Results of testing an experimental industrial installation for fuel-bed gasification using bituminous coal

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Abstract. Experimental studies on the gasification of thermal bituminous coal of the Belovskaya mine at an experimental industrial installation were performed. Technical characteristics of the investigated coal are given. Composition of the obtained synthesis gas is given based on the results of four full loads of 4 tons each. Residence time for one fuel load was at least 45 minutes. The obtained results allowed us to conclude that composition of the synthesis gas did not change significantly according to the results of four experiments and is suitable for use in energy purposes.

1. Introduction
According to the International Energy Agency [1], coal is the dominant type of energy source used as a primary fuel for energy generation. The share of coal consumption from the total amount of energy sources according to 2019 data is 38% [1-3].

There are quite a large number of ways to use coal for energy purposes, for example, direct combustion, as part of CWF, OCWF, multicomponent fuel mixtures, gasification, etc. Gasification is considered the most environmentally friendly direction of thermal conversion of coal. Gasification methods are different and cover a wide range of technological schemes that can be classified according to the developed technological systems, the nature of the gasified fuel movement, the blast type of the gasifying agent, calorific value, obtained gas and its purpose, temperature and pressure of the gasification process, and other parameters [3-7].

At the moment, coal gasification in a fuel-bed is the most common and relevant method applicable on an industrial scale. This method of gasification involves slow movement of particles down the shaft of the gas generator under the influence of gravity with a counter-current flow of steam-air or steam-
The most common method of coal gasification in a fuel-bed is the method at high pressure, which is carried out in gas generators of the "Lurgi" type [2]. Gasifiers of this type are quite unpretentious to changes in fuel characteristics and have a high chemical efficiency, but such gas generators also have disadvantages, for example, implementation of fuel supply, slag removal [8] and other problems. Modeling of fuel-bed gasification is a very complex process due to the more complex nature of the process, which is influenced by heat and mass transfer in individual large fuel particles, conjugate heat and mass transfer, and chemical reaction in a porous layer [9]. Despite a large number of approaches to describing this process, all of them have significant drawbacks [10]. In connection with the above, a reliable description of the processes in an industrial-scale fuel-bed gas generator currently requires confirmation by field tests. A small number of experimental industrial installations of this type in the world (currently only the Sotocarbo site is in active operation [11-15]) does not allow for a breakthrough in the industrial implementation of this technology.

A unique method of fuel-bed gasification was developed and tested on an industrial scale at Tomsk Polytechnic University (TPU) together with All-Russia Thermal Engineering Institute (VTI) to solve the problems of industrial implementation of the above technology. The created industrial design of the gas generator currently has no analogues either in Russia or abroad. This method is called hearth gasification because of its similarity to the domain process. A series of semi-industrial experimental studies on the gasification of bituminous coal was conducted in the fall of 2019. The purpose of this work is to present the results of the synthesis gas obtained during the gasification of bituminous coal in a semi-industrial installation of hearth gas generator.

2. Experimental section
Experimental studies were carried out on the stand of complex tests (Fig. 2), which includes a gas generator itself, a house for receiving and storing coal, its grinding and fractionation, a compressor station, and its own electric substation with all the necessary engineering infrastructure. The total site area is 1240 m², the area of auxiliary coverings is 2410 m². The maximum height of the stand is 22 m. The research was carried out on bituminous coal of the Belovskaya mine. A batch of 16 tons of coal was purchased for the research to form four full loads of 4 tons each.

