Experimental study of two-stage combustion of anthracite mining waste

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Abstract. Here we consider the task of studying the flame burning of low-grade coals and their significantly ballasted waste with a low volatile yield and reactivity. It is shown that when reducing the quality of coal fuel, it is advisable to use two-step combustion methods with preliminary mechanochemical activation, which allows start-up of the boiler from a cold state without application of auxiliary fuels. The methods of mechanochemical activation have proven to be effective technologies for start-up of the boiler and maintaining the combustion of coals of different quality and technical composition. The developed technologies allow approaching the full-scale experimental-industrial implementation at thermal power plants. The two-stage system allows significant reduction in the cost of preparing micro-ground coal and number of start-up of the burners, since fuel from a standard boiler mill is supplied to the second stage with a different ratios, depending on the reaction properties of the fuel, i.e. it is possible to increase the power of a of start-up of the burner several times as compared with single-stage combustion.

1. Introduction
In the long-term outlook, coal remains one of the most important resources of the thermal power complex due to abundant global reserves and competitively low prices [1]. Energy efficient combustion of coal and waste of coal processing is an urgent economic and environmental problem for Russia as a whole, and especially for Siberian regions.

According to the forecasts of the international energy agency, in 2020, accumulation of waste of energy coal dressing will be 924 million tons per year, which will significantly affect the ecological situation not only in Russia, but throughout the world [2-4].

There are a number of problems accompanying combustion of low-grade coals: the work of pulverized coal preparation devices, steam superheater, economizer and air-heating surfaces is greatly complicated, and reliability of smoke exhausters, ash collectors and hydraulic systems of ash removal is reduced. Reliability of the boiler unit as a whole decreases sharply, and the cost of repairs increases. According to the data of All-Russian Thermal Engineering Institute, suction in the furnaces of boiler units that burn sludge reaches 15–20% instead of the design value of 4–5%. In the boiler as a whole, suction rises to 50-60%, for the pulverized coal systems, it is up to 70% or more instead of 25-30% according to the standards.

Along with increased heat losses with flue gases, a noticeable increase in heat loss with mechanical underburning is observed. So, when burning fuels of degraded quality, heat losses with flue gases increase to 8-9% instead of the design value of 5-5.5%. Mechanical underburning in this case reaches 10-12% instead of the design value of 4%. The overall efficiency of boiler is reduced by 5-7%.
However, the role of low-grade fuels in the fuel and energy balance of the country is becoming increasingly important, and in the long-term outlook, low-grade fuels may become the main ones among solid energy fuels combusted at power plants. There are enough reasons for this. First, in Russia has very large reserves of low-grade fuel, primarily brown coal, and secondly, the achievements of modern furnace technology, development and introduction of new technical solutions for combusting high-ash and high-moisture fuels, such as fluidized bed combustion, burning in the form of coal-water suspensions, etc., open up the real prospects for highly efficient use of low-calorie and high-moisture fuels. At integrated use, current low-grade fuel will become the most valuable technological and energy resource for obtaining, along with electric power, a wide range of commercial products and chemical raw materials.

It is shown for a number of coals that the chemical activity of coal can be significantly increased with its mechanochemical micro-grinding to 30-40 µm in special disintegrators. With this treatment, coal becomes highly reactive and can replace high-reactive fuels (gas, fuel oil, diesel fuel) in some cases. Thus, high energy efficiency of fuel oil and diesel fuel substitution is observed at ignition and of start-up on coal-fired boilers using coals [5]. The research aimed at increasing the chemical activity of low-quality coals and their waste is a relevant direction.

This paper presents the experimental results on combusting mining waste of anthracite from Gorlovsky coal basin in the Iskitim district of the Novosibirsk region with ash content of up to 40–80% as fuel strongly ballasted with ash and low reactivity on a two-stage 5-MW setup. During the experiments, the technology of mechanochemical activation and two-stage combustion system developed at IT SB RAS [6-8] were used.

2. Experiment

A modernized 5-MW thermal setup with a two-stage system of ignition and combusion of coal fuel is presented in Fig. 1. The operation principle of a two-stage burner is based on the use of mechanically activated coal fuel supplied to the first stage, from 20 to 50% of the total coal consumption for ignition and combustion of fuel. Coal of standard grinding is fed through the second stage.

In our case, we used coal after high-intensity grinding in a disintegrator-type mill; as a result, pulverized coal is not only dispersed, but it is also activated, which increases the reaction properties of coal fuel. The two-step scheme allows reduction in the cost of mechanically activated grinding and required power of the activator mill.

