Development of a system of energy technological processing of coal deposits for energy and other industries

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Abstract. In connection with the forthcoming toughening of environmental requirements, including during the operation of energy facilities, as well as in order to more fully use the resources of the fuel and energy complex and mineral deposits in the Russian Federation, it is proposed to review the principles of developing coal deposits and preparing energy coal and other resources coal deposits for burning at thermal power plants. The main resources of coal deposits considered in this work are steam coal and mine gas, which is present in most coal deposits of the Russian Federation. The gas content of coal seams can reach 35 m³ in terms of 1 ton of dry ashless coal mass. Direct coal combustion at thermal power plants leads to the formation of a large number of emissions of substances that negatively affect the environment. The main emissions from coal flaring are fly ash and slag, toxic sulfur and nitrogen oxides, carbon monoxide and carbon dioxide. The following technologies are used to reduce the amount of these substances in the flue gases: wet and dry scrubber systems, the organization of fuel combustion, aimed at reducing toxin emissions (in particular nitrogen compounds), the use of various types of filters to clean flue gases from volatile ash and slag particles and etc. To increase the effectiveness of the fight against toxic and polluting emissions, the team of authors proposes to use solid fuel pre-processing as part of the operation of the energy technology plant together with the used cleaning systems. The type of energy technology plant, depending on the tasks to be solved within the development region, can be different. To implement the processes of energy technological processing and in the framework of reducing effluents from energy facilities, the issue of the reuse of highly mineralized, oil-contaminated and oiled wastewater from thermal power plants and highly mineralized wastewater from coal deposits, as well as the reuse of spent TPP lubricants in the plant cycle, is being considered. To increase the calorific value of the synthetic gas produced in the plant’s cycle, the issue of its joint combustion with purified mine gas produced in the coal field under development is considered. Mine gas is also cleaned in the plant cycle.

1. Introduction

In the year of the centenary of the GOELRO plan, it is important to pay attention to fuel and energy resources, which were considered as the main "energy force", which was laid for the implementation of the plan. The main fuel and energy resources in the development of the plan were coal, peat, oil, gas, firewood, water energy. Coal was considered as the main fuel resource [1]. After a hundred years, the list of fuel resources of the energy sector of the Russian Federation (RF) has not changed significantly - the nuclear energy industry has been added, however, the ratio of the volumes of fuel resources use has changed dramatically. At the beginning of 2016, the main energy facilities that
receive electric energy, in general, on the territory of the Russian Federation are gas-fuel oil thermal power plants (TPPs). On the territory of the RF, about 70% of electricity is generated at TPPs [2].

As of January 1, 2016, various types of thermal power plants were operating in the RF:

- fuel for which is gas and fuel oil - 1510 objects;
- fuel for which are various types of solid fuel - 739 objects [3].

Both in Russia and in the world as a whole, there is a tendency to reduce the share of coal use as energy fuel [4]. This is primarily due to the complexity of the operation of solid fuels, in comparison with other fuel and energy resources, and environmental problems that arise during the extraction, transportation, storage and burning of coal [5].

When coal is used as fuel for TPPs, significant emissions of sulfur oxides (SO\(_2\)), nitrogen (NO\(_x\)), carbon monoxide and carbon dioxide, solid volatile ash particles, slag and unburned fuel [4 - 6] are formed. Particularly serious damage to the environment is caused by volatile solid particles of pollutants.

However, at present, coal remains the main fuel for TPPs in a significant territory of the RF. According to research by the Institute of Natural Monopoly Problems (INMP) in Siberia and the Far East, coal generation is competitive with gas generation or has no alternative [4, 5, 7]. In addition, the INMP predicts an increase in the installed capacity of coal generation in the regions of Eastern Siberia and the Far East due to an increase in demand for electric energy, however, in the whole country, a reduction in the capacity of coal generation to 30.2 GW by 2030 is possible [7].

According to the data of the Central Dispatch Department of the Fuel and Energy Complex (CDU TEK) for 2018, 439.3 million tons of coal were mined in the RF, which is 28.1 million tons more than the production in 2017. When analyzing the data of the CDU TEK from 2011 to 2018, coal production in the RF increased. Moreover, export demand for high-quality Russian coal has increased from a number of countries, such as China, India, Mongolia and others [8, 9].

