EURASIAN PHYSICAL TECHNICAL JOURNAL

2024, Volume 21, No. 1 (47)

https://doi.org/10.31489/2024No1/67-73

Received: 18/12/2023 Revised: 04/02/2024 Accepted: 07/03/2024 Published online: 29/03/2024

Research Article

UDC 53.09; 662.612.3; 62.663.2

IMPROVING THE QUALITY OF EKIBASTUZ COAL USING THE DRY ENRICHMENT METHOD

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Abstract. *This paper discusses the possibility of improving the ekibastuz coal quality through the use of "dry enrichment" technology. The experiments and calculations carried out made it possible to determine the optimal scheme for enrichment of samples of thermal coals from the Ekibastuzsky open-pit mine of "Angrensor-Energo" LLP. Testing of technical characteristics, such as moisture content, ash content, volatile matter yield and calculation of energy characteristics of enriched samples of thermal coal was carried out in 3 stages in a coal chemistry laboratory. As a result, it was found that the energy content of the enriched fuel samples increased to 28.5% of the original. This significantly improved consumer properties by obtaining the maximum yield of high quality coal concentrate. Consequently, the developed scheme of enrichment allows to significantly reduce the consumption of electricity, reduce emissions into the atmosphere, reduce the harmful impact on the environment, and expand the markets for coal.*

Keywords: ekibastuz coal, thermal coals, harmful emissions, humidity, ash content, volatile substance, “dry enrichment" technology

1. Introduction

Global climate change, caused by increasing harmful emissions into the atmosphere, necessitates a widespread transition from hydrogen energy to the development of technologies for converting renewable energy sources (RES). According to the Sixth Assessment Report of the International Panel on Climate Change (IPCC), anthropogenic greenhouse gas (GHG) emissions have reached the highest levels in human history, which is already having a negative impact on the Earth's climate [1-7]. In the production of electricity and heat, coal generation retains a dominant position. According to data at the end of 2022 in Kazakhstan, 68.2% of electricity is generated from coal, 20% from gas, about 8.8% from water energy conversion, and about 3.0% comes from renewable energy sources [2, 3]. These statistics are due to the fact that Kazakhstan has huge coal reserves, approximately 34 billion tons. Therefore, to achieve carbon neutrality by 2060 and reduce GHGs in general, along with strategic plans to increase the share of renewable energy projects, the development and implementation of “clean coal” technologies is important.

At the state level, voluntary commitments have been made to reduce harmful carbon emissions into the atmosphere. Kazakhstan has developed a national low-carbon development strategy until 2060, aimed at reducing the energy intensity of gross domestic product (GDP). “The medium-term goal of the Strategy of the Republic of Kazakhstan is to reduce GHG emissions by 15% by 2030 relative to the 1990 emissions level (unconditional goal) and achieve a reduction of 25%, subject to receiving international support for decarbonization of the economy (conditional goal)" [3].

The priority in the modern thermal power engineering development is the problem of energy saving due to the economical use of fuel and energy reserves. Increasing energy consumption with a simultaneous increase in energy prices and widespread environmental degradation necessitates the development and implementation of energy efficient technologies to save fuel, materials and labor costs [5-8]. Energy conservation includes a wide range of interrelated activities and techniques to ensure efficient use of energy. One of the methods is to clean the walls of pipelines of heat exchange devices from scale, which forms during long-term operation and worsens the hydrodynamics of the flow and the intensity of heat transfer processes [5]. To ensure higher combustion efficiency of ekibastuz coal and, accordingly, less harmful emissions into the atmosphere, it is proposed to use laser ignition of the coal mixture [6]. The "three-stage" combustion method makes it possible to increase the reactivity of low-grade Ekibastuz coal and to reduce the content of harmful oxides in combustion products [7]. Energy conservation includes a wide range of interrelated activities and methods that ensure efficient use of energy.

