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To cite this article: A G Korotkikh and K V Slyusarskiy 2017 J. Phys.: Conf. Ser. 891 012223

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Study on coal char ignition by radiant heat flux.

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Abstract. The study on coal char ignition by CO₂-continuous laser was carried out. The coal char samples of T-grade bituminous coal and 2B-grade lignite were studied via CO₂-laser ignition setup. Ignition delay times were determined at ambient condition in heat flux density range 90–200 W/cm². The average ignition delay time value for lignite samples were 2 times lower while this difference is larger in high heat flux region and lower in low heat flux region. The kinetic constants for overall oxidation reaction were determined using analytic solution of simplified one-dimensional heat transfer equation with radiant heat transfer boundary condition. The activation energy for lignite char was found to be less than it is for bituminous coal char by approximately 20 %.

1. Introduction

Coal is one of the main energy sources worldwide nowadays [1]: coal-fired power plants produced near 25 % of electricity in 2016. However, coal is among main sources of pollution, including carbon dioxide [2], nitrogen oxides [2] and solid particles [2]. There are various methods for decreasing negative influence of coal-fuelled equipment on environment including decreasing temperature in reaction zone [3], pre-combustion and post-combustion carbon capture technology [4], gasification [5] etc. All mentioned above methods demand precise data on solid fuel conversion to be successfully implemented.

The ignition temperature is important characteristic of combustion process as well as reaction activation energy. The most widely used method for defining these parameters are thermal analysis [6] and experimental furnaces of different types (like drop-tube furnace) [7]. All these methods apply convective heating of fuel by hot gases. It creates the need for using empirical equations to define value of heat flux applied and decreases the preciseness of calculation results. Furthermore, in actual boilers the contribution of convection into heat flux applied is lesser than contribution of radiation. But number of articles on solid fuel ignition by radiative heat flux is much lesser. In articles [8, 9] the data on ignition of coal powders with different disperse composition under conditions of radiant heat flux. In articles [10, 11] the results on radiant ignition of single coal particle are presented. In all mentioned above publications the impulse lasers with low exposure times, while in real conditions the emission is continuous. Also in all these articles the coal was studied while for some technologies like gasification data on char conversion is more important.

In current study the experimental data on ignition by continuous radiant heat flux tests in air medium for two samples of T-grade and 2B-grade energy coal chars were presented.

2. Experimental section
2.1. Sample characterization

The powders of T-grade bituminous coal (this sample further will be referred to as T sample) and 2B-grade lignite (2B sample) of Kuznetsk and Cansk-Achinsk deposits were studied. Initial fuel was ground in ball mill and sieved through sieve with 80 µm mesh size. Dispersed characteristics of investigated fuel samples were defined using laser-analyzer HELOS. The average diameters and characteristic sizes of coal powders are given in Table 1. Initial fuel was heated in nitrogen medium to 1000 °C and then cooled to 300 °C to obtain char samples.

**Table 1.** Average diameter and characteristic size for studied fuel samples

| Sample | Average diameter, µm | Characteristic size, µm |
|--------|----------------------|-------------------------|
|        | $d_{10}$ | $d_{20}$ | $d_{30}$ | $d_{32}$ | $d_{33}$ | $x_{10}$ | $x_{50}$ | $x_{90}$ |
| **T**  | 36.9±0.2  | 45.4±0.2  | 52.1±0.2  | 69.2±0.1  | 79.2±0.1  | 6.45±0.1  | 31.6±0.1  | 75.3±0.2 |
| **2B** | 38.9±0.1  | 47.3±0.1  | 53.6±0.1  | 69.7±0.1  | 79.1±0.2  | 6.80±0.2  | 34.9±0.2  | 77.5±0.1 |

The proximate and elemental analysis of two investigated samples before charring was carried out according to ISO 17246:2010 method and using Euro EA 3000 analyzer. Analysis results are given in Table 2. The ash, moisture and volatile matter content in coal char samples were defined according to ISO as well.

**Table 2.** Proximate and ultimate analysis data for studied fuel samples.

| Sample | Proximate analysis, wt. % | Ultimate analysis, wt. % |
|--------|---------------------------|--------------------------|
|        | Initial coal | Coal char | Initial coal |
|        | M  | A  | V  | FC | M  | A  | V  | FC | C  | H  | N  | S  | O  |
| **T**  | 3  | 21 | 20 | 66 |  1 | 18 |  0 | 81 | 68 | 4  | 3  | <1 | 4  |
| **2B** | 7  | 16 | 32 | 45 |  1 | 29 |  2 | 68 | 50 | 4  | 2  | <1 | 28 |

Here M, A, V and FC are the moisture, ash, volatile matter and fixed carbon content, respectively. T-grade coal has higher fixed carbon and ash content while moisture and volatile matter content are higher for 2B-grade coal. The same dependences could be observed for char samples. Before testing all samples were pressed into tablets with 10 mm diameter under pressure 310 MPa. The density of tablets of T-grade coal char was 1200 kg/m³ and 1100 kg/m³ for 2B-grade coal char.

2.2. Experimental setup and procedure

Study on solid fuel sample ignition was carried out using experimental setup for radiant heating based on continuous CO₂-laser with 10.6 µm wavelength and 200 W power. The front end of samples was visually controlled for pore, crack and cavity absence. Scheme of experimental setup is given in figure 1.

