Experimental studies of in-line gasification of mechanically activated coal fuel

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Abstract. The 1 MW experimental stand was modernized with a scroll swirler and a crushed fuel supply system. Comparative data on combustion and gasification of coal fuel crushed in high-stress mills - disintegrator, vibrocentrifugal and hammer mill - at a stand with a thermal power of 1 MW were obtained. The experiments used coal of the Kuznetsk Basin, grade D, with technical characteristics: \( W_r, \% = 5.4; A_r, \% = 22.3; V_r, \% = 32.3; Q_{svr}, \text{MJ/kg} = 20.0 \). Elemental analysis showed that: \( C_r, \% = 54.6; H_r, \% = 4.1; N_r, \% = 1.3; S_r, \% = 0.5; O_r, \% = 11.8 \). In experiments with grinding coal on a disintegrator mill, the value of \( H_2 = 4.5 \text{ vol.\%} \) and \( CO = 9.4 \text{ vol.\%} \), when grinding in a vibro-centrifugal mill, the values of \( H_2 = 0.6 \text{ vol.\%} \) and \( CO = 5.8 \text{ vol.\%} \), when grinding in a hammer mill, the values of \( H_2 = 0.3 \text{ vol.\%} \) and \( CO = 2.8 \text{ vol.\%} \). When studying the combustion of mechanochemically treated coal samples, it was found that, all other things being equal, the gasification parameters, namely, the gas concentration and the distribution of temperature zones, depend strongly on the type of equipment used for processing. In particular, processing to approximately the same degree of fineness in mechanical mills-activators with constrained impact and in free impact mills (disintegrators) resulted in different flame parameters.

1. Introduction

Renewable and alternative energy sources are a priority area for the development of world energy today [1]. However, they cannot yet fully provide humanity with energy, their share in the world energy consumption is 26%, including hydropower [2]. Solid fuel energy, mainly coal, still occupies a leading position (about 38%) and, according to forecasts, the share of coal in the world energy balance will be the main part in the coming decades [3]. First of all, this is due to the large world reserves of coal (about 1055 billion tons) and its competitive low prices [4].

Requirements for increasing the efficiency of power plants and ensuring high environmental performance of their work led to the development of new clean energy technologies for fuel processing [5]. One of the directions for the processing of solid hydrocarbon-containing fuel is the production of artificial gas using the process of thermochemical conversion or gasification [6]. Gasification is the most promising process of thermochemical conversion of hydrocarbon-containing solid fuels into universal synthesis gas, which can be used as a fuel in gas turbine plants for the production of heat and electricity, feedstock for chemical synthesis and hydrogen production [7]. The resulting fuel gas in gasifiers is purified from carbon dioxide, tar and other substances that pollute the environment. The gasification technology can be classified by the nature of the movement of the gasified fuel, by the type of blast, gasification temperature and pressure. The design of gasifiers depends on the method of introducing the fuel suspension and gaseous reagents and removing heat. The main flow gasification processes under development are based on the Texaco, Shell, Prenflo, Destec, ABB CE method; in a fluidized bed, they occur according to the Wickler method, U-GAS,
KRW, Westinghouse Corporation [8]. Currently, research aimed at using off-design fuels (biomass, petroleum coke, etc.) with quality deviations in a wide range, using gasifiers of various types, is underway in the world. For the use of the obtained synthesis gas in the combustion chambers of gas turbine plants, developed for the combustion of methane and liquid fuels, it is necessary to assess the possibility of combustion with the adjustment of the input parameters. It is necessary to carry out additional work on the study of operating characteristics, stabilization of the flame front, velocity and temperature fields.

The purpose of this work was to study the effect of high-stress grinding on air gasification of coal fuel.

2. Experimental methods and results

The scheme of the modernized experimental reactor is shown in Figure 1.

![Diagram of experimental setup](image)

Figure 1. Scheme of experimental setup.

scroll swirler (1), steam supply insert (2), reaction chamber (3), afterburner (4), inspection window (5), vacuum controller (6), centrifugal bubbling apparatus (7), smoke exhaust (8), fuel hopper (9), screw feeder (10), mixer (11), frequency-driven air blower (12), diaphragm for measuring air flow rate (13), pilot burner (14), propane tank (15), lighting blower (16), steam generator (17), steam superheater (18)

Before carrying out a series of experiments, the coal screw feeder and air flow sensors were calibrated. The minimum air consumption was determined from the conditions of coal fuel transportation. The airflow rate was measured throughout the experiment. The coal consumption was 12 kg/h. The primary air flow rate of 35 nm³/h was constant; the unit operated in the air gasification mode. The propane burner operated at the ignition stage for 2-3 minutes, the power was 20 kW. Large particles of coke ash falling out of the gas stream formed a layer in the lower part of the afterburner. The capture of fine particles carried away with the flow and cooling of the combustion products occurred in a centrifugal bubbling apparatus. The cleaned combustion products were directed to the chimney using a smoke exhauster.

