Justification of the efficiency of the application of the preliminary processing of the components structure of artificial liquid fuel

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Abstract. In the conditions of tougher environmental requirements for the operation of energy facilities for the regions of the Russian Federation in which solid fuels are competitive with other types of fuels, or have no alternative, the use of artificial fuels derived from coal becomes relevant. One of the types of such artificial fuels are artificial composite liquid fuels. To increase the energy, economic and environmental characteristics, prior to the process of obtaining artificial composite liquid fuels, preliminary preparation of the fuel component composition is required. The article presents the calculated work on the evaluation of the effectiveness of the preliminary preparation of the component composition for the production of artificial composite liquid fuels. The efficiency of the use of coal enrichment processes, the preparation of the water component, and the variation in the content of components in the final product of an artificial composite liquid fuel are considered. The assessment was carried out according to the change in the lower heat of combustion of the resulting fuels to the working and dry ash-free mass, as well as the cost of the fuels.

1. Introduction

In modern conditions of the use of fuel and energy resources and the tendency of tightening environmental requirements for energy facilities, the use of environmentally friendly fuel in thermal power plants (TPPs) is gaining wide popularity. There is a global trend to reduce the use of coal in thermal power plants as the main fuel and replace it with environmentally friendly fuels, such as natural and artificial gas. The experience of a number of countries, such as Great Britain, Germany, Poland, which either completely abandoned the direct combustion of coal at TPPs or reduced its component, is indicative [1, 2]. Coal generation of the Russian Federation (RF) along a similar development path cannot go in view of the presence of a large amount of solid fuel reserves concentrated in the territory of the Russian Federation [1–4], as well as in the presence of regions of the Russian Federation in which the use of natural gas is difficult due to its low competitiveness [5, 6]. Thus, the future development of Russian coal mining should be related to the implementation of technological and construction solutions that allow to reduce the negative impact on the environment during the operation of TPPs on the one hand and save or reduce the minimum energy potential of the coal fuel used on the other hand. One of such solutions can be the use of processes of energy-technological processing of solid fuels –
gasification, pyrolysis, enrichment, briquetting and the production of artificial composite fuels (ACF). Depending on the type of process used, the resulting fuel product in comparison with the initial solid fuel may have one or a number of the following advantages: lower sulfur content and/or ash per working mass of fuel; reduced toxic emissions during combustion; high calorie (heat of combustion); smaller amount of generated waste during combustion, etc. Coal and its derivatives (coal fines, screenings, coke, off-grade coal) of any quality and any coalification stage can be used as the initial fuel for energy technological processing. This will allow a more capacious exploitation of the fuel and energy resources available to the RF.

In connection with the above, the use of fuel mixtures and artificial composite fuels at power facilities as the main fuel will play an important role. Artificial composite fuels can be divided into artificial composite solid fuels and artificial liquid composite fuels. Artificial composite liquid fuels, depending on the composition, can be “two-phase”, “three-phase”, etc. The largest number of studies related to artificial composite liquid fuels on the territory of the Russian Federation and in the world as a whole is devoted to the “two-phase” artificial composite liquid fuels – coal-water fuel, which is a coal-water suspension, the percentage of coal up to 60 – 70%, 29 – 40% and, in most cases, a chemical stabilizing additive (plasticizer) up to 1%. The most detailed description of the list of studies on water-coal fuel is given in [7–16]. In modern conditions, in the process of producing coal-water fuel, special attention should be paid to the preparation of the component composition of the coal-water slurry, which should provide: minimal reduction in caloric content of fuel (compared to initial coal); environmentally friendly combustion of coal-water fuel; maintenance of acceptable parameters of rheological properties of coal-water fuel (stability, dynamic viscosity), allowing its operation at power facilities of various capacities.

