Optical spectra of coal gasification products in the RF plasma-tron

S D Fedorovich1, I A Burakov2, A A Dudolin3, A A Markov4, Aung Khtoo Naing5, Batsamboo Ulziy6, D I Kavyrshin7

1 2 3 4 5 6 National Research University "Moscow Power Engineering Institute" Russia, 111250 Moscow, Krasnokazarmennaya, 14
7 Joint Institute for High Temperature of the Russian Academy of Sciences Russia, 125412, Izborskaya 13, Bldg 2, Moscow

Abstract. The use of solid fuel gasification process is relevant to the regions where there is no opportunity to use natural gas as the main fuel. On the territory of the Russian Federation such regions are largely the Urals, Siberia and the Far East. In order to reduce the harmful effects on the environment solid fuel with high sulfur content, ash content and moisture are subjected to gasification process. One of the major problems of this process is to produce syngas with a low calorific value. For conventional types of gasification (gasification), the value of this quantity ranges 8 - 10 MJ/m³. The use of plasma gasification increases the calorific value of 12 - 16 MJ/m³, which allows the most efficient use of the syngas. The reason for the increase of the value lies in the change of temperature in the reaction zone. A significant rise in temperature in the reaction zone leads to an increase in methane formation reactions constant value, which allows to obtain a final product with a large calorific value. The HFI-plasma torch coal temperature reaches 3000 °C, and the temperature of coal gasification products can reach 8000 °C. The aim is to develop methods for determining the composition of the plasma gasification products obtained optical spectra. The Kuznetsky coal used as the starting material. Received and decrypted gasification products optical spectra in a wavelength range from 220 to 1000 nm. Recommendations for the use of the developed method for determining the composition of the plasma gasification products. An analysis of the advantages of using plasma gasification as compared with conventional gasification and coal combustion.

Provision of natural gas supplies to the Far Eastern Federal District (FD) and Siberian Federal District at the beginning of 2015 amounted to 15.8 and 5.8% of the total number of required supplies, respectively [1]. These indicators are extremely small in comparison with similar indicators for other Federal Districts of the Russian Federation. The main energy fuel in these regions is solid fuel. Its use leads to a number of environmental problems, the main one of which is the presence of hazardous substances in the flue gases when burning this fuel, namely: toxic nitrogen and sulfur oxides (SOx and NOx). In addition, when using solid fuel, the sooting process takes place and the process of entraining of solid gold and fuel particles of small size occurs. One of the solutions to the problem is the use of preliminary thermal processing of the initial solid fuel on the basis of degradation processes occurring under conditions of lack or absence of an oxidizer. Such processes are called gasification and pyrolysis processes, respectively.

The process of gasification of solid fuels is the interaction of the source fuel in high temperature conditions with a controlled amount of oxygen or vapor, called blast components [2]. The syn-
thetic gas produced as a result of the gasification process consists of a large number of components, both molecular and atomic, but the highest concentrations in the synthesis gas are carbon monoxide CO, molecular hydrogen H2 and methane CH4 [3, 4]. The ratio of these three components in the resulting synthetic gas, ultimately, determines the calorific value of the synthesis gas. Moreover, if the presence of CO and H2 in the synthetic gas is largely due to the ratio of the consumption of the components of the blast to the consumption of the initial fuel, the reaction constant for the formation of CH4 increases with increasing temperature in the reaction zone of the process. However, at temperatures close to 1000 °C methane is subject to thermal decomposition into derivative components, and the system of equilibrium reactions can be represented by the formulas (1-5) [5]:

\[
\begin{align*}
\text{CH}_4 & \rightleftharpoons \text{CH}_2 + \text{H}_2 \\
\text{C}_2\text{H}_6 & \rightleftharpoons \text{C}_2\text{H}_4 + \text{H}_2 \\
\text{CH}_2 + \text{CH}_4 & \rightleftharpoons \text{C}_2\text{H}_6 \\
\text{C}_2\text{H}_4 & \rightleftharpoons \text{C}_2\text{H}_4 + \text{H}_2 \\
\text{C}_2\text{H}_2 & \rightarrow 2\text{C} + \text{H}_2
\end{align*}
\]

