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Separation of iron and carbon concentrates from thermal power plant solid waste using physical methods

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ABSTRACT

This research study examined the physical enrichment processes of coal fly ash (CFA) from the 2nd thermal power plant in Almaty. Magnetic separator and flotation enrichment methods were used to separate the magnetite and carbon parts of coal fly ash, respectively. In the study, a laboratory magnetic separator separated hematite content from 4.49 to 5.57% by mass from ash residues of different fractions. Cheap and available kerosene and flotol-b were used as flotation reagents for flotation enrichment. The particle size of coal ash is 63-100μm, and the amount of carbon concentrate is ~16.3% by weight. The remaining mineral of coal ash is an essential raw material for building materials.

Key words: coal fly ash, magnetic separation, hematite, flotation enrichment, coal concentrate

1. Introduction

Coal fly ash (CFA) is a solid phase heterogeneous particle formed as a solid residue after the burning of natural resources during the production of electricity in thermal power plants (TPP) [1]. Morphologically, the size of ash particles varies from nanoscale to Submicron, and compositionally, ferrospheres, cenospheres, aluminosilicate Spheres [2, 3], and nanoscale carbon-based compounds are found [4]. In addition, ash contains many elements found in geological samples, including rare precious metals [5], toxic heavy metals [6, 7], and radicals of some organic compounds [8].

This study examined the solid wastes of Almaty's second thermal power plant (TPP). TPP burns 2.5 million tons of Ekibastuz coal as the primary fuel and releases 1 million tons of solid coal fly ash into the environment [9]. Since the solid waste of this CFA is not processed secondary, it is stored in landfills near the city of Almaty. This causes dust storms to pollute landfills during the summer. In addition, settlements and agricultural areas near landfills may also be contaminated. Dust storms cause significant damage to human health and agricultural areas [10]. Therefore, CFA recycling allows for the reduction of the anthropogenic impact on human health and nature, as well as the use of solid waste as a raw material for synthesizing precious rare metals through metallurgical and chemical processing [11, 12]. In addition, it allows direct use as a raw material in construction [13]. Due to industry development, CFA is currently widely processed and used directly and indirectly in the fields of ceramics and construction, adsorbents, fertilizers, catalysts, geopolymers, and metallurgy [14-16]. Ash directly plays an essential role in the industry that produces building materials. Research shows that it improves some of the physical properties of cement [17]. Indirectly, in chemistry and metallurgy, the possibility of using aluminum, iron, and rare metals as raw materials in production has been studied [18].

Coal fly ash contains iron in the form of magnetite (Fe_3O_4), hematite (Fe_2O_3) and maghemite (-Fe_2O_3) minerals. Most of the iron minerals contained in CFA were extracted by magnetic separation. The rest of the iron is contained in a complex aluminosilicate matrix. In addition, the matrix contains nano-sized carbon particles [19]. The separation, processing, and use of these parts from each other due to their properties are urgent issues.

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In this research, the possibility of separating compounds with magnetic properties in fly ash was investigated using laboratory magnetic separators. In addition, the possibilities of separation of carbon particles and aluminum-based microspheres by flotation and acid-base processing methods were studied.

2. Materials and Methods

2.1. Raw materials

The coal fly ash used in the research was taken from the waste landfill of the 2nd thermal power plant in Almaty. The average values of the X-ray diffraction analysis of CFA are presented in Table 1 and Fig. 1. The results of CFA analysis by different fractions are fully explained in the 3rd part of the research paper.

Table. 1. Chemical composition of CFA of the 2nd thermal power plant in Almaty

$Al(Al_{2.556}Si_{1.444})O_{9.722}$	SiO_2	Fe_2O_3
63.4	30.2	6.4

2.2. Compositional and structural analysis methods of CFA

Compositional analyses of CFA were carried out using D8 Advance (Bruker AXS GmbH, Germany), α-Cu, tube voltage 40 kV, current 40 mA. Analysis and calculations were carried out using EVA software to process and calculate the diffraction data of the obtained CFA residue. Coal fly ash interpretation and phase retrieval Phases were refined using the PDF-2 powder diffractometric database. Surface morphology and microstructure analysis of CFA was performed using a Hitachi TM4000 Plus desktop scanning electron microscope (SEM).

