coal particles is heated, with the emergence and inflammation of volatile matter. The spectra contain the glow of the formed carbon particles, CO flame, and excited molecules H_2^* and H_2O^* . At the laser radiation power density corresponding to the third stage of ignition, the emission from carbon particles with Planck spectrum is recorded. For example, for high volatile C bituminous coal, the spectra arising under the action of microsecond laser pulse with the power density corresponding to the third threshold of ignition $H = 2.4 \text{ J/cm}^2$ are approximated by Planck's formula with the color temperature $T = 3100 \text{ K}$. The recorded emission is connected with the ignition of non-volatile residues of coal particles. The glow intensity increases at this stage with an increase in the radiation power density. Thus, it is demonstrated in [17–20] that there are three stages of coal particle ignition: coal particle heating under the action of laser radiation and subsequent thermochemical reactions in the sample, the emergence and ignition of volatile matter, combustion of non-volatile residues of coal particles. A model is proposed to describe thermochemical processes of coal particle ignition under the action of pulsed microsecond laser radiation [17–20].

Previously we studied pyrolysis of tableted lignite A samples under the action of pulsed microsecond laser radiation (1064 nm, 120 μs , 6 Hz, 1.2–2.0 J/cm^2) [21]. The gaseous products of lig-

nite A pyrolysis were determined to contain H_2 , CH_4 , H_2O , CO and CO_2 . It is established that the volume fraction of H_2 in the gaseous products of pyrolysis increases with an increase in power density in the pulse from 1.2 to 2.0 J/cm^2 , while the volume fraction of CO_2 decreases. The volume fractions of CO and CH_4 are nearly constant. The routes for the formation of the detected pyrolysis products are proposed. It is shown that the volume of the formed combustible gases per unit mass of the reacted sample increases linearly with an increase in the radiation power density, and the volume fraction of combustible gases (H_2 , CH_4 and CO) in the mixture of gaseous pyrolysis products is 93% at the laser radiation power density of 2.0 J/cm^2 . It is also shown that the fraction of reacted coal sample increases linearly with an increase in the laser radiation power density.

It is interesting to investigate the processes of coal thermal decomposition under the action of laser radiation with shorter pulses. In the present work, we report the results of this investigation. Coal samples were subjected to the second harmonic of the neodymium laser operating in the frequency-pulse mode with the active modulation of resonator Q-switching mode. We studied the molecular composition of gaseous products formed in the pyrolysis of tableted samples of high volatile C bituminous coal in argon medium.

The goal of the work was to determine the regularities of pyrolysis of low-metamorphized hard coal with the high parameter of the yield of volatile matter under the action of nanosecond laser radiation.

2. Objects and the procedure

High volatile C bituminous coal from the Sokolovskoe deposit (the Kuznetsk coal basin) was used in the work. The parameters of the proximate analysis of coal were determined using standard procedures. The ultimate composition was determined with the help of an automatic elemental analyzer Flash 2000 for C, H, N, S, O. Results are shown in Table 1.

To prepare the samples, coal was ground preliminarily in a ball mill AGO-2 then sieved through a vibratory sieve with a mesh size 63 μm . It was determined with the help of laser diffractometer Analysette 22 Comfort that coal particle size varied from 0.5 to 63 μm . The maximum particle size distribution was at $\sim 20 \mu\text{m}$.

Table 1
Results of the proximate and ultimate composition analyses of coal

Proximate analysis, wt.%				
W ^a	A ^d	V ^{daf}		
5.7	4.7	42.6		
Ultimate composition (per OMC), wt.%				
N	C	H	S	O
2.3	74.3	5.3	0.3	17.7

W^a – analytical moisture, A^d – ash content, V^{daf} – volatile matter, OMC – organic mass of coal, a – analytical state of coal, d – dry state of coal, daf – dry ash-free state of coal.

In our previous works, coal particles were pressed into tablets without using auxiliary substances [21]. Preliminary experiments showed that the action of nanosecond laser pulses resulted in the destruction of samples prepared according to the procedure used previously [21]. To enhance the mechanical strength of tableted coal samples, we used a 1% solution of polyvinyl alcohol (PVA) in water. To prepare 1% solution, 1 g of PVA was placed in a volumetric flask 100 mL in volume, then 50 mL of distilled water was added, and the mixture was heated with a water bath at a temperature of 90 °C for 40 min. After cooling, the water was added to the solution in the flask to reach the necessary volume.