Figure 2 shows the general scheme of the experimental industrial installation for gasification of solid fuels. Here, the gas generator is a cylindrical vessel lined with lining bricks from the inside. There is a slag bath filled with water in the lower part of the gasifier, which receives slag from the reaction chamber. The lining was heated with a diesel burner during 24 hours to a temperature of 800°C before starting the gas generator. Coal was sorted by size using a vibrating screen, a fraction of 5-50 mm was
selected, then it was fed to the upper fuel hopper using a conveyor, and then it was fed to the gas generator through a hatchway system. Nitrogen was used as a hatchway agent when loading coal into the gasifier, which was fed to the hatchway fuel hopper from the air separation unit (nitrogen generator). The gasifier was supplied with compressed air from the compressor, heated to 300°C by the heat of the exhaust gases, as well as superheated steam from the steam generator with a temperature of 200-300°C. The working pressure in the gas generator during the tests was 6 atm. The obtained generator gas with a temperature of 800-1100°C was sent to the gas cooler, where its temperature was reduced to 500-600°C due to automatically controlled water injection. After that, the synthesis gas entered the cyclone, which is the first stage of gas purification from solid particles, then the pressure was reduced through the pressure-reducing device (to atmospheric) and the synthesis gas passed through the recuperative air heater, the battery cyclone and was sent to the flare unit for its subsequent safe combustion. Synthesis gas was sampled for analysis of its composition immediately after the pressure-reducing device. The synthesis gas composition was analyzed using the TEST-1 gas analyzer (BONER LLC).

3. Results and discussion

Technical analysis of bituminous coal was performed before conducting research on its gasification.

Table 1 shows the technical analysis of bituminous coal.

Table 1. Technical characteristics of bituminous coal

| Grade of coal | Calorific value \( Q^r \) MJ/kg | Ash content \( A^r \) wt. % | Humidity \( W^r_t \) wt. % | Volatile yield \( V_{daf}^r \) |
|---------------|---------------------------------|-----------------|-----------------|-----------------|
| Bituminous    | 17.94                           | 15.76           | 6.28            | 37.41           |

Fig.3 below shows the results of four full loads of the gas generator, each of which was at least 4 tons. The average time interval between loads was 45 minutes. The figure shows the average values of the gas content in the analyzed time interval.

![Figure 3. Average values of combustible gases during the time of each fuel loading.](image)
Analysis of figure 3 allows us to establish that the obtained synthesis gas in each analyzed time interval had in average similar results. The difference in methane content during the analysis of four loads was less than 9 %, hydrogen - less than 15 %, and carbon monoxide - less than 5 %.

Experiments have shown that it is possible to control the methane content, thus, when steam is supplied to the gas generator chamber, the methane content in the resulting gas rises to 45%. Increase in the hydrogen content was found at the moments of maximum methane content. Most likely, this was caused by the overlap of two factors: reactions between the fuel carbon and the hydrogen obtained during the interaction of water vapor with solid-phase carbon and CO; suppression of methane oxidation reactions released during fuel pyrolysis, due to the displacement of air from the gas generator by the supplied water vapor. The established dependences allow to confirm the influence of water vapor on the gasification process, leading to improvement of quality (increase in the content of combustible components - CO, H₂ and CH₄) of the syngas output from the gasifier and increase of its competitiveness as a source of fuel for hydrogen production. However, the established effect should be further investigated on other types of coals, such as lignite, lean coal and anthracite.

Figure 4 shows the image of the flare unit and the process of syngas combustion during gasification of bituminous coal.

![Flare unit and syngas combustion](image)

**Figure 4.** Results of syngas combustion in a flare unit: a) flare unit, b) combustion of syngas obtained from bituminous coal.

### 4. Conclusion

The experimental studies performed on the gasification of bituminous coal at the experimental industrial installation allow us to state that the obtained synthesis gas corresponds to energy gas and is suitable for its industrial application. Test results contribute to the further development of gas-generating technologies and creation of high-tech industrial complexes for deep processing of coal. This method of coal processing is significantly environmentally friendlier compared to traditional methods of coal combustion, which currently incur significant costs in order to meet modern environmental safety requirements.
Expanding the range of low-grade raw materials used for gasification, for example, will allow to involve currently unused resources in the fuel and energy balance of the regions, with minimal economic costs for imported expensive fuel and low impact on the environment.

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