Therefore, to obtain a synthetic gas with the maximum value of the heat of combustion, the temperature conditions of the gasification process are close to 900 - 990 °C. Caloric content of methane is much higher than the calorific value of CO and H2 (35.83 MJ/m³, 12.63 MJ/m³ and 10.78 MJ/m³, respectively). Thus, in order to increase the total caloric value of the syngas produced, it is required to increase the content of CH4 in it. In this paper, the application of the method of plasma gasification of solid fuel of a high-temperature type with the highest temperature in the reaction zone (from 1800 to 3000 °C) is considered. The method of plasma gasification has the experience of successful application both on the territory of our country and abroad, which is confirmed by a number of works [3, 4, 6-9]. As a source material, both solid fuel and solid household waste (SDW) were used in these works, and oxygen, steam, steam-oxygen and vapor-air mixtures in various proportions were used as blast components. Four different grades of coal and one type of peat were taken as the processed initial product, which together represented the representation of all stages of coalification of solid fuels starting from peat and ending with the coal-coal stage. The characteristics of the starting material used are shown in Table 1.

**Table 1.** Characteristics of the initial material for experiments conducted at NRU "MPEI" on high-temperature plasma gasification of solid fuels.

| Name, mark, deposit of source material | Elementary composition of the starting material, % |
|----------------------------------------|-----------------------------------------------|
|                                        | W<sup>r</sup> | A<sup>r</sup> | N<sup>r</sup> | O<sup>r</sup> | S<sup>r</sup> | H<sup>r</sup> | C<sup>r</sup> |
| Vasilievsky moss (peat)                | 35,0          | 2,0            | 1,4          | 22         | 0,5           | 3,8           | 35,3         |
| Shivae-Ovoo coal deposit, B3          | 40,7          | 8,5            | 0,6          | 12,3       | 0,8           | 2,8           | 34,3         |
| Baganur coal deposit, B2              | 33,0          | 12,1           | 0,5          | 12,0       | 0,3           | 2,5           | 39,6         |
| Kuznetsk coal deposit, J              | 7             | 34,8           | 1,5          | 3,3        | 0,8           | 3,5           | 49,1         |
| Long-flame coal, D                    | 7,5           | 21,2           | 0,8          | 11,4       | 0,5           | 3,9           | 54,8         |

The process of plasma gasification of solid fuels was realized by introducing the sample of solid fuel into the flare of the high-frequency plasma discharge of the RF plasmatron of the Department of Nuclear Physics of the Research Institute of the MPEI.

During the experiment, the following conditions were met: the temperature of the solid fuel sample in the reaction zone was 1600 - 1800 °C; Plasma-forming gas is argon at atmospheric pressure. In the work carried out, the process of destruction of solid fuel, which occurs directly under the influence of elevated temperatures, was observed. Additional input of blast components to the reaction zone was absent (the so-called "zero point"). The scheme of the experimental setup is shown in Fig. 1.
The test sample of solid fuel 1 was fixed in holder 2 (Fig. 1) made of 0.5 mm diameter wire made of tungsten and rhenium alloy BP-20f. The sample holder 2 was fixedly movable in the upper part of the plasmatron body 3 and allowed horizontal and vertical movement of the sample 1 to be introduced into the argon plasma torch 5 pre-formed inside the inductor 9. The argon flow rate was 10 l/min with an average flow velocity of 0.32 m/s. The inductor 9 was connected to a high-frequency generator 10 with an output frequency of 27.12 MHz and a power of 4 kW.

Figure 1. The scheme of experimental equipment

Registration of the emission optical spectrum of the gasification products of the solid fuel sample was carried out with the help of a diffractive three-channel fiber-optic spectrometer “AvaSpec-ULS2048x16” from “Avantes” 4. The AvaSpec-ULS2048x16 spectrometer allows calibrated spectro-radiometric measurements to be performed in the study of emission spectra that require a sufficiently high resolving power in a wide spectral range (220 - 1100 nm). The ultraviolet channel of the spectrometer has a resolution of not worse than 0.18 nm, the visible-range channel has a resolution not worse than 0.12 nm, and the infrared channel is not worse than 0.3 nm.