Ground mechanically activated coal fuel is supplied to the scroll swirlor after the disintegrator, where ignition and combustion of the pulverized coal mixture is initiated by means of a gas igniter, and the combustion chamber is heated. When the process the autothermal combustion regime begins, coal fuel of standard grinding is fed to the second stage. Coal, supplied to the heated combustion chamber, is ignited with the help of energy of mechanically activated coal fuel.

Figure1. Experimental setup of up to 5 MW with two-stage system of ignition and combustion of fuel.
Pulverized coal is ignited by a standard device (ignition-safety device) used for fuel inflammation in gas-oil boilers. Ignition and combustion of micro-ground coal occur in a three-sectional response chamber with a total length of 1510 mm and internal diameter of 315 mm, lined with refractory material from the inside. After-burning of dust suspension takes place in a lined afterburning chamber with a diameter of 1000 mm and length of 2800 mm. Combustion products mixed with cooling air through a horizontal cyclone and smoke exhauster are released into the atmosphere.

Gas flow rate is measured by flow meters; temperature is measured by the platinum-platinum-Rd thermocouples. The coal feeder allows regulation of the flow in the range of 50 ÷ 1000 kg/h. Coal from the dust bin is fed by the vibrating feeder to the ejector inlet and then in the form of a dust-air jet it follows along the combustion chamber axis, mixing with the pulverized coal flame. The system allows investigation of the processes of ignition, combustion and gasification in two-stage regimes.

To determine the particle size distribution, the samples of coal fuel, crushed in a disintegrator mill, were taken. The spectral size of samples was measured by a microscope with built-in software for determining the particles sizes.

3. Results
The experiments were carried out with anthracite screening, selected on the field of Gorlovsky coal basin in the Iskitim district of the Novosibirsk region. The anthracite screening contains clay fine-grained sedimentary rock, which complicates the process of ignition and further combustion. Initially, the possibility of ignition and combustion was tested on a single-stage stand with grinding at a disintegrator mill, but when anthracite screening was supplied, the power of ignition device of 35 kW was not sufficient. In the future, a modernized thermal setup of 5 MW with a two-stage sequential system of coal ignition and combustion, presented in Fig. 1, was chosen for the experiments.

In the two-step operation regime: high-reaction mechanically activated brown coal was supplied to the first stage with a flow rate of 100 kg/h, anthracite screening with the flow rate of 250 kg/h occurred in the second stage.

Table 1 shows the characteristics of brown coal. Coal was obtained from station No. 2B of the branch of PJSC “OGK-2” - Krasnoyarskaya SDPP-2.

| Name and designation of indicator | Measuremen unit | Test result |
|----------------------------------|---------------|-------------|
| Operational moisture, $W'$      | %             | 30.8        |
| Analytical moisture, $W^a$       | %             | 19.0        |
| Ash, dry state, $A^d$            | %             | 16.0        |
| Ash, operational state, $A'$     | %             | 11.1        |
| Lowest combustion heat, operational state, $Q_{ri}$ | kcal/kg | 3651 |
| Sulphur, operational state, $S'$ | %             | 0.29        |
| Yield of volatiles, dry ash-free state, $V_{daf}$ | % | 49.1 |

When using the additional energy of the first stage, it is possible to establish a stable regime of ignition and combustion when anthracite wastes are fed to the second stage. The results of experiment on two-stage ignition and combustion in the case of sequential supply of brown coal to the first stage and ASSh-01 anthracite screening in the second stage are presented in Fig. 2.
Figure 2. Temperature distribution in sequential two-stage operating regime of 5-MW setup: the first stage – mechanically activated lignite of 100 kg/h, the second stage – ASSh-01 anthracite screening.

After the disintegrator mill, mechanically activated brown coal entered the ejector, where air and coal were mixed. Pulverized coal was fed through the first stage to the ignition device where ignition occurred. Further ignition and burning proceeded in the scroll swirler and combustion chamber. The autothermal operating regime was achieved within 50 seconds. After 300 seconds at the temperature of 800°C in the combustion chamber, ASSh-01 anthracite was fed through the second stage with a flow rate of 250 kg/h. The temperature along the entire length of the furnace rose by an average of 400°C; stable combustion of pulverized coal was observed in the afterburning chamber through the observation windows.

Conclusions
Successful experiments on two-stage burning of brown coal and ASSh-01 anthracite screening were carried out on a two-stage setup with a thermal power of up to 5 MW. The ratio of the flow rates of micro-ground coal fuel of the first stage to the flow rate of standard grinding coal of the second stage was 1 to 3. The results obtained allow the beginning of industrial testing of a two-stage system, which reduces the cost of purchasing the additional high-stressed mills without changing the total power of the start-up of the boiler with possible flaring of coal preparation waste.

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