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Prospects for production of synthetic liquid fuel from low-grade coal

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Abstract. In the paper, we compare the energy costs of steam and steam-oxygen gasification technologies for production of synthetic liquid fuel. Results of mathematic simulation and experimental studies on gasification of low-grade coal are presented.

The Long-Term Programme for the Development of the Coal Industry of Russia for the Period up to 2030 [1] assumes an increase in the amount of exported coal of up to 170 mln tons per year, approximately. In Russia today 95% and 22% of coking power-generating coal are enriched, resulting in a significant amount of low-grade carbon compounds that degrade the environment. Only Kuzbass has accumulated more than 25 million tons of sludge. These substances are not used, although they can be processed using the non-fuel technologies, for instance, gasification.

One of such technologies for processing the carbonaceous materials is anoxic gasification, where steam, superheated to 1200 °C, acts as a gasification agent. Synthesis gas (water gas) obtained in this manner, by its parameters is a high-quality raw material for production of synthetic liquid fuel. The main advantages of steam oxygen-free gasification are:

– absence of oxygen in the blast. This can significantly reduce the capital and energy costs for production of O2, required to maintain the gross value of endothermic gasification process;
– use of steam blast determines the largest amount of produced synthesis gas from one kilogram of carbon of the gasified material among the most widely used gasification technologies ([2], Table 1);
– use of the gasifying agent in the form of superheated steam provides the content of target components (H_2 and CO) in the synthesis gas of up to 90 vol.%.

The developed model of the process of oxygen-free gasification [3] and calculation results for the corresponding conditions of experiments in a stationary layer showed that steam oxygen-free gasification allows processing of high-ash ($A^d = 62\%$) coals in synthesis gas, in particular, sludge of concentration mills, and obtaining gas with content of hydrogen and CO (Fig. 1). Comparison of calculated and experimental temperatures (Fig. 2) demonstrates satisfactory agreement of experimental and theoretical dependences.

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Table 1. Characteristics of ideal gases for different gasification technologies [2].

Gas	Gas composition, % (vol.)			Gas yield, m^3/kg	Heat of gas combustion, MJ/m^3
	CO	H_2	N_2		
Air	34.7	–	65.3	5.39	4.4
Water	50	50	–	17.7	11.77
Semi-water	40.3	18.2	41.5	4.63	7.08
Oxygen-water	68.9	31.1	–	2.71	12.15

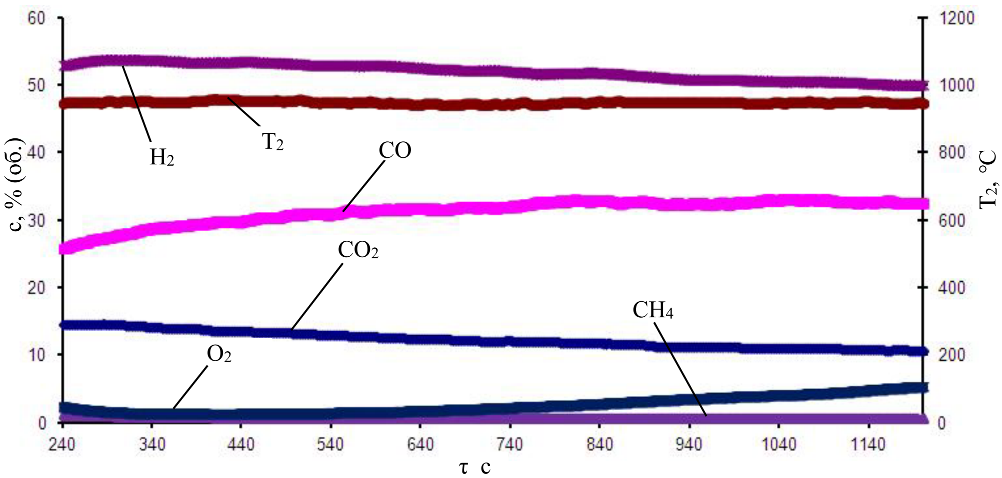

Figure 1. Time dependences of concentrations of the main reaction products for sludge from CCM "Berezovskaya". The temperature in material layer is 950 °C.