One of the ways to reduce the volume of harmful emissions into the atmosphere, including greenhouse gases, from coal combustion is its enrichment [9-12]. The beneficiation process involves refining coal, where "clean" coal is separated from unnecessary impurities to produce a higher quality fuel. The study of methods and technologies for the enrichment of thermal coals, a technical analysis of the characteristics of coal from the Ekibastuz open-pit mine of Angrensor-Energo LLP, made it possible to develop a technology for their enrichment. The fundamental novelty lies in the use of the dry enrichment method instead of the traditional averaging of low-grade thermal coals from the ekibastuz coal basin by mixing with high-grade coals.

2. Materials and research method

The developed method of dry enrichment using a combined dry enrichment machine type FGX-12 was applied at the Ekibastuz open-pit mine for processing KSN grade coals. To develop a scheme for enriching ekibastuz coal and obtaining the maximum yield of coal concentrate of the required quality, the technical (working) characteristics of ekibastuz coal were previously determined, such as humidity, ash content, volatile matter yield, etc. Studying the characteristics of thermal coal from the Ekibastuz open-pit mine of Angrensor-Energo LLP in the coal chemical laboratory of Gamma LLP in Ekibastuz. The preparation of thermal coal before the enrichment process was carried out in three stages.

Stage 1: sampling of coal from the surface of the massif (on a stack) of the Ekibastuz open-pit mine. A coal sample was selected manually from the massif prepared for transportation from each coal unit composing it. Spot samples taken evenly throughout the entire volume of the batch of raw coal, in the amount of 32 samples of 5 kg each. each, according to GOST 10742-71, were combined into a common sample [13-15].

The pooled sample was then thoroughly mixed by hand and divided in half. Thorough mixing of one part followed by its division into 2 parts was repeated until the final result was obtained in the form of a sample weighing 10 kg.

Stage 2: processing of the coal sample for laboratory testing.

The coal sample was placed on a baking sheet to dry for 8 hours. The laboratory sample, dried in this way and cooled in air, is crushed in a crushing machine to a particle size of 0.2 mm to 0.8 mm.

Stage 3: determination of the technical (working) characteristics of coal in the laboratory.

Technology of enrichment of Ekibastuz coal based on the use of a combined dry enrichment machine type FGX-12. The dry enrichment scheme for Ekibastuz coal is shown in Figure 1.

A detailed description of the structure and parts of the dry enrichment machine type FGX-12 and a general view are given in [12]. The developed method for processing ekibastuz coal using the dry enrichment method consists of 3 stages too. At the first stage, coal extracted from the face is cleaned of large pieces of rock, then transported to a coal receiving funnel with a feeder, where coarse coal is crushed to a fraction of 0 - 80 mm. This fraction size is determined by the size of the sieve with holes with a diameter of no more than 80 mm, located under the funnel corner of the receiving area with the feeder. At the second stage, crushed coal is loaded into the receiving hopper of a combined dry preparation machine.

Then, along a conveyor belt, it enters a gravity sieve, where the process of coal enrichment directly occurs by separating rock and mineral impurities from the coal with strong air flows and vibration of the sieve. Strong air currents lift small dust particles upward, which are then sent to the dust collector, and the

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broken rock and middling product, under the influence of vibration and air currents, are directed upward through the vibrating sieve and fall onto different conveyor belts designed for their output (two separate outlets).

Coal purified from fine dust, rock and clay with fractions up to 80 mm in size is enriched, as its energy characteristics are significantly improved. In order to verify this, we will calculate the technical parameters before and after processing.