The mixture composition for subsequent pressing was prepared as follows. A weighted 2 g portion of coal was placed in an agate mortar and wetted with 5 drops of ethyl alcohol, and then 1 mL of 1% PVA solution was added. The resulting suspension was homogenized with the help of a pestle. Then the mixture was heated in a water bath at a temperature of 80 °C for 15 min. After cooling, the mixture was placed in a glass weighting bottle.

Then tableted coal samples 6.2 mm in diameter and 2.5 mm high were made by means of direct pressing at a pressure of 2.5 MPa. The samples were then dried to the air-dry state. So, the moisture content in the initial coal particles listed in Table 1 and the samples was the same. Sample mass was 75 mg, and sample density was 1.00±0.02 g/cm³. The content of polyvinyl alcohol in the samples was 0.005 wt.%.

The source of laser radiation was a YAG:Nd³⁺ laser SOLAR Laser Systems LQ929 operating in the Q-switching mode at the wavelength of 532 nm. Pulse duration was 14 ns. The diameter of the laser beam coincided with the sample diameter. The la-

ser pulse frequency was 6 Hz. Five series of experiments were carried out. The energy characteristics of laser pulses used in the experiments are listed in Table 2. Five samples were used for each series of experiments.

The experimental setup [21] for the investigation of the composition of gaseous products formed in the pyrolysis of coal samples is shown schematically in Fig. 1.

Experiments were carried out in the medium of high-purity argon. Radiation power was regulated with the help of neutral glass light filters (1) with the known attenuation coefficients. To control the power, a portion of the beam (8%) was redirected by a transparent beam splitter (2) to the pyroelectric energy sensor Ophir Photonics PE50BF-C (PLES). Energy instability of laser pulse did not exceed 2%. With the help of a rotating mirror (3) and focusing lens (4) the radiation was directed on sample (7).

With the help of the backing vacuum pump (14) the chamber was evacuated to the residual air pressure of 0.01 mm Hg. The pressure was controlled with an ionization vacuum gauge (13). Argon flow entering the chamber was adjusted with a gas pressure reducer (10) on cylinder (11).

Gas products were detected with a gas analyzer SRS QMS 300 (GA). Gas ionization in the analyzer was performed through the electron beam impact with the energy of 70 eV. Mass spectra were measured within the mass range of 1 to 300 a.m.u.

Gas sampling from the experimental chamber was carried out with the help of a capillary (8), which was connected to a gas analyzer. Continuous sampling was employed.

The ions that were formed in the ion source and recorded by the gas analyzer were recalculated from the corresponding mass per unit time into the units of pressure P. The coefficient connecting the number of ions and the pressure is determined by the manufacturer of the gas analyzer.

Table 2
Energy characteristics of the pulses of laser radiation

No.	Energy per pulse, mJ	Power density, J/cm ²	Power of radiation, MW	Heat flux density, MW/cm ²
1	60	0.2	4.3	14.3
2	91	0.3	6.5	21.4
3	121	0.4	8.6	28.6
4	151	0.5	10.8	35.7
5	181	0.6	12.9	42.9