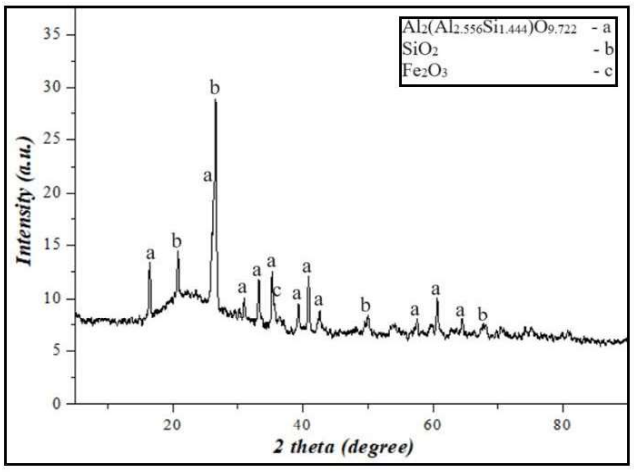

Fig.1. X-ray diffraction patterns of raw CFA from the Almaty TPS - 2.

2.3. Magnetic enrichment of coal fly ash

The laboratory magnetic separator «SMS-20-PM1» (СМС-20-ПМ1, Russia) was used to enrich and separate the magnetic fractions contained in CFA. An electronic sieve classified CFA into different fractions (> 63 μm, 63-100 μm and 100-250 μm). 100 g of coal fly ash samples were loaded into the magnetic separator. It was studied using different measurements of magnetic intensity.

2.4. Coal fly ash flotation enrichment

The carbon content of CFA was determined by high-temperature combustion in a Snol muffle furnace. CFA from the landfill was dried in an oven at 80 °C for 4 hours. Samples were measured from dried ash with an accuracy of ~ 0.001g, placed in high-temperature resistant quartz crucibles, and ignited in the Snol muffle furnace at 850 °C. Carbon concentration in CFA was determined by mass loss of samples during combustion.

The FML 1 (237 FL, Russia) flotation machine was used to enrichment carbon in CFA. Kerosene and flotol-b were used as flotation reagents.

The following processes carried out the separation of carbon in the ash: 100 g of the non-magnetic part of ash in different fractions (63 μm >, 63-100 μm, and 100-250 μm) is measured and mixed with 500 ml of water in a flotation chamber for 5 minutes. After that, add the flotation agent and mix for 3 minutes until bubbling. A flotation machine separates the mineral waste section and the carbon concentrate section and dries them at 60 °C. In addition, the yield of carbon concentration was determined on the DTA-TG equipment at a heating rate of 10 °C/min, with a mass loss when heated to 900 °C.

3. Results and discussion

3.1. General characteristics of coal fly ash

The composition of CFA consists of aluminosilicate compounds $Al(Al_{2.556}Si_{1.444})O_{9.722}$, silicon oxide ($SiO_2$), and hematite ($Fe_2O_3$) shown in Fig. 1. In addition, the result of the structural analysis of coal fly ash is presented in Fig. 2. In many research studies [20], it has been shown that spherical shapes in the structure of coal fly ash belong to aluminosilicate compounds, and hematites are located around the spherical shape. In addition, the porous free structures in the structural analysis were found to be carbon particles.

Before the magnetic enrichment of coal ash, primary coal ash was classified into different fractions using a vibrating sieve, and the results of compositional analyses for each size are shown in Fig. 3.

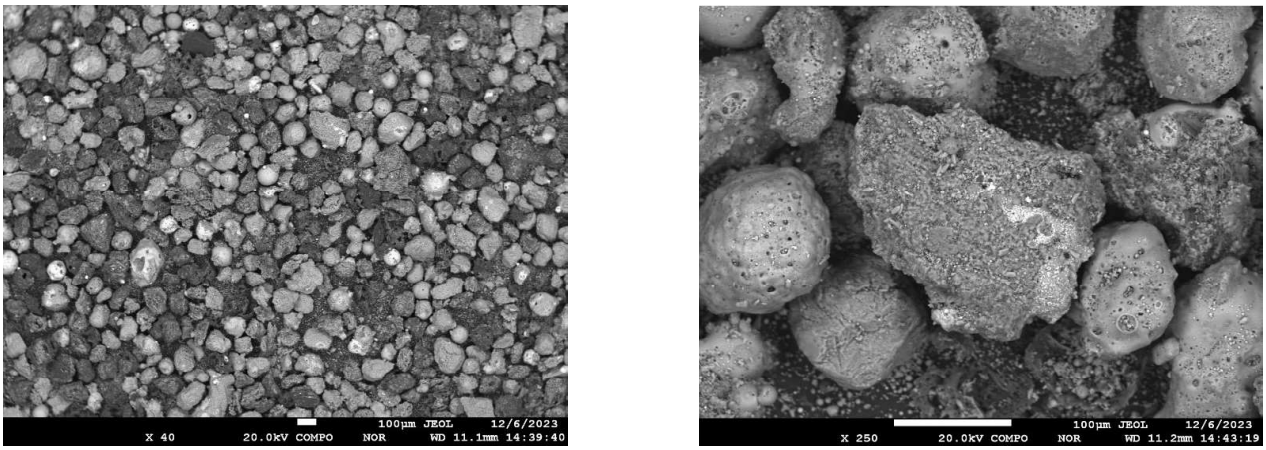

Fig.2. SEM results of CFA from 2nd thermal power plant in Almaty.

