Application of the underground natural brines for energy coal enrichment

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Abstract. As part of the development of coal generation in the Russian Federation, one of the important issues is the use of enrichment processes for thermal coal. There are a large number of mineral processing methods, namely: gravity processing, flotation processing, methods of magnetic and electrical processing, as well as special processing methods, from which there are: radiometric, chemical and mechanical methods of coal preparation. Based on the results of an economic evaluation of existing enrichment methods, the team of authors identifies the gravity enrichment method as the most applicable method for thermal coals in view of the low cost of the resulting coal concentrate during its implementation. Among the existing methods of gravitational enrichment, one can distinguish enrichment in a heavy medium, as the most easily implemented, and again, the cheapest of all existing methods of gravitational enrichment. In industry, magnetite and water-sand suspensions are most often used as a heavy medium. The advantage of using these difficult media is the depth of the enrichment process - the output of coal concentrate and the amount of valuable rock recovered (combustible part of the fuel). The downside is the difficulty in operation - the suspensions must be homogenized, and the contamination of the resulting coal concentrate with weighting particles (magnetite or sand), which reduces the amount of valuable rock. It is proposed to solve this problem by using sodium chloride and calcium chloride as a natural medium in underground brines. According to the results of the work, the main indicators of the enrichment processes are estimated when using brines as a dividing medium.

1. Introduction.
In connection with the increasing demand for high-quality coal, in particular, the export of Russian coal to countries such as China, India and others, the urgent issue is to obtain high-quality coal as a result of mining and (or) processing of the initial coal resource. In recent years, according to the Ministry of Energy of the Russian Federation (RF), there has been an increase in the number of coal mines entered into operation in the territory of the Russian Federation. This is done to ensure the implementation of the project for the widespread use of enrichment processes in order to improve the quality of coal used (increase calorie content, lower components of external ballast), both energy and coking. There is a need for quality improvement for all types of coal, since according to data for 2015, the volume of coal consumption in the Russian Federation, taking into account import supplies, amounted to 197.5 million tons. The presented value of the volume consists of consumption: thermal power plants (TPPs) 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 in the amount of 23.9 million tons [1]. Energy
coals are called coals, which can be used as energy fuels at energy facilities of small, medium and high power. Coking coals are coals of the middle stage of coalification, from which lump coke is obtained from industrial coking. The fundamental difference between thermal coals and coking coals is characterized by a technological indicator of sintering, namely, the value (y, mm) of the plastic sintered layer, determined according to GOST 1186-2014 [2].

In the framework of the presented work, the team of authors set the task to work out methods for the enrichment of thermal coal with new process conditions.

2. The choice of the enrichment process.
The enrichment methods are diverse and classified according to the various properties of the coals used as a separation feature and the separation forces. The following enrichment methods are distinguished:

- Gravity enrichment is based on the difference in the densities of the separated grains of minerals. It is carried out in the field of gravitational forces;
- Flotation concentration or flotation is based on the difference in physicochemical properties (wettability) of the separated minerals;
- Magnetic enrichment is based on the difference in the magnetic susceptibility of the shared minerals. It is carried out in the field of magnetic forces;
- Electrical enrichment is based on the difference in electrical conductivity of the shared minerals. It is carried out in the field of electric forces;
- Special enrichment methods are based on differences in the combination of properties of the shared minerals. Special enrichment methods include:
  - Radiometric enrichment, based on the difference in the radiospectroscopic properties of the shared minerals;
  - Chemical enrichment, based on the difference in chemical properties (solubility) of the shared minerals;
  - Mechanical enrichment is based on the difference in physical and mechanical properties (mechanical strength, shape, friction, rebound elasticity) of the shared minerals [3, 4].

It is believed that the most acceptable methods for the enrichment of steam coal are gravity and flotation methods of enrichment [5 - 8]. However, at the first stage of work, the team was given the task of evaluating the application of all types of enrichment processes presented from an economic point of view and choosing the least costly method for its subsequent implementation.

