Experimental study of pine sawdust ignition in a vertical tube furnace

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Abstract. The combustion processes of composite particles of powdered fuel from lignocellulose and coal have not been previously studied. It is planned that a non-obvious relationship will be established between the structure and properties of solid fuels obtained under various conditions of preliminary machining of individual fuel components and joint mechanochemical processing of fuel components before burning in the combustion chamber. Based on the data obtained, the description of both individual chemical and physical processes and complex mathematical models will be improved. In this paper, we investigate the influence of the structure and dimensions of a particles pine sawdust as one of the components of composite fuel on ignition and thermal decomposition.

1. Introduction

Renewable plant resources are almost inexhaustible sources of biopolymers, which can be chemically or biotechnologically processed into several popular substances and materials, as well as utilized in modern power plants with energy. In a number of countries (for example, Russia, USA, EU countries, Japan), scientific and technological works aimed at the integrated use of natural resources, in particular, the production of liquid and solid biofuels, have been actively developing in recent years [1].

Unlike liquid biofuels, largely represented by ethanol that is successfully used in the European Union, the progress in obtaining solid biofuels is not so significant and is limited to fuel pellets or briquettes obtained from wood waste by simple grinding and molding at elevated temperatures [2].

The fundamentals of deep modification of chemical composition of the main components of plant materials (biopolymers, cellulose, lignocellulose, lignin) pay insufficient attention to improving the thermal properties of the fuel. This is largely due to the multi-level structuring of the raw material “plant tissue - cells - cell walls - cell wall polymers - crystalline/amorphous polymer sites”, making the object in question difficult to study in the framework of the classical “chemical composition - properties” approaches.

During the mechanical processing of the mixture of different types of fuel, for example, coal and vegetable raw materials, along with formation of mechancomposite particles, a change in the defectiveness of components is observed. Considerable attention has been paid to changing the reactivity of coal particles in order to increase the burning rate in recent years. [3]. It is known that in the process of mechanical activation of the surface of coal particles, active radial centers are formed, which
significantly affect the combustion processes of coal [4]. The effect of mechanical treatment on the combustion of particles of plant materials and composite particles remains unexplored.

From the point of view of combustion control, at present, such a complex non-equilibrium physicochemical combustion process must be considered in a simplified way, often optimizing the experiments on real power plants empirically through trial and error, practically without using the predictive power of calculations and simulations. It is necessary to carry out fundamental work on the study of aerodynamic, thermal and chemical phenomena in the flame, development of physical models that more accurately consider the process of flame burning (pulverized coal, vegetable, mixed, composite).

2. Experimental stand and research methodology
The vertical tubular reactor (Fig. 1) is a vertical heat-insulated steel pipe 1 m long and 0.4 m in internal diameter. The system of low-voltage transformers is electrically heated. Along the entire length of the combustion chamber, photodiodes and thermocouples (TXA) are located in special openings in increments of 0.1 m, designed to register the flash and temperature, respectively. To stabilize the temperature at the inlet to the reactor, as well as to remove parasitic convective flows and combustion products, an air stream is fed into the chamber at a speed of 0 - 1 m/s.

The trigger mechanism consists of a magnetic valve and a chamber with a volume of $45 \times 10^{-9}$ m$^3$. Above the valve, there is a dust feeder, where samples weighing from 0.1 to 1 g are poured. Then air is pumped into the chamber and coal dust is injected into the reactor. The maximum temperature that can be obtained using the available transformers is 1000°C. The entry of dust into the combustion chamber is recorded by a microphone connected to the Analog-to-Digital Converter Lcard (ADC). The ignition monitoring system consists of photo sensors, excitation circuit, signal processing circuit, and data acquisition unit and software for signal processing on a personal computer (PC). Figure 2 shows the structure and main components of the system. The flame detector has a photodiode with a lens that focuses the light of the flame on its window, covering the spectral band between 400 and 1100 nm.