2. Preparation of component composition of water of coal fuel

2.1. Preparation of solid fuel to produce coal water.

In early research and development on the water of coal fuel, its preparation is considered as a method for the utilization of dispersed coal slurries – wastes of enrichment processes, hydraulic extraction and hydrotransportation of coal from the mine, and then as a method for producing hydrocarbon liquid fuel from conditioned ordinary coal [7]. In the context of toughening of environmental requirements for energy facilities and to increase the competitiveness of fuels derived from coal, the coal component of the fuel composition should be refined before the coal fuel preparation is prepared, that is, the sulfur and ash content of the working mass should be reduced by using enrichment processes. The use of such a technology is described in [7–11, 14]. From the preparation of the coal component, the water of the coal suspension, first of all, depends on ensuring the requirements for minimizing the reduction in the caloric content of the fuel product, the ecological compatibility of its combustion and the achievement of acceptable rheological properties.

Norms and ways to achieve standards for stability and dynamic viscosity of coal water are given in [7, 8]. Depending on the type of energy object, the value of dynamic viscosity of coal water must be ensured: for coal-fired TPPs not more than 1.0 Pa·s; for boiler houses - no more than 0.6 Pa·s [7, 8]. These values are provided by the content of the "fine" fraction in the coal component of the fuel - the fineness of coal grinding.

To change the elemental composition of fuel in order to minimize the heat of combustion, artificial composite liquid fuels and to reduce the negative impact on the environment when coal water is burned, the process of coal enrichment is intended. The enrichment process is efficiently applied to fuels, with more than 0.06 (% * kg) / MJ of sulfur characteristics, ash content greater than 0.75 (% * kg) / MJ, that is, for solid fuels with medium and high sulfur content and ash content [17, 18]. There are several methods of solid fuel enrichment that can be divided into gravity methods, flotation methods, magnetic methods, electrical methods, oil agglomeration methods and special enrichment methods [22–25]. The most common for coal enrichment are gravity methods: jigging, enrichment in a heavy-weight suspension, in separators of screw, cone, counterflow type, and enrichment in hydrosayers. These processes have a high productivity of concentrating devices, a simple device of the production complex,
a relatively cheap cost and high efficiency of separation of mineral mixtures [23–25]. Gravitational and flotation methods of enrichment make it possible to reduce the value of the working ash content of the elemental composition of coal to 5% minimum [10, 11], however, the depth of demineralization depends on a number of factors, and primarily on the composition of the initial fuel. The method used for calculating the depth of demineralization of the initial solid fuel is presented in [19–22].

2.2. Preparation of water and aqueous solutions for the preparation of coal water.

With regard to the preparation of the water component for the production of coal water, there are studies on pretreatment of water to improve the favorable conditions for the formation of a suspension. In particular, in [13], application of a cavitation rotor-impulse device allowing more deeply interacting with water and coal particles and simplifying the technology of water preparation of coal suspension in the part of cavitation and homogenization is noted. The resulting fuel has a higher stability value without the conditions for additional use of plasticizers.

In [23], special features of the application of NaOH plasticizers are noted, which create an alkaline medium in the aqueous solution being treated, which leads to an improvement in the conditions for obtaining water, coal suspension.

In the framework of experimental work [24], the filtrate after Na-cationite filters had pH values of the order of 8.4–8.9. The use of water with such pH values will undoubtedly have a positive effect on the formation of the suspension and will increase the stability value of the resulting fuel product. It is possible to consider the use of Na-cation-exchange filters as pretreatment of water before using it to create coal water from a technological and economic point of view.

In a number of works [7, 9, 11, 14] it is noted that it is possible to use water of various types of water to create water from coal, from surface water to wastewater from industrial facilities without preliminary preparation. However, the peculiarities of the influence on the heat of combustion of the resulting water of coal fuel as a result of the use of these waters in these works have not been noted.

3. Influence of preliminary preparation of components on calorific

In the context of tightening of environmental requirements for power facilities of the Russian Federation, the thermal power station is becoming of great importance for the technology of reducing the amount of waste water. There are works on this subject, whose task is to reuse wastewater at power facilities [25]. One of the possibilities of using wastewater is their use to create energy fuels, in particular, artificial composite liquid fuels.