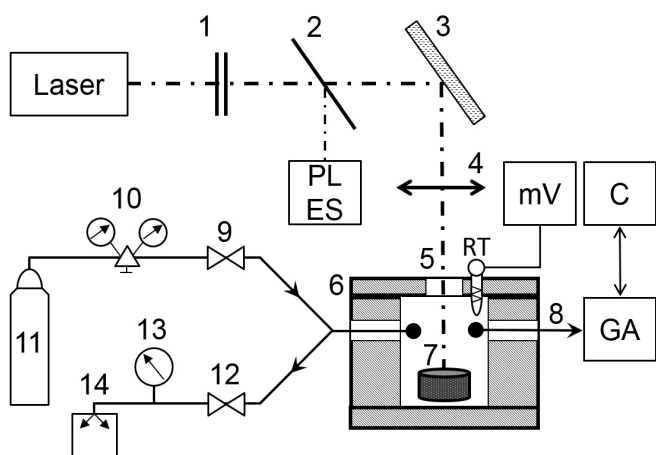


Fig. 1. The functional layout of the experimental setup: 1 – neutral light filters; 2 – beam splitter; 3 – rotating mirror; 4 – lens; 5 – the window of experimental chamber; 6 – experimental chamber ($D = 80$ mm, $h = 150$ mm); 7 – sample; 8 – capillary tube of the mass spectrometer; 9, 12 – lock valve; 10 – gas pressure reducer; 11 – gas cylinder; 13 – vacuum meter; 14 – backing vacuum pump, laser – pulsed YAG:Nd³⁺ laser; PLES – pyroelectric energy sensor; GA – gas analyzer; C – computer; RT – resistance thermometer; mV – millivoltmeter.

Then the concentration n of gaseous products was calculated using Eq. (1).

$$n = \frac{P}{kT} \quad (1)$$

where k is Boltzmann constant, T is temperature measured with the resistance thermometer (RT).

During the reference experiment, we recorded the mass spectra of the vapor of chemically pure benzene, hexane and toluene. The recorded mass spectra are in good coincidence with the data collected in the NIST database. To determine the quantitative composition of the mixture from its mass spectrum, a gas analyzer was calibrated concerning pure gases and reference mixtures.

The volume of the formed combustible gases per unit mass of the reacted coal sample was calculated as follows.

$$n_{fl} = \frac{V_{fl}}{\Delta m}, \quad (2)$$

$$\Delta m = m_1 - m_2 \quad (3)$$

where m_1 and m_2 are the masses of a coal sample before and after laser action, respectively, V_g is gas volume calculated using Mendeleev-Clapeyron (Eqs. 4–6).

$$PV_{\text{exp.chamber}} = \nu RT \quad (4)$$

$$\nu = \frac{V_g}{V_{\text{mol}}} \quad (5)$$

$$V_g = \sum V_{gi} = V_{\text{mol}} \cdot \frac{\sum P_i V_{\text{exp.chamber}}}{RT}, \quad (6)$$

where $\sum V_{gi}$ and P_i are the sums of volumes and partial pressures of the recorded combustible gases (H_2 , CO , CH_4 , C_2H_2), ν is the amount of substance, $V_{\text{exp.chamber}}$ is the volume of the experimental chamber, V_{mol} is the volume of one mole of the ideal gas at the corresponding temperature measured with the resistance thermometer (RT), R is the universal gas constant, T is temperature.

Before experiments, the background mass spectrum of gaseous substances was recorded in the experimental chamber. An additional experiment was carried out to determine the effect of PVA addition on the products of thermal decomposition of coal samples. Tableted samples of the inert matrix, namely technical carbon of P267-E grade, containing 0.005 wt.% PVA, were prepared according to the above-described procedure. The mass spectrum of the gaseous products of thermal decomposition of PVA was recorded. Small concentrations of CO and CO_2 were detected. Then the mass spectrum of the gaseous products of coal sample pyrolysis was recorded, from which the background mass spectrum and the mass spectrum of the gaseous products of PVA thermal decomposition were subtracted.

3. Results and discussion

The composition of the gaseous products of coal sample pyrolysis was studied by means of mass spectrometry. The experiment was arranged according to the scheme shown in Fig. 1. The peaks that were recorded in the mass spectra of the gas phase over coal samples were $m/z = 2, 1 [H_2]^+$; $m/z = 16, 15, 14, 13 [CH_4]^+$; $m/z = 26, 25, 13, 24 [C_2H_2]^+$; $m/z = 28, 12, 16, 29, 14 [CO]^+$; $m/z = 44, 28, 16, 12 [CO_2]^+$. A comparison of the relative intensities of these peaks with the catalog values allows us to conclude that these peaks correspond to H_2 , C_2H_2 , CH_4 , CO , CO_2 .

The dependences of changes in the concentrations of gaseous products of coal pyrolysis on the time of action of the laser radiation with power density $H = 0.4$ J/cm² are shown as an example in Fig. 2.

Qualitatively similar dependences were obtained for all the series of experiments.