Schemes for enrichment units were developed, including preliminary, main, and auxiliary enrichment processes. The schemes were developed taking into account the requirements for the implementation of enrichment processes to the source coal, as well as taking into account the requirements for the final product. The maximum cost per tonne of coal concentrate produced by the above methods was estimated. It amounted to: for gravitational enrichment - 59.25 rubles/ton; for flotation concentration - 69.68 rub/t; for magnetic enrichment - 79.98 rub/t; for electric enrichment - 81.08 rub/t.

The gravitational enrichment method was chosen as the least expensive method, the maximum cost of which amounted to 59.25 rubles per ton of produced coal concentrate.

At the second stage of choosing the enrichment method, a comparison was made between varieties of gravitational enrichment. The following varieties of methods of gravitational enrichment of coal:

- Enrichment in heavy media is the process of gravitational enrichment in liquids and suspensions having an intermediate density between the densities of the separated solid particles, carried out in gravitational and (or) centrifugal fields. The enrichment processes in heavy media are implemented in separators of cone, drum, trough, combined and cyclone type.

  - Coal enrichment by depositing is an enrichment method based on density separation of a mixture of mineral grains on a sieve under the influence of a water stream pulsating at an alternating speed relative to the sieve. The processes of enrichment of coal by depositing are implemented in depositing machines.
Enrichment in a water stream on an inclined plane is the process of gravitational enrichment in a thin layer of water flowing along a slightly inclined deck performing reciprocating movements in a horizontal plane perpendicular to the direction of water movement. This type of enrichment is implemented on concentration tables and screw separators and locks [3, 4].

The results of calculating the maximum cost of various methods of gravitational enrichment are shown in table 1.

| Enrichment method                                      | Cost price, rub/t |
|--------------------------------------------------------|-------------------|
| Coal beneficiation in heavy media                      |                   |
| Trough separator                                       | 55,82             |
| Drum separator                                         | 56,50             |
| Cone separator                                         | 57,22             |
| Coal dressing                                          |                   |
| Jigging machine                                        | 59,25             |
| Concentration in a stream of water on an inclined plane |                   |
| Screw separator                                        | 58,26             |
| Concentration table                                    | 56,46             |
| Enrichment in countercurrent apparatus                 |                   |
| Horizontal screw separator                             | 57,97             |
| Steeply inclined separator                              | 57,38             |

According to the results of the comparison, the least costly was gravitational enrichment in heavy media using a trough separator. The cost of this method amounted to 55.82 rubles per ton of coal concentrate produced.

Thus, according to the results of economic analysis, for the subsequent implementation, the gravitational enrichment method in heavy media using a trough separator was chosen as the least expensive.

3. The use of harsh environments.

In the coal industry, for enrichment processes as a separating heavy medium, magnetite suspension and water-sand suspension are most widely used. Their density is about 1300 - 1600 kg/m³, depending on the concentration and characteristics of weighting particles (magnetite and sand) [3, 4]. The advantages of using magnetite and water-sand suspensions as a heavy medium are the depth of coal enrichment (yield of coal concentrate and the amount of valuable rock recovered), variability of the density of the separation medium. Among the problems of using magnetite and water-sand suspensions, one can name difficulties during operation (constant homogenization of the suspension is required), contamination with coal concentrate weighting particles.

To solve the above problems, it was proposed to use highly mineralized solutions, namely, underground natural brines, as a separating heavy medium. On the territory of the Russian Federation there are two main types of underground natural brines - underground natural chloride sodium brines and underground natural calcium chloride brines.
Calcium chloride brines have a density of 1160 - 1180 kg/m³, and are not suitable for full deep enrichment, however, for the extraction of coal concentrate, which can be used as energy fuel, and also for the separation of coal mass from which rare valuable chemical elements can be extracted and then send to the stage of deeper enrichment, they are suitable.

Since rare and scattered elements are distributed in the coal mass with a density of 1200 kg/m³ or more [9]. For the same purposes as underground natural sodium chloride brines, the high-saline wastewater of TPPs, namely, effluents after a Na-cation filter having a density of the order of 1120–1160 kg/m³, are studied in the present work [10].