Within the framework of the presented work at the departments of Theoretical Foundations of Heat Engineering named after M.P. Vukalovich (TOT) and TPP NIU "MPEI" considered the possibility of using different types of water and aqueous solutions for the preparation of coal water. The task of the study was to determine the effect on the caloric content of coal water using various, in composition of impurities, water as an aqueous component. For this purpose, the following types of waters were considered in this paper: water from a surface source; water after the pre-treatment stage of the water treatment plant (sequential bleach and mechanical (clarifying) filters); water, past pre-treatment stages and Na-cation exchanger filters of the water treatment plant; water, past pretreatment stages, H-cation and OH-anion exchanger filters of the water treatment plant; waste water from the objects of ferrous metallurgy, non-ferrous metallurgy, chemical industry, pulp and paper industry, petrochemical and oil refining industry; domestic wastewater; Wastewater from energy facilities. The types of waste water considered refer to the industries of greatest water consumption [25]. The types of surface waters and partially demineralised water allow us to evaluate the feasibility of preliminary preparation of the water component to create coal water.

Calculations have been carried out for the coals of the Cheremkhovsky and Pechorskoye deposits and the types of waters listed above, which resulted in lower calorific values for the working and dry ash-free mass. The main characteristics of the initial coals are given in table 1.

In accordance with the calculations, the total salt content of the water component for the lower heat of combustion of coal water was estimated. As a result, it was found that when the total salt content is
changed by 140 g/dm³, the net calorific value for the working mass of the produced fuel changes by 9–10 kJ/kg, and the lowest heat of combustion for dry ash-free mass remains practically unchanged. Thus, the results of the calculation confirm that it is possible to use different types of water with a range of total salt content up to 140 g/dm³ to create coal water, without significantly affecting the calorific value of this fuel.

Table 1. The main characteristics of the initial coals used in the work.

| Fuel deposits     | Elementary composition of fuel for the working mass, % | Coefficient of grindability | The lowest heat of combustion of fuel for the working mass, MJ/kg |
|-------------------|--------------------------------------------------------|----------------------------|---------------------------------------------------------------|
|                   | C’  | H’  | S’  | N’  | O’  | A’  | W’  |                               |                               |
| Cheremkhovskoye   | 50.0 | 3.7 | 1.0 | 1.0 | 8.8 | 21.5 | 14.0 | 1.4                          | 19.5                          |
| Pechorskoye       | 59.6 | 3.8 | 0.8 | 1.3 | 5.4 | 23.6 | 5.5  | 1.5                          | 23.7                          |

In [26, 27], technologies for creating a "three-phase" artificial composite liquid fuels are described, the main components of which are coal, water and products of oil refining (fuel oil, diesel fuel, used oils). One of the most important tasks of creating a "three-phase" composite fuel is to increase the reactivity of artificial composite liquid fuels. The ignition temperature of coal water is 450–650 °C [8], which causes certain difficulties at the stage of ignition of fuel. One solution to this task, as well as to increase the net calorific value of combustion of artificial composite liquid fuels, is to inject into fuel as a component of the petroleum products listed above.

In the next part of the work, the most optimal ratio of components (coal-water-oil products) was selected to create a "three-phase" artificial composite liquid fuel. Controlled calculation parameters were the calorific value of the fuel produced and its cost.

"Three-phase" artificial composite liquid fuels consisting of components - coal, water and oil products, can be obtained by preparing a suspension of raw coal, fuel oil and water; by preparing a slurry from the raw coal and "oil water" (a solution extracted from oil wells with a component composition of water: petroleum products of 92:8); by preparing a slurry from the raw coal and waste water containing petroleum products.

In the presented work, artificial composite liquid fuels were obtained by preparing a suspension of coal, water and fuel oil. The main characteristics of the fuel oil M-100 used in the work are presented in Table 2.