The X-ray results in Fig. 3 show that as the size of coal ash decreases, the amount of ferritic compounds decreases. It can be assumed that the iron compounds in the solid waste accumulate as molten slag in the outer part of the aluminosilicate compounds, and the particle size increases.

3.2. Magnetic enrichment of ash-based solid waste

Many research works have studied iron compounds in CFA based on various magnetic separation processes [21-22]. Valeev et al. [23] studied the possibilities of wet and dry magnetic separation of iron. It is shown that the amount of magnetite in the magnetic fraction increases during the wet magnetic separation process. Therefore, the research was studied based on the wet magnetic separation method in a laboratory magnetic separator. Before magnetic separation, coal ash was separated into different fractions using a sieve. Using a magnetic separator, coal ash fractions of different sizes were classified into magnetic and non-magnetic parts. The magnetic part of the ash of the 2nd power plant of Almaty was separated into different fractions, ranging from 4.49 to 5.57% by mass. The results of the compositional analysis of non-magnetic (a) and magnetic (b) parts of ash separated by a magnetic separator are shown in Fig. 4.

According to the XRD analysis, the non-magnetic fraction consists of quartz, mullite, and kaolinite. It is shown that the magnetic fraction contains mainly magnetite, iron silicon oxide, and a small amount of quartz. Based on the process of wet magnetic separation, it was possible to completely isolate the iron compounds in the CFA. The results of the structural analysis of the magnetic part of the ash are shown (Fig. 5). As shown in the pictures, iron concentrate is available in spherical forms, molten forms, etc., indicating that it is formed in the structures. In addition, since the initial coal fly ash was obtained below 250 µm and the ferrous compounds were in molten or spherical forms, it can be assumed that the particle sizes would vary in the submicron range.

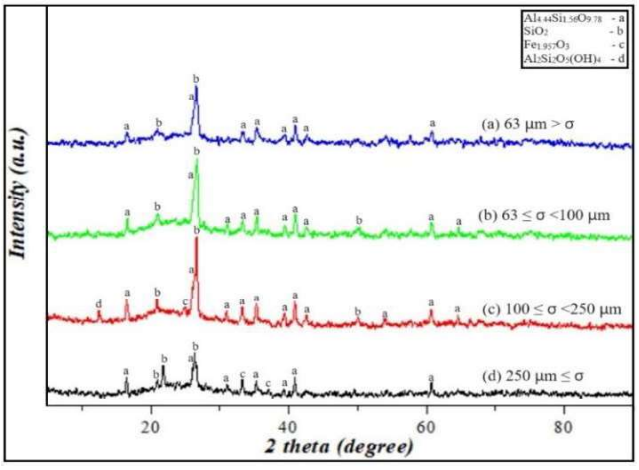

Fig. 3. X-ray diffraction patterns of coal ash of different sizes.

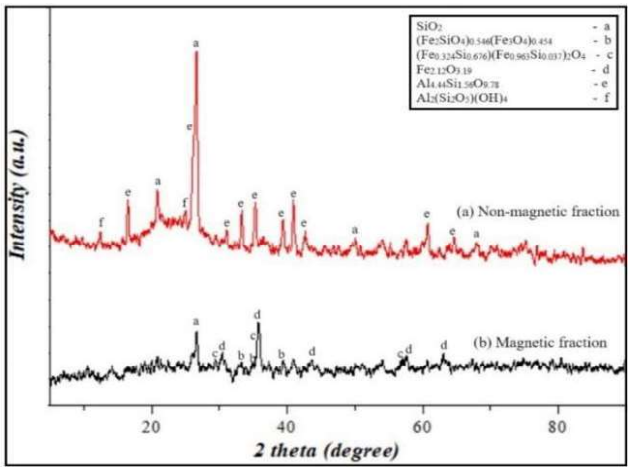

Fig. 4. XRD patterns of the non-magnetic (a) and magnetic (b) fractions of CFA after magnetic separation.