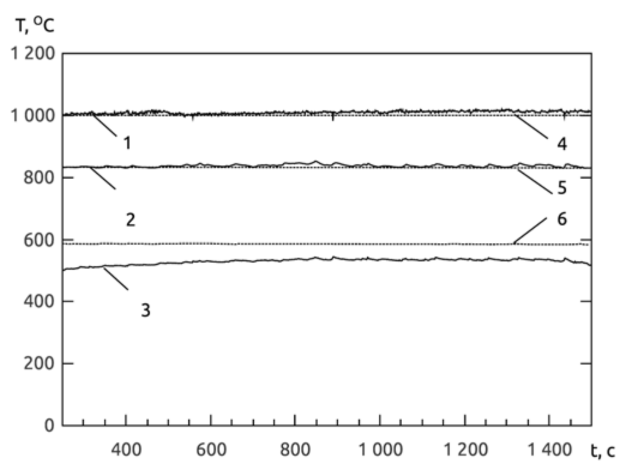

Figure 2. Calculation and experimental dependences of temperature on process time: 1,2,3 – experimental temperature; 4,5,6 – calculated temperature;1 and 4 – steam temperature before material gasification; 2 and 5 – temperature of steam-gas mixture in a layer of gasified material; 3 and 6 – temperature of steam-gas mixture after the zone of gasification.

Table 2. Comparison of costs for steam and steam-oxygen gasification.

Type of gasification	Steam	Steam-oxygen
Production costs of 1 m^3 of $CO+H_2$ mixture, rub.	1.28	0.79
Production costs of 1 t of SLF	6400	3950

Experimental and theoretical results of oxygen-free gasification allow grounding for the technology of production of synthetic liquid fuel (SLF) from synthesis gas formed in experiment. Two technologies of SLF production at steam and steam-oxygen gasification were compared by their energy costs (in prices of 2013).

Steam oxygen-free gasification was calculated under the following conditions: superheated steam temperature was 1200 °C, cost of 1 kg of steam at the cost of heat energy for Kuzbass (Kemerovo) of 900 rub./Gcal was assumed 1.07 rub./kg of steama. Analysis of publications and our experimental results allow us to assume in the first approximation that the main contribution to syngas formation is made by reaction:

$$C + H_2O = CO + H_2. \tag{1}$$

According to experimental data, at sludge gasification synthesis gas is formed in the amount $V_g = 4\,\text{m}^3$ of gas/kg of *coke*. At that, the costs for production of 1 m^3 of synthesis gas are:

$$u = \frac{g_s}{V_g} = \frac{7.86}{4} \cdot 1.07 = 2.1\,\text{rub./m}^3 \text{ of } synthesis\ gas,$$

where g_s is theoretical consumption of steam (7.86 kg of *steam*/kg of *coke*) in stoichiometric relationship of reaction (1).

The cost of 1 t of SLF at required consumption of 5000 m^3 of gas mixture per 1 t of SLF is:

$$sgt = 2.1 \cdot 5000 = 10500\,\text{rub./t}.$$

The estimated cost can be significantly reduced, for instance, using steam heat at the stage of steam-gas mixture cooling. In this case, the cost of 1 ton of SLF can be 6400 rub./t (1.28 rub./m^3 of *synthesis gas*).

For the steam-oxygen technology the required consumption of steam and oxygen were taken from [4]. The cost of oxygen is 0.931 rub./kg of *coal* and the cost of required steam is 0.24 rubs./kg of *coal*. Common energy costs for production of synthesis gas are 1.055 rub./kg of *coal*.

Taking into account that we obtain 1.326 nm^3 of gas from 1 kg of coal using steam-oxygen technology, then the cost of 1 m^3 of synthesis gas is:

$$z = \frac{1.055}{1.326} = 0.79\,\text{rub./m}^3 \text{ of } synthesis\ gas.$$

The cost of 1 t of SLF at required consumption of 5000 m^3 of gas mixture per 1 t of the product is:

$$sgt = 0.79 \cdot 5000 = 3950\ \text{руб./Т}.$$

Generalized results of calculations are presented in Table. 2.

The theoretical yield of gas (Table 1) for the steam technology is significantly higher than for the steam-oxygen. When the certain conditions of gasification process are achieved, we can significantly reduce the difference in the costs of producing one ton of SLF by two considered technologies due to increasing the amount of synthesis gas obtained by the steam technology of up to 9 m^3/kg and more. This can be achieved by using the fluidized bed gasifiers, where heat and mass transfer is more intense than in a dense layer (compared with the results shown in Fig. 2).

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