Dependences of changes in the concentrations of gaseous products of coal sample pyrolysis on the laser radiation power density at the moment $1.6 \cdot 10^3$ s are presented in Fig. 3. The formation of CH_4 and C_2H_2 was not detected under the action of laser radiation with power density $H = 0.2$ J/cm 2 .

The dependence of gas mixture composition on the laser radiation power density at the moment $1.6 \cdot 10^3$ s is presented in Fig. 4.

The dependence of the volume of combustible gases per unit mass of the reacted coal sample on

power density in the pulse is shown in Fig. 5 along the main axis. The dependence of the fraction of reacted sample on the laser radiation power density is plotted along the auxiliary axis.

In Fig. 6, the dependence of the volume of the formed combustible gases per unit mass of the reacted sample on the fraction of the reacted coal sample is plotted along the main axis. The dependence of the volume of the formed combustible gases on the fraction of the reacted coal sample is plotted along the auxiliary axis.

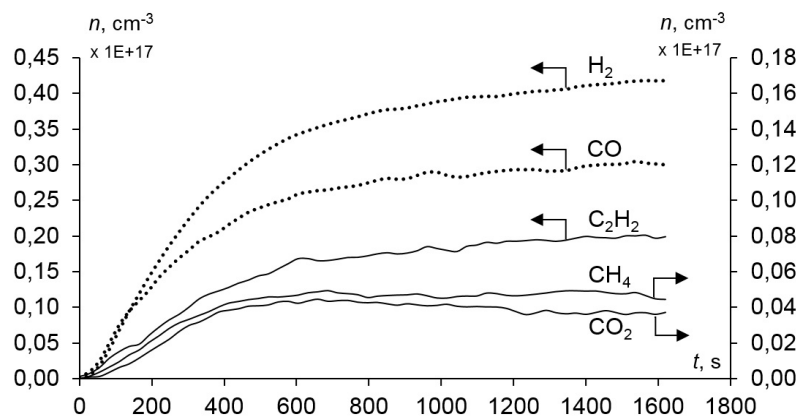


Fig. 2. Dependences of changes in the concentrations of gaseous pyrolysis products on the time of laser radiation action on coal samples. $H = 0.4$ J/cm 2 .

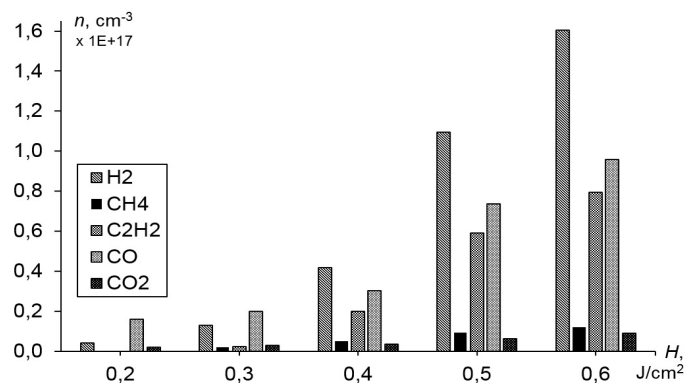


Fig. 3. Dependences of changes in the concentrations of gaseous products of coal sample pyrolysis on the laser radiation power density at the moment of time $1.6 \cdot 10^3$ s.

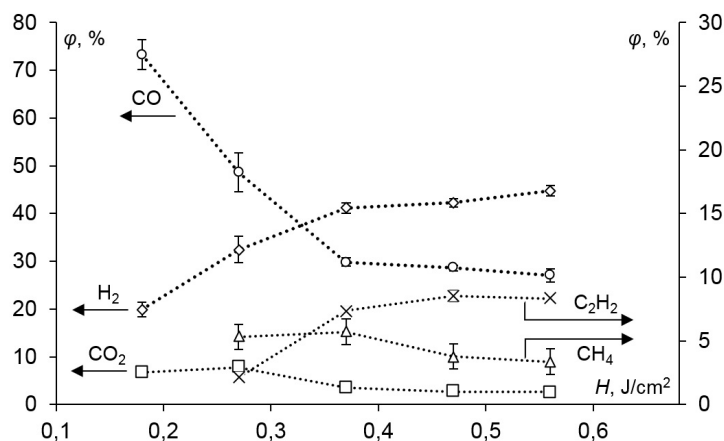


Fig. 4. Dependence of gas phase composition on the laser radiation power density at the moment of time $1.6 \cdot 10^3$ s.

