Study of the dependences of coal-wood composition, identification of combustion features of the obtained composite materials

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Abstract. In the study of the combustion of samples, it was found that, other things being equal, under the experimental conditions and with the fixed technical characteristics of the fuel, different parameters of the flame are observed, namely, the speed of reaching a stationary mode, the completeness of fuel combustion, the size and distribution of temperature zones strongly depend on the methods used to carry out the mechanical fuel processing. Comparison of the results showed that under the same experimental conditions, the temperature distribution along the length of the experimental stand, in a stationary mode of operation, is higher for the composite fuel. In the case of composite fuel, 70 percent of the fuel burned up was observed at a 1 m section, which is indicative of these fuel consumption and kindling processes at industrial thermal power plants.

1. Introduction

Renewable plant resources represent an almost inexhaustible source of biopolymers that can be chemically or biotechnologically processed into a number of demanded substances and materials, as well as utilized in modern power plants to obtain energy. In a number of countries (for example, Russia, USA, EU countries, and Japan), over the past years, scientific and technological work has been actively developing aimed at the integrated use of natural resources [1, 2], in particular, at obtaining liquid and solid biofuels [3].

Unlike liquid biofuels, mostly represented by ethanol 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 an elevated temperature [4].

Insufficient attention is paid to the fundamental foundations of deep modification of the chemical composition of the main components of plant raw materials (biopolymers cellulose, lignocellulose, lignin) in order to improve the thermophysical properties of fuel. This is largely due to the multilevel structuring of the initial raw material "plant tissues - cells - cell walls - cell wall polymers - crystalline/amorphous polymer regions", which makes the object under consideration difficult to study within the framework of classical approaches "chemical composition - properties".

The creation of modern vortex and flare burners for finely dispersed fuel makes the development of new specialized types of powder fuels an urgent task. In particular, this project proposes the creation of a composite powder fuel, in which particles consisting of several phases, for example, coal and vegetable raw materials, are subjected to combustion. Composite particles, characterized by an increased contact surface of phases and defectiveness in comparison with particles from individual phases, exhibit high reactivity in many chemical reactions, including thermal processes.

The combustion processes of composite particles of powder fuel have not been studied previously.
The unexplored aspects of mechanochemical technologies for the production and, more importantly, the use of powder biofuel include:

- micromechanics of grinding plant materials and mixtures with coal under mechanical deformation;
- the structure of mechanocomposite particles of powder fuel;
- mechanisms of accelerated initiation of combustion and combustion proper in composite particles;
- the dependence of the kinetics of combustion on the chemical and phase composition of the powder fuel and the defectiveness of the components;
- change in the activation energy of the ignition process;
- processes of formation of glass slag from inorganic (ash) components as a key to control slag formation.

During mechanical processing of a mixture of combustible fuels, for example, coal and plant raw materials, along with the formation of mechanocomposite particles, a change in the defectiveness of components is observed. Changes in the reactivity of coal particles in order to increase the combustion rate have been significantly influenced in recent years. It is known that in the process of mechanical activation of the surface of coal particles, active radical centers are formed, which significantly affect the combustion of coal \[5, 6\]. The effect of mechanical treatment on the combustion of plant material particles and composite particles remains unexplored.

From the point of view of combustion control, at present such a complex non-equilibrium physicochemical combustion process has to be considered in a simplified way, often optimizing experiments on real power plants by empirical trial and error, practically without using the predictive power of calculations and modeling \[7, 8\]. It is required to carry out fundamental work on the study of aerodynamic, thermophysical and chemical phenomena in the flame and the development of physical models that more accurately consider the process of flame combustion (pulverized coal, vegetable, mixed, composite).

The authors suggest that the main mechanisms for accelerating the initiation of combustion and the actual combustion of composite particles of powder fuel can be:

- earlier initiation and accelerated combustion due to more flammable and mechanically activated components of the composite particle;
- initiation of a radical combustion reaction due to paramagnetic centers formed on the surface of the components of the composite particle during grinding.

The purpose of this work is to obtain fundamental data on the processes occurring during the mechanochemical production and subsequent combustion of composite powder fuel from coal and waste from woodworking, pulp and paper industries and agriculture.

Researches of combustion of composite fuel "coal-vegetable raw material" were carried out, as well as studies of separate combustion of components (coal and vegetable raw materials, necessary for comparison), using a number of original experimental installations: a tunnel vortex-type stand with a power of 50 kW.

2. Experiments

Combustion of composite powder fuel and a mixture of components was carried out on an experimental stand of the tunnel vortex type (Figure 1). The combustion chamber consists of 7 muffle sections with an inner diameter of 110 mm and a length of 150 mm. The walls of the muffle are made of refractory mixture "Mertel" with the addition of plasticizing additives. In the center of each section, a round channel is provided for the installation of a quartz sight glass, which facilitates an optical access to the combustion volume. The solid fuel burner consists of two stages. The first stage is a tangential mixing chamber, in which a protective ignition device is axially installed. A mixture of propane-butane and air was introduced into a primary tangential swirler with two tangential inlets with primary air. The fuel was supplied from the bunker to the air line of the coiled swirler, the fuel flow rate was monitored using a scale with a mass measurement error of 1 gram. The air flow for the tangential and spiral swirler is controlled by means of orifice devices and differential pressure meters. This measurement method gives an error of no more than 4%. The fuel mixture is ignited with a pilot
flame obtained from the propane-butane ignition at the first stage. The choice of geometry is due to the simplicity of the construction of tangential and snail-type swirlers, which are often used when burning various types of fuels, including solid ones.