During the recording of the spectra, the sample under study was located inside the argon plasma torch 5 at a double focal length from the center of the quartz lens 6 (Fig. 1). The entrance window 7 of the fiber optic cable 8 of the spectrometer was placed in the plane of the image of the torch 5 and directed to the investigated region near the sample. The emission spectrum was recorded at a point 1-2 mm above the test sample in an area where the combustion of the mixture of the resulting synthetic gas and air had not yet formed. Automatic detection of spectra during the experiment was carried out with a period of 0.5 seconds (63 emission spectra for 31 seconds). Each experiment was repeated 3 to 5 times.

Based on the results of decoding the emission spectra, the following results were obtained. For the test sample of peat of the Vasilievsky moss type throughout the entire experiment, spectral bands characteristic for the emission of carbon monoxide CO molecules in the wavelength range from 220 nm to 289 nm were fixed. As can be seen in Fig. 2, the bands of CO molecules are not overlapped by emission bands of OH ions with characteristic wavelengths of 280-290 nm and 306-322 nm, which indicates a relatively weak concentration of CO. The presence of CO and OH is fixed during the destruction of all solid fuel types studied in the work, and the intensity of the CO bands increases with the degree of coalification of the initial sample (Fig. 2 - 4).

In the gasification of coals of grades B3 and B2 of the Mongolian deposits Shivee-Ovoo and Baganur, respectively, in the emission spectra of the resulting synthetic gas, in addition to the spectral bands listed above, low-intensity bands were observed related to the characteristic CN spectra with a wavelength of 356-361 nm, 374-390 nm, 425 nm. In addition to the CN bands, bands of C2 molecules with a wavelength of 450-474 nm, 480-517 nm, and 530-564 nm were observed (Fig. 2).
Figure 2. Emission optical spectra of products of gasification of coal of grade B2 of the Baganur coal deposit.

Similar bands, of a higher intensity, were observed in emission optical spectra recorded during the gasification of coal of the J grade of the Kuznetsk coal deposit (Fig. 3). In the experience of gasification of solid fuel at temperatures of 900-990 °C, it is possible to expect the appearance in gasification products of spectral bands of methane CH₄ molecules, whose molecules are destroyed at temperatures in the reaction zone 1800-2000 °C of this work. To determine the temperature of the sample surface, the dependence of the spectral radiation intensity of the sample on the wavelength in the Wien coordinates [10] was used in the wavelength range of the emission continuum of 600-1000 nm (Fig. 4).

Figure 3. Spectra of coal gasification products of the brand J of the Kuznetsk coal deposit of the visible range.

When decoding the optical emission spectra of gasification products of all the listed solid fuel samples, the presence of sodium doublet lines with wavelengths of 589.0 and 589.6 nm was observed. For most spectra, the sodium doublet is represented by high intensity values. Based on the results of the spectral analysis of the five original solid fuel samples, only CO was detected from the combustible components of the synthetic gas. Therefore, the maximum value of the heat of combustion of the synthetic gas obtained after the processes of high-temperature plasma gasification can be no more than 12.63 MJ/m³.
The purpose of the future experimental work is to carry out experiments to determine the optical emission spectra of the gasification products described in this work samples of the initial solid fuel with imitation of steam, air and steam-air blasting, as well as a decrease in the temperature in the reaction zone to 900-990 ºC at which there will be no Destruction of CH₄ molecules occurs. The implementation of these tasks will be carried out by watering the samples of the initial solid fuel before starting the experiments and moving the point of registration of the emission spectra to the mixing region of the synthetic gas with air.

In the future, it is planned to implement an experimental work to determine the component composition of the synthesis gas produced by developing and setting up an experimental stand for studying the processes of high-temperature plasma gasification, which will include a line for quenching synthetic gas at the stage of quenching and evaporating devices. The implementation of this work will make it possible to more accurately determine the composition of the synthetic gas produced and the value of its heat of combustion.

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