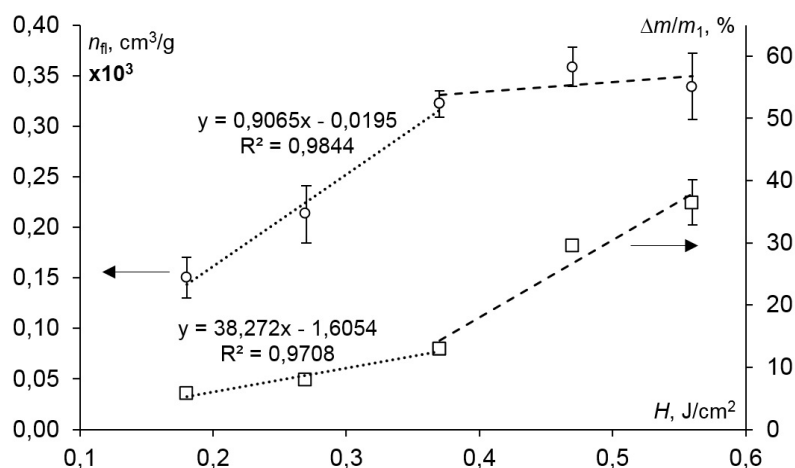


Fig. 5. Dependence of the volume of formed combustible gases per unit mass of the reacted sample on energy density in the pulse. The dependence of the fraction of reacted coal sample on the laser radiation power density is shown along the auxiliary axis.

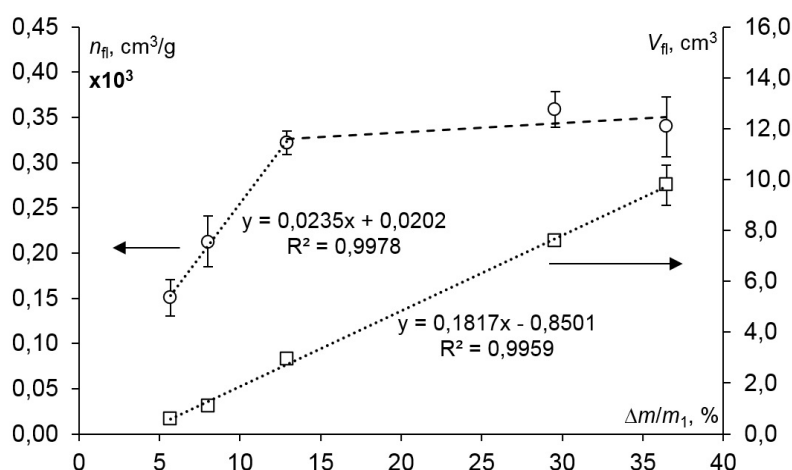


Fig. 6. Dependence of the volume of the formed combustible gases per unit mass of the reacted coal sample on the fraction of the reacted coal sample. The dependence of the volume of the formed combustible gases on the fraction of the reacted coal sample is plotted along the auxiliary axis.

The products of coal sample pyrolysis under the nanosecond laser action in argon are H_2 , CH_4 , C_2H_2 , CO and CO_2 . One can see in Figs. 2 and 3 that the concentrations of gaseous pyrolysis products increase with an increase in the laser radiation power density H . After achieving the maximal value, the concentrations of pyrolysis products are nearly constant.

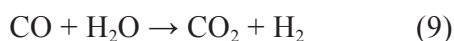
The volume fraction of carbon dioxide in the gaseous products of pyrolysis is nearly constant under the action of laser radiation with power density $H = (0.2\text{--}0.3) \text{ J/cm}^2$. With an increase in the laser radiation density $H > 0.3 \text{ J/cm}^2$, the volume fraction of carbon dioxide decreases. The volume fraction of methane exhibits similar behavior. The volume fraction of methane in the gaseous products of pyrolysis is nearly constant under the action of laser radiation with power density

$H = (0.3\text{--}0.4) \text{ J/cm}^2$, while a further increase in the laser radiation power density causes a decrease in the volume fraction of methane. The volume fraction of carbon oxide in the gaseous products of pyrolysis decreases within the studied range of laser radiation power density, while the volume fractions of hydrogen and acetylene increase. It may be stressed that a decrease in the volume fraction of carbon oxide and an increase in the molar fractions of hydrogen and acetylene become slower under the action of laser radiation with power density $H > 0.4 \text{ J/cm}^2$.

