Investigation of steam-air gasification of mechanically activated coal fuel at a setup with thermal capacity of 1 MW

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Abstract. In this work, steam-air gasification of mechanically activated coal was studied experimentally. To increase the energy efficiency of coal flaring, a technology with mechanochemical activation of coal by the mills is being developed at the Institute of Thermophysics SB RAS. The technology is aimed at increasing coal reactivity and can be used to replace high-reactive expensive and difficult-to-obtain fuel oil for ignition and lighting of pulverized coal boilers of thermal power plants (TPP) using mechanically activated microground coal. In experiments, we used brown coal from a deposit in Siberia. The results on the effect of steam flow rate to the continuous gasifier and the point of injection were obtained. During the experiment, the time of autothermal regime stabilization was measured, and it was 105 s. Five different regimes of continuous gasifier operation have been tested. For steam-air gasification with a steam flow rate of 32 kg/h and air excess coefficient of 0.5, concentrations of combustible gases at the end of the continuous gasifier were obtained: $H_2$ (vol.%) = 6.3; $CO$ (vol.%) = 10.7; $CH_4$ (vol.%) = 0.4.

1. Introduction
In the long-term outlook, coal remains one of the most important resources of the heat and power complex due to abundant global reserves and competitively low prices [1, 2]. According to the forecast of the Ministry of Energy of the Russian Federation, the development of electricity production from fossil fuels in Russia relies heavily on improving the efficiency of existing coal-fired power plants, including the process of coal gasification with synthesis gas production. Coal gasification is one of the priority areas for the development of modern electric power industry. All over the world, the works on studying the gasification process and its further implementation in industrial facilities are actively underway [3].

The solution to this problem involves the development of coal gasification technology for pulverized coal boilers in order to increase energy efficiency and reduce emissions into the environment. To understand the process that occurs during coal gasification, it is necessary to perform the additional research using such advanced methods of intensification of the combustion and gasification processes as mechanical activation, which allows improving the physicochemical characteristics of the fuel at the stage of preparation for burning. It is known that mechanical effects on coal and carbon-graphite materials lead to decomposition of individual chemical bonds and formation of free macroradicals, which initiate the development of various chemical reactions and allow a change both in the chemical and physical properties of these materials [4, 5]. A change in conformation of molecular chains and a change in interatomic and intermolecular distances occur at any mechanical effect on coal as a solid, whose organic component is a high-molecular formation, due to its deformation, therefore, deformation...
of macromolecules in the general case. All these changes are accompanied by weakening of the intra- and intermolecular bonds and corresponding increase in the free energy of substance [6, 7].

The use of a relatively new method of fuel preparation for gasifiers (mechanical activation) is caused by the fact that the rate of gasification reactions is significantly lower than the rate of combustion. The rate depends on the internal and external surfaces of the particles as well as on temperatures and concentrations of reagents. The set of measures under consideration (mechanical activation of coal, steam supply of up to 0.5 kg per 1 kg of coal) will increase the efficiency of gasifier (chemical efficiency) by more than 7-8%, and efficiency of gas turbine on the resulting synthesis gas will increase by more than 1-2% in comparison with the achieved world level. An increase in the H2/CO ratio in the synthesis gas will increase its combustion efficiency and reduce formation of nitrogen oxides. Efficiency and environmental friendliness of IGCC with such units will approach the NGCC parameters [8-10].

The goal of this work is to study continuous steam-air gasification and effect of location of steam injection point along the length of continuous gasifier on the process of steam-air conversion of mechanically activated coal.

2. Experimental setup and methods

The thermal setup of 1-MW power for coal combustion and gasification is shown in Fig. 1. Coal, ground in the standard boiler mill, is supplied by the feeder to the disintegrator; then, it is fed with transport air to the scroll inlet of the reactor-burner. 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 Wrl – 30.8, ash Ar - 11.1, volatile content - 49.1, sulfur Sdl - 0.29, high heat value Qdaf - 6900 kcal/kg.

![Figure 1. Experimental setup.](image)

Coal consumption (20 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.

To increase the reactivity of coal, it was ground in a disintegrator type mill. The disintegrator consists of two mutually opposite rotating discs with round fingers arranged on each disc in concentric circles in several rows perpendicular to the plane of rotation, forming a basket. The fingers of one basket are located between two rows of fingers of the other. Basket discs are mounted on shafts located on the same geometric axis, each with independent drive. Fractional composition of dust obtained in the disintegrator mill is determined by an optical-digital method in the particle size range of 0-180 microns. The maximum particle size does not exceed 70 microns (fig. 2).
Figure 2. Spectrum of coal particles after disintegrated mills.

From the mill, coal dust through a vacuum created by an ejector enters a snail entrance of square section with a face of 108 mm, where the dust-air flow is twisted and ignited by means of an ignition safety device built into the snail swirler. The swirling flow of gases and coal enters the gasification chamber with a diameter of 150 mm and a length of 1100 mm. By adjusting the amount of air and coal supplied, it is possible to work in the modes of both gasification and complete combustion.

Steam flow rate was regulated by the flow of feed water in the steam generator equipped with a level gauge. Steam temperature was adjustable from 100 to 250°C.

The steam was supplied to the chamber through a nozzle made of stainless steel with a diameter of 32 mm and wall thickness of 2 mm, placed in the center of the snail swirler and having the ability to move along the axis of the installation. The nozzle was immersed inside the installation from 100 to 250 mm (D, mm).