**Figure 1.** Scheme of experimental setup based on CO₂-laser: 1 – CO₂-laser; 2 – semi-transparent; 3 – thermoelectric sensor of radiation power; 4 – electromagnetic shutter; 5 – video camera; 6 – fuel sample; 7 – photodiode; 8 – holder; 9 – ADC; 10 – PC; 11 – thermal imaging camera.
Studied fuel sample (6) was attached to sample holder (8). After opening of shutter (4) the laser emission was directed to studied fuel sample (6). Signals from photodiode (7) and emission power measurer (3) were directed to personal computer (10) through ADC of signal L-card E-14-440 (9). Later they were processed via LGraph2 software. The fuel ignition delay time $t_{ign}$ was defined as a difference between signals from photodiodes (7): one registered appearance of flame on the surface of sample, another – opening of the shutter.

The surface temperature of samples during the heating, gasification, ignition and combustion of fuel was registered via thermal imager Jade J 530 SB with frequency 50 Hz in the temperature range of 260–1800 °C. Thermo and video-imaging data as well as photodiode signal were synchronized by signal of shutter opening. The radiant heat flux density was measured using Ophir FL400A thermoelectric sensor.

2.3. Activation energy

The activation energy value for overall oxidation reaction was defined by solving the reverse one-dimensional heat transfer equation. More detailed data on solution of this problem is given in [12]. Actual equation for activation energy definition is given below:

$$\frac{0.349 E c}{(1 - 0.8\beta) R Q z} + \frac{E}{R T} \log(e)$$

(1)

here $t_{ign}$ – solid fuel ignition delay time, s; $T_n, T_T$ – initial and characteristic temperatures, K; $E$ – activation energy, J/mole; $c$ – sample heat capacity, J/(kg K); $\beta = RT_e / E$ – dimentionless parameter; $R$ – universal gas constant, J/(mole K); $Q$ – thermal effect of overall reaction, J/kg; $z$ – frequency factor, 1/s.

Characteristic temperature could be calculated using following equation:

$$T_s = T_n + q_s \sqrt{\frac{t_{ign}(1 - 0.8\beta)}{0.698}}$$

here $q_s$ – radiant heat flux density, W/cm$^2$.

3. Results and discussion

3.1. Sample ignition delay

The dependences of ignition delay time on radiant heat flux density in range 90-200 W/cm$^2$ for fuel samples are given in figure 2.

Ignition delay time for 2B sample is in average 2 times lower compared to T sample. It is tend to decrease with heat flux density. It is connected to lower activation energy of overall reaction for 2B sample compared to T sample. That will be further addressed in paragraph 3.2.

Experimental data was approximated using the following equation:

$$t_{ign} = A \cdot e^B$$

here $A, B$ – approximation constants. Its values are given in table 3 as well as determination coefficient $R^2$.

| Sample | $A$     | $B$     | $R^2$ |
|--------|---------|---------|-------|
| T      | 6.025·10$^{11}$ | -4.510  | 0.991 |
| 2B     | 1.104·10$^{12}$ | -7.192  | 0.980 |
Figure 2. The ignition delay time of coal char samples vs radiant heat flux density.

The slope of approximation lines reveals that ignition delay times for 2B coal char quicker decreases with heat flux density compared to T coal char.

3.2. Reaction activation energy

The activation energy values were defined using equation 1. The thermophysical properties of char samples were taken according to [13] for fuel of the same origin and chemical composition. The graphs with approximation curves for activation energy definition are given in figure 3. Determination coefficient of approximation curve is 0,92 for T sample and 0,82 for 2B sample.

Figure 3. Graph for activation energy definition.

Activation energy value for T sample was 22,05 kJ/mole while for 2B sample this value is 20 % lower – 17,39 kJ/mole. Obtained values are in good agreement with data for oxidation of these coals by means of thermal analysis (especially, in low conversion values area) [6].
4. Conclusion
The ignition properties of T-grade bituminous coal and 2B-grade lignite chars by continuous CO₂–laser setup were studied. The chemical and disperse composition of studied samples were defined. Ignition delay times for samples were defined and approximated by power law in radiant heat flux range 90-200 W/cm². Ignition delay times for T-grade sample were approximately 1.5 times higher compared to 2B-grade and this difference tend to decrease with heat flux density. Activation energy of overall reaction was calculated using one-dimensional heat transfer equation. For T sample activation energy value (22.05 kJ/mole) was 20 % higher compared to 2B sample (17.39 kJ/mole). Obtained values are in good agreement with presented in literature data for same grade coals.

Acknowledgements
The work was supported by the Ministry of Education of the Russian Federation within the framework of the project №13.7644.2017/CU.

References
[1] 2016 BP Statistical Review of World Energy
[2] 2016 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014
[3] Zha Q., Li D., Wang C., Che D. 2017 Appl. Therm. Eng. 116 170
[4] Araújo O.D.Q.F. 2017 Curr. Opin. Chem. Eng. 17 22
[5] Jankovskiy S., Luzhkovoj D., Larionov K., Matveeva A. 2015 MATEC Web Conf. 37 01026
[6] Slyusarskiy K.V., Larionov K.B., Osipov V.I., Yankovsky S.A., Gubin V.E. 2017 Fuel 191 383
[7] Rokni E., Levendis Y.A. 2017 J. Energ Eng. 143 04016067
[8] Chen J.C., Taniguchi M., Ito K. 1995 Fuel 75 323
[9] Dubaniewicz Jr. T.H., Cashdollar K.L. 2003 J.Laser.Appl. 15 184
[10] Qu M., Ishigaki M., Tokuda M. 1996 Fuel 75 1155
[11] Wong B.A., Gavalas G.R., Flagan R.C. 1994 Energy Fuels 9 484
[12] Vilyunov V.I. 1984 Theory of condensed matter ignition (Novosibirsk: Nauka)
[13] Lisenco V.G., Chelokov J.M., Ladigichev M.G. 2003 Fuel: Rational combustion, control and technological application (Moscow: Teplotehnik)