The volume fraction of combustible gases φ_{fi} (H_2 , C_2H_2 , CH_4 and CO) in the mixtures of gaseous pyrolysis products are only slightly dependent on the laser radiation power density. Under the action of laser radiation with power density $H = 0.2 \text{ J/cm}^2$ the volume fraction of combustible

gases is $\varphi_{\text{H}} = (93 \pm 3)\%$, while at $H = 0.6 \text{ J/cm}^2$ it is $\varphi_{\text{H}} = (97 \pm 2)\%$.

Previously we detected H_2 , CH_4 , CO and CO_2 in the gaseous products of lignite A pyrolysis under the action of microsecond laser pulses (1064 nm, 120 μs , 6 Hz, 1.2–2 J/cm^2) in argon and considered the mechanisms of their formation [21]. C_2H_2 was not detected in the products of pyrolysis [21]. Under the action of nanosecond laser pulses, the mechanisms of the formation of H_2 , CH_4 , CO and CO_2 are likely to be the same. The interaction of water vapor and hydrogen with heated coal and the reaction of steam conversion of CO (7–9) are also likely to proceed [22].



The presence of acetylene in the recorded pyrolysis products may be explained by the possible reactions (10) and (11) [23, 24].



One can see in Fig. 5 that the ratio of the volume fraction H_2/CO increases linearly from 0.3 to 1.7 with an increase in the laser radiation power density within the range 0.2–0.6 J/cm^2 . It is known that the ratio of the optimal reagents for obtaining liquid hydrocarbons according to Fischer-Tropsch process is $\text{H}_2/\text{CO} = 2.15$ [25]. Then, admitting further linear increase of the volume fraction H_2/CO , the optimal ratio of these components will be achieved at the laser radiation power density $H \sim 0.7 \text{ J/cm}^2$. In the case of the action of microsecond laser radiation, the ratio H_2/CO reaches 1.7 at the power density of 2 J/cm^2 [21].

The yield of synthesis gas may be increased by the steam conversion of methane [26] or by the catalytic decomposition of methane, for example, [27]:



The composition of the gaseous products of laser pyrolysis of coal was reported in [14–16]. Under the action of the continuous radiation of CO_2 -laser, the formation of naphthalene, phenan-

threne, pyrene and so on was detected [15]. The authors of [14] detected the formation of ethylene, ethane and so on under the action of the radiation of CO_2 -laser pulses lasting for a second. In the case of the action of millisecond radiation of the neodymium laser, the formation of propylene, propine, benzene and so on was detected [16]. It may be concluded that the composition of gaseous products of coal pyrolysis under the action of nanosecond laser radiation is simpler than from coal pyrolysis under the action of millisecond or continuous laser radiation. A possible reason may be as follows. In the case of pulsed nanosecond laser action, coal particles are extremely rapidly heated to a high temperature, the primary pyrolysis products are formed, and the reactions of their decomposition take place.

As stressed above, each coal sample was weighted before and after the action of laser radiation, and the fraction of reacted coal sample was calculated. The volume of the formed combustible gases per unit mass of the reacted coal sample n_{H} (Figs. 5 and 6, along the main axis) increases with an increase in the laser radiation power density within the range $H = (0.2\text{--}0.4) \text{ J/cm}^2$. With further increase in the laser radiation power density, the volume of the formed combustible gases per unit mass of the reacted coal sample remains practically unchanged. At the same time, the volume of the formed combustible gases V_{H} increases linearly with an increase in the fraction of the reacted coal sample (Fig. 5, auxiliary axis). It should be also stressed that the fraction of reacted sample $\Delta m/m_1$ sharply increases under the action of laser radiation with power density $H > 0.4 \text{ J/cm}^2$ (Fig. 6, auxiliary axis). The observed phenomena may be explained as follows. The action of laser radiation with power density $H > 0.4 \text{ J/cm}^2$ causes intense ablation of coal samples. Coal particles are carried into the gas phase. The formed suspension of coal particles screens sample surface from the direct laser action. This effect causes a decrease in the laser pulse power that reaches the surface of the coal sample, thus pyrolysis efficiency decreases.