Measurements of local temperature distributions were carried out using thermocouples of type TXA. To measure the gas composition of the reaction products, a system based on the multi-component TEST-1 gas analyzer was used.

Before each experiment, the fuel feeder and air flow sensors were calibrated, and a gas and temperature analysis system were tested.

The experiment included the following steps:
1. Preheating of the swirl with the help of the ignition safety device.
2. Achievement of an autothermal operating mode of installation at coal flow rate of 20 kg/h with coefficient of excess of air 0.9.
3. Reduction of the air excess factor from 0.9 to 0.4 by reducing the air flow rate from 90 to 40 Nm³/h (air gasification).
4. Steam supply with a temperature of 150°C and a flow rate from 20 kg/h to 32 kg/h with immersion of the nozzle from 100 to 250 mm (steam-gasification).
5. Increase in steam flow rate of up to 10 kg/h (mode 4: vapor-gasification).
6. Turn off the installation.

3. Results
In 105 seconds after the start of supply of mechanically activated coal to the combustion chamber, the gas igniter was turned off and combustion occurred in the autothermal regime without the use of additional energy sources.
The experimental results are presented in Table 1 and Table 2. The temperature and composition of gas correspond to point T3.

When steam was introduced into the combustion chamber, insignificant changes in temperature in the furnace were observed. When steam was injected into the center of the continuous gasifier at a distance of 100 mm from the swirler edge, the temperature at thermocouple T5 was above 1200°C, and in the afterburner, it did not exceed 700°C.

Table 1. A change in temperature at steam-air gasification.

| No. | Steam flow rate (kg/h) | D (mm) | T1, (℃) | T2, (℃) | T3, (℃) | T4, (℃) | T5, (℃) | T6, (℃) | T7, (℃) |
|-----|------------------------|--------|---------|---------|---------|---------|---------|---------|---------|
| 1   | 20                     | 100    | 901     | 1093.9  | 1028.8  | 1100.8  | >1200   | 1013.1  | 701.2   |
| 2   | 32                     | 100    | 879.7   | 1091.2  | 1029.5  | 1112.2  | >1200   | 1049.9  | 708.1   |
| 3   | 20                     | 200    | 904.1   | 1140.9  | 1084.6  | 1153.6  | >1200   | 1097.3  | 733.3   |
| 4   | 32                     | 200    | 881.3   | 1078.3  | 1017.3  | 1099.5  | >1200   | 935     | 698.9   |
| 5   | 20                     | 250    | 904.8   | 1121.3  | 1064.3  | 1151.2  | >1200   | 1066.9  | 728     |

After increasing the steam flow rate (regime 2), the temperature in the chamber was in the same ranges as in regime 1, while concentration of combustible gases at the end of the continuous gasifier increased for H₂ (vol.%) from 4.7 to 5.5, for CO (vol.%) it increased from 7.4 to 8.9, and for CH₄ (vol.%) it increased from 0.2 to 0.4. Despite the supply of steam to the reaction zone, uniform temperature distribution of 1000°C was observed on the wall. The temperature at thermocouple T5 in all regimes was higher than 1200°C.

Table 2. A change in gas concentrations in the reaction chamber at steam-air gasification.

| No. | O₂(vol.%) | H₂(vol.%) | CO₂(vol.%) | CO(vol.%) | CH₄(vol.%) | NO(PPM) |
|-----|-----------|-----------|------------|-----------|-----------|---------|
| 1   | 0         | 4.7       | 14         | 7.4       | 0.2       | 223     |
| 2   | 0         | 5.5       | 15         | 8.9       | 0.4       | 281     |
| 3   | 0         | 5.6       | 13.3       | 8.9       | 0.4       | 281     |
| 4   | 0         | 6.1       | 13.4       | 9.5       | 0.3       | 235     |
| 5   | 0         | 6.3       | 14         | 10.7      | 0.4       | 245     |

With an increase in the distance of steam supply from the swirler edge (regime 1, 3, 5 at the same steam flow rates of 20 kg/h), an increase in concentration of combustible gases H₂ (vol.%), CO (vol.%) and CH₄ (vol.%) was observed. In regime 1, steam is fed into the swirler zone, where coal ignites at a temperature of about 900°C; in regimes 2 and 3, steam is fed into the zone, where stable combustion is already taking place at the higher temperatures. In regimes 2 and 4, an increase in concentration of combustible gases was also observed. Throughout all experiments, the concentration of O₂ did not exceed 0 vol.%.

Conclusion
In the experiments on steam-air gasification of mechanically activated coal, the results on the effect of flow characteristics of the steam supply and location of the injection point in the reaction zone of the continuous gasifier were obtained. Mechanical activation of coal allows the achievement of the autothermal regime in 105 seconds after the start of experiment and implementation of steam-air gasification using the energy of coal fuel. With a change in the location of steam injection, an increase in concentration of combustible gases was observed when approaching the high-temperature zone. When steam was introduced into the swirler zone, a slight decrease in temperature and concentration of gases was observed. An increase in steam flow rate from 20 kg/h to 32 kg/h led to an increase in
concentration of H₂ (vol.%), CO (vol.%) and CH₄ (vol.%) gases. The highest concentration of combustible gases was observed in regime 5: H₂ (vol.%)= 6.3; CO (vol.%)= 10.7; CH₄ (vol.%)= 0.4.

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