Figure 1. Installation scheme of vertical tube furnace.
2.1. Sample characteristics

In this work, sawdust of pine obtained from the forestry Kurtamyshsky, Kurgan region, Russia was used. Data on technical characteristics are given in Table 1.

| Cellulose | Lignin | Resins | Pentosans | Humidity | Ash | Carbon | Volatile |
|-----------|--------|--------|-----------|----------|-----|--------|----------|
| 44,66±0,90 | 29,62±0,05 | 4,89±0,02 | 6,3±0,01 | 1,66±0,02 | 0,61±0,04 | 23,60±0,1 | 85,61±0,16 |

Pine sawdust was ground on two types of mill devices: a mill disintegrator with a rotor speed of 6,000 rpm and a vertical roller mill with a rotor speed of 1500 rpm. After grinding, the particle size of the sample treated with a disintegrator is 100-200 microns, and the particle size of the sample prepared in a vertical roller mill is 40-100 microns.

For the samples of pine sawdust, the degree of crystallinity according to powder X-ray diffraction is the same and it is 59%. The degree of crystallinity is understood as the value characterizing the proportion of molecular fragments with regular packing and ensuring the appearance of Bragg reflections in the diffraction pattern from the proportion of randomly located molecular fragments of diffuse scattering radiation [5-7].

3. Results

For each sample, a series of experiments was carried out at different temperatures in the chamber. The choice of temperature was based on 100% flammability of the fuel, taking into account preliminary studies. To determine the effect of the grinding method on the reactivity, the ignition delay time was measured. The ignition delay time is used to determine the kinetic constants of the ignition process.

Figure 3 shows an example of data obtained from a photodiode. The figure shows the line tm, which signals the passage of pulverized particles a microphone installed at the entrance to the tubular reactor. Before ignition, a voltage drop occurs on the photodiode sensor, which is associated with the darkening of the observed area with sawdust. The ignition delay time td is defined as the time from the moment the particles enter the reactor until the visible flame is detected. The black curve is the output signal from the microphone, the remaining curves are signals from the photodiodes.

During the experiments, the dependence of the ignition time on the furnace temperature for pine sawdust of various type of grinding was determined.

The temperature variation over the height of the tubular furnace does not exceed 50°C. After each experiment, the furnace was purged with air, and the temperature distribution along the furnace height was similar to the previous experiment.

Table-2 shows the times from the beginning of the introduction of particles into the chamber until the moment of their ignition according to the results of experiment.

Conclusion

Experiments have shown the effect of structure and particle size on the ignition process. Grinding on a disintegrator, which is accompanied by the destruction of the structure of the particles, turned out to be
a less effective way of preparing samples, although the effect is opposite for coal. For more efficient ignition of sawdust, it is important to maintain the internal structure of the substance.

![Graph showing voltage over time]

**Figure 3.** Characteristic data from photodiodes and microphone during ignition of pine sawdust.

| Temperature | Ignition delay time, s |
|-------------|------------------------|
| Vertical roller mill | Disintegrator |
| 800         | 0.08                  | 0.10 |
| 700         | 0.19                  | 0.24 |
| 600         | 0.41                  | 0.52 |

**Table 2.** Ignition time.

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**References**

[1] Gaurav N, Sivasankari S, Kiran G S, Ninawe A, Selvin J 2017 *Renewable & Sustainable Energy Reviews* **73** 205–14

[2] Myasoedova V V 2012 *Polymer Science* Series D **5** (3) 213–8

[3] Burdukov A P, Popov V I, Yusupov T S, Lomovsky O I 2009 *Chemistry in development studies, 17* (5) 471–8

[4] Burdukov A P, Butakov E B, Kuznetsov A V, Chernetskiy M Y 2018 *Combustion, Explosion and Shock Waves* **54** (1) 20–3

[5] Burdukov A P, Butakov E B, Popov V I, Chernetskiy M Yu, Chernetskaya N S 2016 *Thermal Science* **20** 23–33

[6] Burdukov A P, Popov V I, Yusupov T S, Chernetskiy M Yu, Hanjalić K 2014 *Fuel* **122** 103–11

[7] Welham N J, Berbennib V, Chapman P G 2002 *Carbon* **40** 2307–15