It should be stressed that the experimental data depicted in Figs. 5 and 6 ($n_{\text{H}}(H)$, $\Delta m/m_1(H)$, $n_{\text{H}}(\Delta m/m_1)$) could be approximated with one nonlinear dependence. However, as stressed above, within the laser radiation power density $H = (0.2\text{--}0.4) \text{ J/cm}^2$ pyrolysis proceeds without sample destruction, while laser radiation with $H > 0.4 \text{ J/cm}^2$ involves intense ablation of the samples. So, different processes take place under the action of laser radiation

with power density within the range 0.2–0.4 J/cm² and $H > 0.4$ J/cm², and, in our opinion, it is incorrect to approximate experimental results with one function.

Attention should be paid to the fact that coal samples containing no binding material (PVA) are destroyed under the action of nanosecond laser radiation with power density $H \geq 0.2$ J/cm². Most likely, additional studies aimed at the search for an optimal concentration of the binding material are necessary to increase the efficiency of pyrolysis of tableted coal samples under the action of nanosecond laser radiation.

The results obtained in the present work may be used in further studied aimed at understanding the detailed mechanism of thermal decomposition of fossil coal under the action of radiant energy from a high-intensity radiation source.

4. Conclusions

1. The detected products of pyrolysis of the tableted high volatile C bituminous coal samples under the action of nanosecond laser pulses (532 nm, 14 ns, 6 Hz, 0.2–0.6 J/cm²) are H₂, CH₄, C₂H₂, CO and CO₂.

2. With an increase in power density in the pulse from 0.2 to 0.6 J/cm² (532 nm, 14 ns, 6 Hz), the volume fraction of carbon oxide in the gaseous products of pyrolysis decreases, while the volume fractions of hydrogen and acetylene increase. A decrease in the volume fraction of carbon oxide and an increase in the volume fractions of hydrogen and acetylene slow down under the action of laser radiation with power density $H > 0.4$ J/cm². Within the laser radiation power density from 0.2 to 0.3 J/cm² (532 nm, 14 ns, 6 Hz) the volume fraction of carbon dioxide among the gaseous products of pyrolysis is nearly constant and decreases with an increase in power density $H > 0.3$ J/cm². The volume fraction of methane in the gaseous products of pyrolysis is nearly constant under the action of laser radiation with $H = (0.3–0.4)$ J/cm² and decreases with a further increase in H .

3. Under the action of nanosecond laser radiation (532 nm, 14 ns, 6 Hz, 0.6 J/cm²) on the tableted samples of high volatile C bituminous coal, the volume of the formed combustible gases per unit mass of the reacted coal sample n_{fl} increases with an increase in the laser radiation power density within the range $H = (0.2–0.4)$ J/cm². With further increase in the laser radiation power density, the volume of the formed combustible gases per unit

mass of the reacted coal sample remains practically the same. The volume fraction of combustible gases φ_{fl} (H₂, C₂H₂, CH₄ and CO) in the mixture of gaseous pyrolysis products is only slightly dependent on the laser radiation power density. Under the action of laser radiation with power density $H = 0.2$ J/cm², the volume fraction of combustible gases is $\varphi_{fl} = (93 \pm 3)\%$, while at $H = 0.6$ J/cm² it is $\varphi_{fl} = (97 \pm 2)\%$.

4. The action of nanosecond laser radiation (532 nm, 14 ns, 6 Hz) with power density $H > 0.4$ J/cm² causes intense ablation of the tableted sample of high volatile C bituminous coal containing 0.005 wt.% polyvinyl alcohol. A tableted coal sample containing no binding material is destroyed under the action of nanosecond laser radiation (532 nm, 14 ns, 6 Hz) with power density $H \geq 0.2$ J/cm².

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