In 2015, the volume of coal consumption in the RF, taking into account imports, amounted to 197.5 million tons. The presented value of the volume consists of consumption: thermal energy facilities in the amount of 114.2 million tons; coke plants in the amount of 36 million tons; a population of 23.4 million tons; other consumption (metallurgical and cement plants, Russian Railways, etc.) in the amount of 23.9 million tons [8]. Thus, the main consumers of coal in the Russian Federation are energy facilities, coke plants and the population.

In view of all of the above, the conclusion suggests itself that in the near future a complete rejection of Russian coal generation, similar to the British scenario [4, 5], will not take place.

Moreover, there is a tendency to increase absolute indicators of the volume of coal production in Russia. In this regard, an important area of coal generation in the RF is the search for solutions to problems associated with environmental pollution when using solid fuel. How to solve the environmental and operational problems identified above when using solid fuels?

### 2. Systems for cleaning flue gases from harmful emissions

To solve environmental problems arising from the burning of solid fuels, it is possible to use systems for cleaning from harmful emissions of flue gases. Tables 1 - 3 provide a list of the main ways to deal with harmful emissions of flue gases and evaluate the effectiveness of their use.

In addition to the presented methods for solving environmental problems, there is the possibility of preliminary preparation of solid fuel before burning it, the essence of which is the deep energy-technological processing of coal to produce products that differ from the original fuel in their energy and environmental indicators. These products can be presented in solid, liquid, gaseous state of aggregation and, in essence, are artificial fuels.
Table 1. Methods for cleaning exhaust gases from suspended particulate emissions

| Cleaning Method   | Particle Size (μm) | Cleaning Efficiency (%) |
|------------------|--------------------|-------------------------|
| Precipitation chamber | 100                | 40–50                   |
| Cyclone          | 30                 | 50–60                   |
| Multicyclone     | 10–15              | 90–95                   |
| Fabric filter    | 0,5                | до 99                   |
| Scrubber         | 0,5                | 75–85                   |

Table 2. Methods for flue gas desulfurization

| Multiplicity of reagent use | Degree of capture | Aggregate state of reagent and waste |
|-----------------------------|-------------------|--------------------------------------|
| Regenerative (reusable)     | Small (10-35%); Medium (35-70%) | Dry (reagents and waste in a dry state); Wet-dry (reagents in a liquid state, waste in a dry state) |
| Non Regenerative (Single Use) | Medium (35-70%); High (over 70%) | Wet-dry (reagents in a liquid state, waste in a dry state); Wet (reagents and waste in suspension or solution) |

Table 3. Methods of suppressing the formation of nitrogen oxides

| Technological events                     | NOx reduction efficiency (%) |
|------------------------------------------|------------------------------|
| Low fuel surplus fuel combustion         | up to 33 %                   |
| Flue gas recirculation                   | up to 33 %                   |
| Non-stoichiometric fuel combustion       | up to 35–40 %                |
| Multi-stage fuel combustion              | up to 35–40 %                |
| Use of low NOx burners                   | up to 60 %                   |
| Injection of water (or a water-oil emulsion) into the core of the torch | up to 25–44 %                |
| Combined method                          | up to 90 %                   |

3. Integrated use of coal deposits.
For the effectiveness of the application of deep energy technological processing methods, the development of a coal deposit is most correctly considered in the complex. Figure 1 shows the technological scheme using the products of a coal deposit in the processes of deep energy technological processing - in the cycle of the energy technological plant (ETP). The products received at the ETP are focused on use at energy facilities (TPPs, IES, etc.)

Coals of a developed coal field, mine gas present in varying amounts in this field, as well as wastewater generated during the development of the coal field under consideration are considered as raw materials for ETP systems.
The extracted coal, depending on the brand, can be either energy or coking, that is, it can be a raw material for energy facilities, or coke plants. In addition, in the present work, it is proposed to consider coal as a source of rare and dispersed elements. In addition, in the present work, it is proposed to consider coal as a source of rare and dispersed elements. Coals contain small amounts of a very large number of rare, scattered elements, non-ferrous metals and radioactive elements [10, 11].