Table 2. Main characteristics of M-100 fuel oil.

| Fuel oil grade | Elementary composition of fuel for the working mass, % | The lowest heat of combustion of fuel for the working mass, MJ/kg |
|----------------|--------------------------------------------------------|---------------------------------------------------------------|
| M-100          | C’  | H’  | S’  | N’  | O’  | A’  | W’  |                               |                               |
|                | 87.32 | 11.90 | 0.40 | 0.10 | 0.10 | 0.03 | 0.15 | 39.5                          |                               |

As a coal component, artificial composite liquid fuels, the coal of the Pechora deposit was used, before and after the enrichment process. Based on the results obtained, the graphical dependence shown in figure 1.

Further calculations were carried out proceeding from the requirements of reducing the concentration of petroleum products in the composition of the obtained artificial composite liquid fuels, which allowed to significantly reduce the cost of the fuel produced, as well as to reduce the negative impact on the environment and boiler equipment when burning this fuel (by minimizing the content of unstable compounds included in the composition of fuel oil). The calculations used artificial composite liquid fuels of two types: the first type of artificial composite liquid fuels composition – 50%, fuel oil – 20%,
water – 30%; the second kind of artificial composition liquid fuel composition of coal – 60%, fuel oil – 10%, water – 30%.

Figure 1. The lowest heat of combustion on the working mass of artificial composite liquid fuels, depending on the ratio of fuel components when using the original coal. The graph in shown blue line are 20% water content, orange line are 30% water content and silver are shown as 40% of water content.

In figure 2 shows the lower calorific values derived from the calculation for the considered types of artificial composite liquid fuels, when used as components for their production of raw and enriched coals, as well as the heat of combustion of the initial and enriched coals.

Figure 2. Lower heat of combustion of fuels.
1 – lower heat of combustion of the initial coal; 2 – the lowest heat of combustion of coal after enrichment; 3 – lower heat of combustion artificial composite liquid fuels composed of 50% coal, 20% fuel oil, 30% water; 4 – lower heat of combustion artificial composite liquid fuels composed of 50% enriched coal, 20% masut, 30% water; 5 – lower heat of combustion artificial composite liquid fuels composed of 60% coal, 10% masut, 30% water; 6 – lower heat of combustion artificial composite liquid fuels composed of 60% enriched coal, 10% masut, 30% water.
In figure 3 shows the cost for the two types of artificial composite liquid fuels, M-100 black oil, the initial coal of the Pechora deposit and the same coal after the enrichment process.

![Figure 3. The cost of a ton of fuel.](image)

1 – The cost of fuel oil; 2 – cost of initial coal; 3 – the cost of coal after enrichment; 4 – the cost of artificial composite liquid fuels composed of 50% coal, 20% fuel oil, 30% water; 5 – the cost of artificial composite liquid fuel composition 50% enriched coal, 20% fuel oil, 30% water; 6 – the cost of artificial composite liquid fuel composition 60% coal, 10% fuel oil, 30% water; 7 – the cost of artificial composite liquid fuels composed of 60% enriched coal, 10% masut, 30% water.

4. Conclusions

The choice of the optimum composition for obtaining artificial composite liquid fuels using coals of the Cheremkhovo and Pechora basins was made in the work;
calculations were carried out to determine the lowest heat of combustion for the working and dry ashless artificial composite liquid fuels;
shows the effectiveness of the use of preliminary preparation of the coal component in the form of coal enrichment processes with subsequent use of it in the creation of artificial composite liquid fuels;
heat of combustion artificial composite liquid fuels after the process of enrichment of the coal component is increased by 1.12 times, the cost increases by 1.75 – 2.33 times;
the highest caloric value obtained is the artificial composite liquid fuels below the calorific value of fuel oil M-100 by 1.84 times;
the possibility of using an aqueous component to create artificial composite liquid fuels with a total salt content of not more than 140 g / dm³ is shown. At the same time, the change in the net calorific value for the working mass of the produced composite liquid fuels is no more than 9 kJ / kg.

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