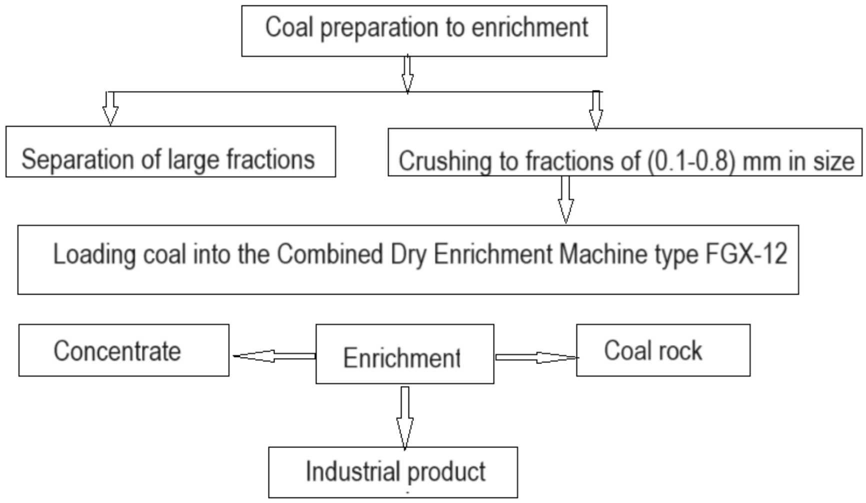

Fig.1. Scheme of enrichment of ekibastuz coal using the dry enrichment method using FGX-12

Coal of the 0-80 mm fraction, cleared of fine dust, rock and clay, is enriched, as its quality characteristics are significantly improved. The dry enrichment method using a combined dry enrichment machine type FGX-12 was used at the Ekibastuz open-pit mine for processing KSN grade coals.

3. Calculation of coal technical characteristics

The crushed sample was thoroughly mixed and laboratory tests were carried out on its basis and the following results were obtained. The moisture content of coal of this sample from the Ekibastuz open-pit mine of Angrensor-Energo LLP was determined. To determine the moisture content of coal from the Ekibastuz open-pit mine of Angrensor-Energo LLP, the crushed sample was thoroughly mixed and prepared.

$$W_t = W_{ex} + W_h \frac{100 - W_{ex}}{100}, \tag{1}$$

where W_t is the total amount of moisture; W_{ex} is external moisture per mass fraction of coal; W_h is the moisture of air-dry fuel

External moisture W_{ex} per mass fraction of coal was calculated using equation:

$$W_{ex} = \frac{G_3}{G_t} 100,$$

where G_t is the mass of the baking sheet with a portion before drying, g; G_3 is the weight loss of the sample during drying, g.

The weight of the baking sheet with the attachment is the sum of the mass of the baking sheet (1.6 kg) plus the weight of the attachment (10 kg), a total of 11.6 kg, or 11600 g. The weight loss of the sample during drying was 348 g.

Thus, the mass fraction of external moisture is determined as

$$W_{ex} = \frac{348}{11600} \cdot 100 = 3\%.$$

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1) To determine the moisture of air-dry fuel (A^d) per mass fraction of coal, we need to determine the analytical moisture of coal W_t, since if a coal sample is dried to a constant mass at room temperature, external moisture is released, and the sample is brought to an air-dry state (analytical mass), i.e. the formula [13]:

$$W^a = W_h$$

Let us calculate the analytical mass of coal moisture as follows:

$$W^a = \frac{m_1}{m} \cdot 100 .$$

Here the loss of mass of a sample of fuel during drying, measured in grams, is already known to us and amounts to 348 g; the mass of the fuel sample, also measured in grams, is also known and amounts to 10,000 grams. Therefore, the analytical mass of coal moisture W_t and the moisture fraction of air-dry fuel W_h equals to 3.48%. The total moisture of coal can determine using (1):

$$W^a = \frac{348}{10000} \cdot 100 = 3.48\%$$

Having received all the necessary data, the total moisture of coal is determined:

$$W_t = W_{ex} + W_h \frac{100 - W_{ex}}{100} .$$

$$W_t = 3 + 3.48 \cdot \frac{100 - 3}{100} = 6.38\%$$

Thus, the total moisture per mass fraction of coal is 6.37%.

$$W^r = W_{ex} + W^a \frac{100 - W_{ex}}{100} ,$$

where, an analytical moisture W_a is calculated within the total concentration of the visible fraction of coal and moisture 3.48%.

