On investigation of burning and gasification of coal fuel crushed at mills with high-energy impact

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Abstract. The development of new promising technologies based on coal fuel is certainly topical. This article is devoted to application of new technology of gas and fuel oil replacement by mechanically activated micronized coal in power engineering: ignition and stabilization of pulverized coal flame combustion. Enhancement of coal reactivity at its grinding with mechanical activation is associated with an increase in the reaction rate of carbon material. The process of combustion was studied on the 1-MW setup with tangential scroll supply of pulverized coal-air mixture and cylindrical reaction chamber. Experiments were carried out by using brown coals. Coal, ground by the standard boiler mill, was fed to the input of high-energy mills and then was directed to the scroll inlet of the burner-reactor with the transport air. The suspension was ignited by a gas igniting device with the power of 50 kW. Experimental studies on air gasification of micronized coal were conducted in the reaction chamber at the temperature of 1000-1200 °C and air excess ratio \( \alpha = 0.5 \). Intensive mechanical activation of coals led to increase the chemical activeness. This effect can be used for development of new highly boosted processing methods for coals with various levels of metamorphism. The obtained results of visualization were used to train the state-of-art deep convolutional neural network. It was shown that the developed neural network was able to automatically determine the combustion regimes from flame images.

1 Introduction

Energy is one of the main life-supporting industries. At present, about 40% of the world's electricity is generated by coal-fired power plants [1]. The use of ordinary coal in power, especially in "small" energy, is associated with its inefficient combustion: low efficiency of existing boiler equipment and increased losses, unstable combustion, slagging of heating surfaces, higher harmful emissions into the atmosphere. Continuously growing energy consumption and environmental safety issues require maximum optimization of the process of coal combustion. One of the most promising and effective methods for intensifying the combustion of coal fuels is microgrinding of coal with mechanical activation.

With the preliminary mechanical treatment of coal in mills with high-energy impact, the reactivity of coal dust increases. The results on mechanical activation grinding of the coals of various stages of metamorphism and their ignition and combustion were obtained for the first time in the world at IT SB RAS. Differential thermal analysis of mechanically activated microgrinding coal has demonstrated a significant increase in their chemical activity, and studies of the ignition and combustion of their dusts on thermal stands up to 5 MW have shown that the torch magnitude and temperature levels are close to those for gas oil fuels. The effectiveness of this method has been proved previously [2-5], but there is still no complete understanding of the physical chemistry of combustion of mechanically activated
carbon. A topical issue is the effect of mechanical activation on the chemical composition of incomplete combustion products, which always take place in real power plants. It is known that mechanical activation creates highly reactive centers on the surface of carbon particles [6-7], which can substantially accelerate the conversion of coal fuel during pyrolysis and combustion. As a result, more complete combustion with less harmful emissions can be expected.

These studies are of great interest for "large", as well as industrial energy, where the average efficiency of using fuels does not exceed 60%. Carrying out work to create optimal combustion technologies for mechanically activated solid fuels, as well as burner device designs, allows us to achieve a new level of energy use of the most common coal fuels.

2 Experimental setup and procedure
To study the gasification process, 1 MW thermal furnace with tangential scroll supply of coal-air suspension and cylindrical reaction chamber was used. Brown coal (one of the main coal deposits of Siberia) was used in experiments. The technical composition of coal is as follows (mass %, dry): moisture $W_{dl} = 30.8$, ash $A_r = 11.1$, volatile content - 49.1, sulfur $S_{dl} = 0.29$, high heat value $Q_{daf} = 6900$ kcal/kg. Coal was fed to the high-energy mills and then was directed by an ejector with transport air to the scroll burner.

Pulverized coal was ignited by a gas igniting device with the power of 50 kW. Coal consumption (30 kg/h) was controlled by voltage sensors of the feeders on the basis of preliminary calibration. Gas composition along the reaction chamber was measured by the optical-absorption gas analyzer at three points; temperature is measured in the same cross-sections of the chamber by the platinum-platinum-rhodium thermocouples. The flow rate of supplied air was obtained by the metering orifices and rotameters. The coefficient of air excess in the reaction chamber was 0.5. During experimental study ignition and gasification on coals of various grinding were investigated.

The thermal setup of 1-MW power for coal combustion and gasification is depicted in Fig. 1. Coal, ground in the standard boiler mill, was supplied by the feeder to the disintegrator (D) or vibrocentrifugal mill (VCM) and then was fed with transport air to the scroll inlet of the reactor-burner.

Figure 2 demonstrates measurement results of the brown coal particles dimensions after grinding in the mills of both types.