Figure 1. Experimental setup: 1 - flow meters, 2 - gas cylinder, 3 - blower, 4 - frequency converter, 5 - data collection unit, 6 - rotameter, 7 - valves, 8 - thermocouples, 9 - feeder, 10 - ignition device, 11 - coil inlet, 12 - gas burner, 13 - viewing windows, 14 - LDA system, 15 - computer.

Filtration of flue gases and solid particles is provided by means of a centrifugal bubbler (CBA). CBA refers to devices for wet gas cleaning. Data collection from thermocouples is carried out by an eight-channel temperature meter with a built-in RS-485 interface, through which data were exchanged with a personal computer. All instrumentation of this stand is integrated into single software. The software allows you to obtain experimental data in a single file with reference to the time of the experiment.

The temperature versus time dependences shown in Figure 2, measured during the experiment, allow us to distinguish three characteristic stages.

Stage 1 - heating up the combustion chamber: fuel supply through the swirler; coal ignition by the gas igniter and further combustion to warm up the combustion chamber.

Stage 2 - main: fuel supply while maintaining a stable mode. The maximum temperature in the reaction chamber reaches 1500°C.

Stage 3 - final: cut off the fuel supply, free cooling of the unit.

After turning on the fuel supply, the combustion chamber heats up within 100 seconds, the stationary mode is achieved within the next 300 seconds. After an increase in the fuel flow rate, the temperature in the chamber increased. In all experiments, the maximum value was reached at the end of the combustion chamber. The temperature on the T8 thermocouple during the combustion of the composite fuel in all modes was above 1400°C. Experimental studies of ignition and combustion of the composite fuel, mixture and sawdust have been carried out. Comparison of the results showed that, under the same experimental conditions, an increase in temperature during combustion of a composite fuel begins earlier than an increase in temperature in the case of combustion of a mixture of components. Two stages of combustion are distinguished, which corresponds to the general ideas about the mechanism of combustion of solid particles: at the first stage, gaseous components of solid
fuels are released and burn, at the second stage, coal particles formed at the first stage burn. In almost all areas of the composite combustion, the temperature distribution along the length of the experimental stand, in a stationary mode of operation, is higher for the composite fuel. Apparently, the composite fuel has an increased calorific value as compared to coal. Since the combustion of the composite provides higher temperatures, an increase in the calorific value can be achieved by increasing the completeness of combustion of the fuel.

When burning a composite fuel, as compared with burning a mixture of components of the same composition, the first stage begins about 100 seconds earlier than when using a composite fuel and it occurs at temperatures 50 - 100°C higher. Combustion of the composite fuel at the second stage occurs approximately simultaneously, but ensures the temperatures 100 - 400° higher; the difference in combustion temperatures increases towards the chimney exit.

**Figure 2.** Temperature distribution in the center of the combustion chamber.

**Figure 3.** Temperature distribution at the end of the combustion chamber.
Investigations of the gas phase upon ignition of samples of powder fuel of different composition were carried out in a tubular furnace. In experiments with composite and sawdust, complete O\textsubscript{2} burnout is implemented; in the mixture, the minimum O\textsubscript{2} value is 1.9 vol. %. When O\textsubscript{2} reaches 3\%, the concentrations of CO and H\textsubscript{2} begin to increase. The CO\textsubscript{2} concentration increases and reaches a maximum when O\textsubscript{2} is completely burned out.

In the study of the combustion of samples, it was found that, other things being equal, under the experimental conditions and with the fixed technical characteristics of the fuel, different parameters of the flame are observed, namely, the speed of reaching a stationary mode, the completeness of fuel combustion, the size and distribution of temperature zones strongly depend on the methods used to carry out the mechanical fuel processing. Comparison of the results showed that under the same experimental conditions, the temperature distribution along the length of the experimental stand, in a stationary mode of operation, is higher for the composite fuel. In the case of composite fuel, 70 percent of the fuel burned up at a 1 m section, which is indicative of these fuel consumption and kindling processes at industrial thermal power plants. The high reactivity of the composites leads to displacement of the ignition zone closer to the beginning of the combustion chamber, a decrease in the time to reach the stationary mode is observed, this indicator significantly affects the further combustion process in the boiler and reduces the probable entrainment of unburned particles.

3. Conclusion
Stable combustion of the composite fuel was obtained as a result of its mechanical grinding and ignition with a gas burner. The results of the study confirm the possibility of using mechanical grinding for gasification and combustion. The data obtained on the ignition and combustion of composite fuels allows us to recommend this technology for oil-free ignition of boiler plants. To create real highly efficient processes and devices for gasification of composite fuel, further research is needed to optimize the operating parameters of the process: the levels of temperatures, excess air, the residence time of the dust suspension in the reaction chamber, etc.

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References
[1] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC
[2] Roadmap EU-Russia Energy Cooperation until 2050. March 2013. Kremlin, Moscow, Russia
[3] Gaurav N, Sivasankari S, Kiran G S, Ninawe A, Selvin J 2017 Renewable & Sustainable Energy Reviews 73 205-214
[4] Myasoedova V V 2012 Polymer Science 5(3) 213-218
[5] Burdukov A P, Butakov E B, Kuznetsov A V, Chernetskiy M Y 2018 Combustion, Explosion and Shock Waves 54(1) 20-23
[6] Shadrin E Y et al. 2021 Fuel 303 121182
[7] Abdurakipov S, Butakov E 2018 Journal of Physics: Conference Series 1105 1 012043
[8] Chernetskii M Y et al. 2018 Solid Fuel Chemistry 5 2 1 30-35