A study of their distribution in solid fuels revealed a series of decreasing affinities for organic matter [10, 12]:

\[
\text{Ge} > \text{W} > \text{Ga} > \text{Be} > \text{Nb} > \text{Sc} > \text{Y} > \text{La} > \text{Zn} > \text{Pb}
\]

Where the elements to the left of Nb in most cases, after the enrichment process, fall into coal concentrate, and Nb and all other elements into mineral waste. To isolate the coal mass, from which, during subsequent processing, rare and dispersed elements can be extracted, the density of the separation (heavy) medium of the gravity enrichment process should be reduced to values of the order of 1200 kg/m³.

Figure 1. The technological scheme of the integrated development of a coal field using ETP processing cycles.

1 - coal deposit; 2 - site enrichment of the first stage; 3 - node receiving ACLF (WCF); 4 - gasification unit; 5 - system for purification and processing of mine gas; 6 - a system for extracting rare and trace elements; 7 - TPP; 8 - extracted elements; 9 - node enrichment of the second stage; A - mine gas; B - refined mine gas; C - waste water from coal deposits; D - wastewater TPP; E - spent lubricants TPP; F - coal; G - intermediate product and waste of the first stage of enrichment; H - selected rare elements; I - an intermediate product of the first stage of enrichment, after node 6; J, K, L - coal concentrate after the second stage of enrichment; M - coal concentrate after the first stage of enrichment; N - ACLF (WCF); O - synthetic (generator) gas.

The task can be achieved by using underground natural sodium chloride brines as a separation medium, the density of which reaches an average of 1160 - 1180 kg/m³. It is proposed to implement such technology at the first stage of enrichment of the technological scheme of ETP (Figure 1). The concentrate after the first stage of enrichment enters the unit for the preparation of artificial composite liquid fuel (ACLF) (or, depending on the initial components, the unit for the preparation of water-carbon fuel (WCF)), and then the resulting fuel is subjected to gasification. Synthetic gas obtained after gasification, which is an environmentally friendly fuel, is used as a starting fuel at an energy
facility. The advantages of the developed scheme are considered in detail in [4, 5]. Wastes (or an intermediate product) of the process of the first stage of enrichment are further processed in order to extract rare and trace elements. After extraction, the coal mass is re-enriched in the second stage, where both traditional magnetite and water-sand suspensions [13] and natural calcium chloride brines having a density of the order of 1300 - 1400 kg/m³ can be used as a separation medium. The obtained coal concentrate after the second stage of enrichment can be used as energy fuel for thermal power plants, as well as feedstock at the sites for the preparation of ACLF and gasification.

The mine gas extracted at the field is subjected to purification, after which it can be used as the main fuel at low-power energy facilities, or as a component of the fuel mixture intended for combustion at thermal power plants. Mine gas cannot be used as the main fuel for high power TPPs due to the low gas content of coal seams (on average about 35 m³ per 1 ton of dry ashless coal mass) [14]. Wastewater generated in large quantities in coal deposits is considered in the present work as a component of ACLF. In the same way, it is possible to deal with waste water and spent lubricants of TPPs. In the same way, it is possible to deal with waste water and spent lubricants of TPPs. Moreover, the high content of mineral impurities in the wastewater of a thermal power station and a coal field will not significantly affect the calorific value of the obtained ACLF. The change in calorific content of ACLF with an increase in total salinity by 140 g/dm³ does not exceed 9 kJ/m³ [15 - 18].

4. Conclusions
In this paper, the issue of the competitiveness of coal generation in the Russian Federation relative to other fuel generations of the Russian Federation is considered.

The ways of solving environmental problems arising from the extraction and use of coal fuel are presented.

Ways of solving the problems of resource conservation in relation to minerals mined in coal deposits are presented.

The general technological scheme of ETP as an element of a coal deposit and the ways of its functioning in terms of interaction with thermal power plants is considered.

The possibility of reuse of wastewater from coal deposits and thermal power plants, and the possibility of utilizing waste lubricants of thermal power plants are considered.

The use of ETP will allow solving environmental problems arising from the operation of coal as energy fuel at thermal power plants, as well as ensuring the full use of valuable resources of coal deposits.

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