The results obtained showed the same values of total moisture per mass fraction of coal W_t and the working moisture indicator W_r.

2) To determine the ash content of coal (A^d), we burned a fuel sample under laboratory conditions in a muffle furnace heated to a temperature of 820°C. As a result, a mass of ash (A) was obtained, amounting to 40.5% of the burned sample. The indicator of analytical moisture of coal (Wa) was calculated by us above and amounted to 3.48%. Thus, the ash content of the coal sample from the Ekibastuz open-pit mine was 41.9%

$$A^d = 40.5 \cdot \frac{100}{100-3.48} = 41.9\%.$$

This indicator is generally similar to the ash content of coals from other open-pit mines of the ekibastuz coal basin, which, on average, is 40–45%.

3) The volume of volatile substances released from the sample from the Ekibastuz open-pit mine of Angrensor-Energo LLP was calculated for the combustible mass of fuel (V^{daf}) based on the results of determination in the analytical sample (V^a). The volume of volatile substances released in the analytical fuel sample (V^a) was calculated using the formula [13]

$$V^a = \frac{M_{vol}}{M_m} 100 - W^a ,$$

where M_{vol} is the mass of released volatile substances, g; M_m is the fuel weight, g; Wa is moisture content in the analytical fuel sample, %.

To determine the yield of volatile substances in practice, we used a high-shaped porcelain crucible No.5 with a lid, weighing 110 g and volume 85 ml. We placed a 1gramm sample of air-dry fuel into the crucible,

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placed the lidded crucible with the fuel sample into the stable temperature zone of a muffle furnace, preheated to (900 ± 5°C), and held it for 7 minutes.

Then the crucible was removed from the furnace, cooled first in air for 5 minutes, and then in a desiccator to room temperature. After the non-volatile residue cooled down to room temperature, we weighed it and calculated it using the formula given above. As a result, a yield of volatile substances was obtained

$$V^{a} = \frac{0.28}{1} \cdot 100 - 3.48 = 24.5\%$$

Next, the ash content in the analytical fuel sample (A^{a}) is calculated

$$A^{a} = \frac{M_{ash}}{M_{m}} \cdot 100\,,$$

where M_{ash} is the mass of ash after calcination, g; M_{m} is fuel weight, g.

To do this, the crucible is placed in a sample of air-dry fuel weighing 1 g, where it is installed at the leading edge of a muffle furnace, preheated to 820°C. The crucible is kept in this position for 30 minutes, which helps prevent the active release of volatile substances. The crucible is then gradually moved to a constant temperature zone to avoid fuel flare-ups. The duration of ashing process is 30 minutes. After the set time has elapsed, the crucible is removed from the furnace and cooled to room temperature. At the end of the procedure, the crucible with the ash residue is weighed. Thus, the initial data were obtained for calculating the ash content in the fuel sample M_{m} , which, as a result of a laboratory study, amounted to 41.9%, which was almost identical to the ash content of coal on a dry weight basis

$$A^{a} = \frac{0.41}{1} \cdot 100 = 41\%$$

Calculation using the standard formula for the volume of volatile substances released per combustible mass of fuel V^{daf} showed 24.1%, it's a slight decrease. The value of this indicator generally corresponds to similar values of the volume of volatile substances obtained in other quarries of the Ekibastuz coal basin, and varies from 24 to 26%.

4. Discussion of results

The practical implementation of the dry enrichment scheme for thermal coal using the FGH-12 combined dry enrichment machine at the Ekibastuz open-pit mine was carried out in March 2020. Before the implementation of this scheme, it was not clear exactly the possibility of dry enrichment of coal from the KSN arch of the ekibastuz coal mine. Enrichment of KSN grade coal was carried out according to our proposed model of the ekibastuz coal enrichment scheme using the dry enrichment method using a combined dry enrichment machine of the FGH-12 type.