Coal fuel was crushed using three types of mill devices: a disintegrator mill (Des) with a rotor speed of 6 thousand rpm (Patent for invention of the Russian Federation No. 2511314), a vibratory centrifugal mill (VM) with a vibration frequency of 3 thousand rpm (Patent for invention of the Russian Federation No. 2043156) and a hammer mill (Hammer) with an output sieve of 100 microns with a rotor speed of 3 thousand rpm (Molot 200). The size of particles obtained in 2 types of mills - VM and Dez - was approximately the same; the size of particles obtained on the Hammer is larger. Average particle size: MCM = 50 microns, Des = 45 microns, Hammer = 85 microns.
The in-line gasifier was heated under the established conditions; when gas was turned off, the combustion proceeded in an autothermal mode. The stationary regime was reached with insignificant temperature deviations along the length of the combustion chamber and gas concentrations at the end of the combustion chamber. Experimental studies were carried out with an excess air ratio \( a = 0.5 \).

On the thermocouple T1, located at a distance of 300 mm from the end of the coiled swirler, the temperature after the Des and VM mills was 1250°C, after the Molot mills, it was 1170°C. The temperature values at point T2 for coals after VM reached 1150°C, after Des, it was 1180°C, and after Molot, it was 1130°C. The temperature at point T3, located at 800 mm from the end of the swirler, was 1204°C in experiment with Des, which is 200°C higher than in the experiment with MCM, and it was 300°C higher than in the experiment with Hammer. In the afterburner chamber, the temperature in the experiments was kept at the level of 560°C.

In experiments on gasification with grinding coal in Des, the value of \( \text{H}_2 \) is 4.5 vol.\% and \( \text{CO} = 9.4 \) vol.\%. When grinding in VM, the values of \( \text{H}_2 \) are 0.6 vol.\% and \( \text{CO} = 5.8 \) vol.\%, when grinding in the Hammer, the values of \( \text{H}_2 \) are 0.3 vol.\% and \( \text{CO} = 2.8 \) vol.\%. According to the readings of the gas analyzer, it can be seen that with a decrease in the concentration of \( \text{O}_2 \), an increase in the concentration of \( \text{CO} \) and \( \text{H}_2 \) occurs. The \( \text{CO}_2 \) concentration values increase with decreasing oxygen and have a maximum at complete \( \text{O}_2 \) burnout, and then decrease due to the gasification reaction in carbon dioxide. A decrease in oxygen concentration entails an increase in the concentration of \( \text{NO} \) and \( \text{CO}_2 \), while \( \text{CO}_2 \) begins to decrease at 1000°C and a decrease in \( \text{NO} \) concentration occurs at 700°C. During operation of the reactor, liquid slag is formed, which, under the influence of the gas flow, moves in a spiral to the outlet of the reactor. With a sharp cooling of the reactor (stopping the fuel supply and blowing with air), the slag solidifies. However, during subsequent firing up of the reactor, the slag softens and leaves, the accumulation of slag inside the reactor does not occur. Experimental studies of air gasification of mechanochemically activated coal fuel have shown that under identical experimental conditions, for samples of different mechanical preparation, the concentration of gases and the distribution of temperature zones depend strongly on the type of equipment used for processing. Processing in mills with constrained impact (vibratory centrifugal mill-activator VTSM) and in mills with free impact (disintegrators) leads to different characteristics of the gasification process.

For more detailed understanding of the effect of mechanical activation by different mills, the chemical composition of the flame is studied using gas chromatography. For this, a gas sample from the flame is taken by the probe method at different points of the reactor. The sampling probe is a quartz tube with a tapered taper and a hole at the top. The tube diameter is 8 mm, the wall thickness is 1 mm, the external cone solution is ~ 20°, the hole diameter is ~ 0.1 mm. The probe is connected to a chemical flask through a line evacuated by a 2NVR-5DM1 vacuum pump. Prior to sampling, the probe tube is separated from the vacuum line by a valve, and the line itself and the flask are evacuated to a pressure of ~ 1 Torr. After inserting the probe into the investigated zone of the reactor, the valve is opened and the gas sample is sucked into the probe. Due to the pressure drop, the gas expands and cools down strongly, which almost completely inhibits further chemical reactions. The sampling is carried out for several minutes until the pressure of the gas sample reaches 30-50 Torr, then the probe is again cut off by the valve, and the pressure in the flask with the taken sample is pumped to an atmospheric pressure of inert gas (Ar or He). After that, the flask with the sample is transferred to the GC.

3. Conclusion

An experimental stand with a capacity of up to 1 MW was modernized with a crushed fuel supply system and a scroll swirler. Experimental studies of in-line air gasification of mechanically activated coal fuel were carried out. Experimental data were obtained on the course of the gasification reaction along the length of the reaction chamber, the average concentration values for coal crushed in a high-stress disintegrator mill were \( \text{H}_2 = 4.5 \) vol.\% and \( \text{CO} = 9.4 \) vol.\%. Under identical experimental conditions, for samples of different mechanical preparation, the concentration of gases and the distribution of temperature zones depend strongly on the type of equipment used for processing.
Using the obtained experimental data, a complex mathematical model was adapted for the processes of in-line gasification of mechanically activated fuel. The values of gas concentrations along the length of the reactor were obtained for various operating modes of the gasifier.

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