For deeper enrichment (the second stage of enrichment), the team of authors proposes to use natural underground calcium chloride brines, the density of which is about 1300 - 1400 kg/m³.

In the experimental work, the task was set to determine the main characteristics (such as enrichment efficiency, recovery, concentration, reduction) of the enrichment processes using underground natural chloride calcium brines and highly mineralized wastewater from thermal power plants as a separation medium.

4. Characterization of enrichment processes.

When calculating the values of the characteristics of the beneficiation processes, it is required to determine the amount of valuable rock of the obtained coal concentrate, the waste of the beneficiation process and the source coal. To do this, in laboratory conditions, the ash content in the samples of coal mass (in coal concentrate, in waste, in the initial coal) is determined, and then, according to the data obtained, the amount of valuable rock is calculated using the following expressions

\[
\alpha = 100 - A_i^d., \\
\beta = 100 - A_k^d., \\
\theta = 100 - A_o^d.
\]

Where \( \alpha, \beta, \theta \) – the content of valuable rock, respectively, in the source coal, concentrate and waste, %; \( A_i^d, A_k^d, A_o^d \) - ash content, respectively, in the initial coal, concentrate and waste, %.

For conducting experimental studies, the types of energetic coals B2 and DP were used as initial coal, which varied during the size studies (coal particle sizes were 500 μm and 1.5 mm). These coal grades were chosen to demonstrate the feasibility of using the test separation medium, both on brown coals and on fossil fuels.

Table 2. Efficiency of coal enrichment processes using highly mineralized solutions as a heavy medium

| Grade of coal, particle size | The efficiency of the enrichment process, % |
|-----------------------------|----------------------------------------------|
| Underground natural sodium chloride brine with a density of 1160 kg/m³ | |
| B2 brand coal, size 500 microns | 30,68 |
| DP brand coal, size 500 microns | 47,45 |
| B2 brand coal, size 1.5 mm | 54,40 |
| DP brand coal, size 1.5 mm | 31,37 |
| | |
| Underground natural sodium chloride brine with a density of 1165 kg/m³ | |
| B2 brand coal, size 500 microns | 36,16 |
| DP brand coal, size 500 microns | 43,14 |
| B2 brand coal, size 1.5 mm | 50,44 |
| DP brand coal, size 1.5 mm | 32,16 |
| | |
| Wastewater after regeneration of Na-cation exchange filters with a density of 1125 kg/m³ | |
| B2 brand coal, size 500 microns | 36,48 |
| DP brand coal, size 500 microns | 43,53 |
| B2 brand coal, size 1.5 mm | 43,80 |
| DP brand coal, size 1.5 mm | 58,04 |
In the experimental work, underground natural sodium chloride brines with a density of 1165 kg/m$^3$ and 1160 kg/m$^3$, as well as wastewater after regeneration of Na-cationite filters with a density of 1125 kg/m$^3$, were used as a separating heavy medium. Ash content was determined according to GOST R 55661-2013 [11].

The values of the efficiency parameter of the enrichment process, obtained by the results of experimental and subsequent calculation work, are presented in Table 2. The obtained values of the efficiency of the studied enrichment processes according to the classification presented in [3, 4] exceed 25%, which means that the use of the proposed separation medium is advisable. Moreover, a number of obtained values of the efficiency of the enrichment process exceeds 50%, that is, it is considered effective.

5. Conclusions

Based on the research results, it can be concluded that it is advisable to use natural underground chloride sodium brines as a separating heavy medium for enrichment processes (the parameters of the enrichment process efficiency vary from 31.37 to 54.40 %).

It is also advisable to use highly mineralized wastewater from thermal power plants with increased density as a separation medium for enrichment processes (the parameters of the efficiency of enrichment processes range from 36.48 to 58.04%).

Coal mass, which did not enter the coal concentrate after the enrichment processes studied, can be used to extract rare and dispersed elements from it, and then be re-enriched using a denser separating heavy medium - magnetite or water sand slurry, as well as natural underground calcium chloride brines.

6. References

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