![Figure 1. Experimental setup of up to 1 MW.](image1)

![Figure 2. Spectrum of coal particles after: 1) disintegrated mills 2) BCM.](image2)
It can be seen that the average size of particles is practically the same and equals \(\sim 100\) mm. The reacting surface in both cases is practically the same and, therefore, velocities of inflammation and combustion of the dust coal flame should be identical under the given conditions of coal combustion.

3 Results and discussion

Experiments were carried out with constant fuel flow rate (30 kg/h), air excess ratio (0.5), and ignition devise power (50 kW).

The results of experimental studies on ignition and combustion of brown coal after its grinding with activation in a mill-disintegrator or vibrocentrifugal mill are illustrated in Fig 3, 4.

**Figure 3.** The distribution of temperature along the length as a function of time at a 1 MW booth with the combustion of coal dust milled in a disintegrator mill and a VCM. 1 – \(L = 300\) mm, 2 - \(L = 600\) mm, 3 - \(L = 800\) mm, 4 - \(L = 1200\) mm – thermocouples in the furnace

In 120 s after filing the pulverized coal mixture in both cases, thermocouple T1 showed 1200 °C. The temperature value already reached 1000 °C at the point T2 for coals after the VCM by 50 s (by the fiftieth second), and after the disintegrator the uniform heating was observed at the temperature of 1000 °C for 150 s. The maximum temperature of the coal after the disintegrator at point T3 was higher by 200 °C than in the experiment with the VCM. In the afterburner, the temperature in the experiment with the disintegrator was 100 °C higher than in the experiment with the VCM.

In an experiment with grinding coal by a disintegrator, the value of \(H_2\) was 1.8 vol.% and CO was 8 vol.%, when the value of \(H_2\) was reduced to 0.6 vol.% in the VCM and CO – to 4 vol.%. It can be seen that there were jumps in oxygen concentrations in the case of the VCM, which indicated unstable combustion.

When studying the combustion of mechanochemically treated coal samples, it was found that, other things being equal, the parameters of the flame, namely, the size and distribution of the temperature zones, strongly depend on what type of mills was used for grinding. In particular, processing to approximately the same degree of dispersion by using mechanical impact mills with constrained impact (vibrocentrifugal activator VCM) and by using free-impact mills (disintegrator) led to different parameters of the flame.

As a result of the experiments on the large-scale stand for the combustion of coals of various stages of metamorphism, mechanoactivated by grinding on a vibrating centrifugal mill and a disintegrator, it
was found that, with an almost undifferentiated particle size spectrum, the burnup rate of the particles in the flare after the disintegrator type mill was higher.

![Gas Concentration Diagrams](image)

**Figure 4.** Distribution of gas concentrations along the length as a function of time at a 1 MW booth with the combustion of coal dust pulverized in a disintegrator mill and VCM.

Since the flame parameters are the main characteristics that determine the design of heat generators, the study of the physical and chemical causes of the detected phenomenon is relevant. On the other hand, the method for controlling the parameters of a torch created on the basis of a mechanochemical phenomenon also opens up new technical prospects.

4 Conclusion
As a result of experimental study, new data on the effect of preliminary high-stress grinding of coal fuel in mill devices on the reactivity of fuel were obtained. Comparative experimental data on the combustion and gasification of coal fuel crushed at highly stressed mills (in a disintegrator and a vibration centrifugal mill) were obtained at 1 MW thermal furnace.

During the research, important experimental information was obtained that can be used for development of energy systems and devices without burning fuel oil and stabilizing the combustion of boilers from pulverized coal, as well as schemes and technical solutions necessary to replace highly reactive fuels with a mechanically activated microfield at industrial power plants.

The obtained results objectively allowed 1) to evaluate the technical and economic feasibility of introducing a system without fuel oil ignition, 2) to organize a system without fuel oil ignition applying mechanically activated coal dust of a microfield obtained from coals used on boilers (PK-38 Station No. 2B of Krasnoyarsk).

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References.
[1] Chernetskiy M Yu, Burdakov A P, Butakov E B, Anufriev I S, Strizhak P A 2016 *Combustion, Explosion, and Shock Waves* 52(3) 326–8
[2] Burdukov A P, Butakov E B, Popov V I, Chernetskiy M Y, Chernetskaya N S 2016 Thermal Science 20 23-33
[3] Burdukov A P, Popov V I, Chernova G V, Chernetskiy M Yu, Dekterev A A, Chernetskaya N S, Markova V M, Churashev V N, Yusupov T S 2013 Thermal Engineering 60(12) 889-94.
[4] Messerle V E, Ustimenko A B, Karpenko Y E, Chernetskiy M Y, Dekterev A A, Filimonov S A 2015 Thermal Engineering (English translation of Teploenergetika) 62(6) 442-51.
[5] Burdukov A P, Popov V I, Chernetskiy M Yu, Dekterev A A, Hanjalić K 2014 Applied Thermal Engineering 74 174-181