The results of the study using this method showed the feasibility of using the installation of a combined dry enrichment machine FGX-12 at the Ekibastuz open-pit mine of Angrensor-Energo LLP. The results are presented in Table 1. An improvement in the technical characteristics of coal according to the main indicators (humidity, ash content, calorific value) of the finished product (concentrate) after processing is shown.

Table1. Characteristics of coal and of the finished product before and after enrichment

Basic characteristics	before enrichment	after enrichment
Moisture, W_t	6.37%	4.2%
Ash content, A^d	41.9%	37.0%
Specific calorific value, Q_i	13179.6 kJ/kg	16945.2 kJ/kg
Release of volatile substances V_{daf}	24.5%	24.1%

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Thus, the new technology made it possible to increase the energy content of enriched fuels to 28.5% of the original, which indicates the effectiveness of the proposed enrichment scheme for ekibastuz coal, which includes the dry enrichment method using the FGX-12 combined machine.

The obtained indicators confirm the effectiveness of dry enrichment of coals from the Ekibastuz mine. The proposed enrichment scheme will significantly reduce energy consumption, reduce the harmful impact on the environment and, as a result, expand coal sales markets. The developed coal enrichment scheme was tested experimentally on thermal coals of the KSN grade from the Ekibastuz open-pit mine of Angrensor-Energo LLP. The enrichment results confirmed its effectiveness, as well as the feasibility of installing a combined dry enrichment machine FGX-12 at the Ekibastuz open-pit mine of Angrensor-Energo LLP to obtain an enriched product of the required quality (concentrate).

5. Conclusions

An analysis of the quality of ekibastuz coal was carried out. Technical characteristics of ekibastuz coal (moisture content, ash content, release of volatile substances and calorific value) were determined using the example of coal from the Ekibastuz open-pit mine of Angrensor-Energo LLP. Thermal coals of the Ekibastuz basin are characterized as low-caking, high-ash, low-calorie. A technical analysis of a coal sample from the Ekibastuz open-pit mine was carried out in the coal chemical laboratory of Gamma LLP.

It should be noted that in the experiments, 100 tons of KSN grade coal were taken as the test sample. At the output after dry enrichment using the FGX-12 combined machine, the concentrate of the required quality was 35%, middling product is 35%, and coal rock is 30%. The obtained indicators are quite high for this type of coal, which confirms the possibility of processing difficult-to-enrich coal using the dry enrichment method. Such results were obtained due to the fact that the pneumatic separation process in the FGX-12 installation occurs in an air flow of constant speed, in which coal particles are suspended and stratified by density.

Thus, as a result of the enrichment of thermal coal using the dry enrichment method at the FGX-12 installation, the moisture content Wt decreased by 2.17% and amounted to 4.2%. The ash content of Ad also decreased by 41.9% and amounted to 37.0%; and the heat of combustion (Q_i), on the contrary, increased by 3765.6 kJ/kg and amounted to 16945.2 kJ/kg.

This, in turn, helps to improve the consumer properties of coal by obtaining the maximum yield of coal concentrate of the required quality. This enrichment scheme can significantly reduce energy consumption, reduce the harmful impact on the environment, and, as a result, expand coal sales markets.

Conflict of interest statement

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

CRediT author statement

Shaimerdenova K.M.: Supervision; Conceptualization, Methodology; Sakipov K.E.: Formal analysis, Review & Editing; Abdirova N.T.: Data Curation, Writing - Original Draft; Suleimenova S.: Investigation, Visualization.
The final manuscript was read and approved by all authors.

Acknowledgements

The authors express their gratitude to Shunkeev T.3., Head of the Coal Chemical Laboratory "Gamma" (Ekibastuz), for the opportunity to take part in test experiments on processing of KSN grade coal by the “dry enrichment” method using the combined installation FGH-12.

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