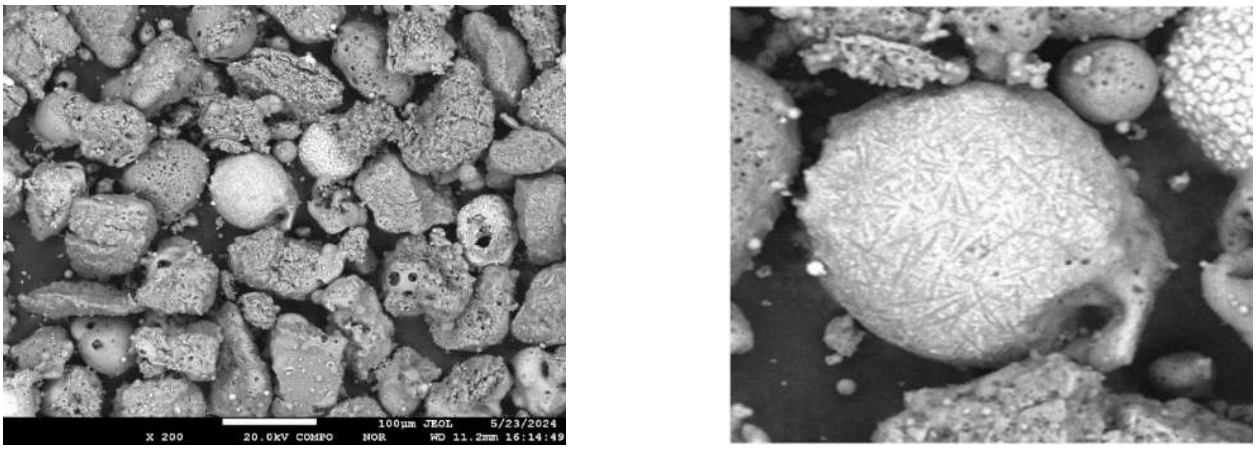

Fig. 5. Results of SEM analysis of the magnetic part of coal fly ash.

3.2. Flotation separation of carbon from the non-magnetic fraction of coal fly ash

The amount of carbon in CFA was ignited in a muffle furnace at 850 °C and determined based on the mass loss of the sample. According to the ash sample, the mass loss was determined between 4.5 and 7% for each fraction, respectively. To separate the carbon content of the CFA, the flotation enrichment process was carried out with the non-magnetic fraction of the coal fly ash obtained after the wet magnetic separation for each fraction of the CFA. The research determined that the most suitable particle size for flotation enrichment of carbon in ash is 70-100 µm [24]. The research involved studies on three different fractions of particle sizes (> 63 µm, 63-100 µm, and 100-250 µm). Studies have shown that using kerosene as a flotation collector of flotation enrichment was obtained due to its high efficiency and availability [25]. Flotol-b was used in flotation tests to prevent the coalescence of formed air bubbles and to create stable foam.

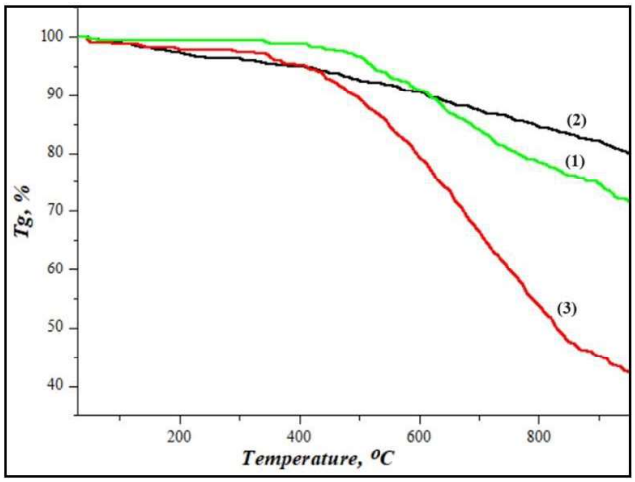

Fig. 6. Thermogravimetric analysis of coal fly ash at the heating rate of 10 °C/min: 1 – coal fly ash; 2 – the mineral part of CFA; 3 – carbon concentrate of CFA.

During flotation enrichment, the volume of kerosene in the flotation collector was determined to be between 1 ml and 8 ml, and the yield of carbon concentrate was determined. The results showed that the highest results were obtained when 3 ml of kerosene and 1 ml of Flotol-b were used. The carbon yield varied from 10.8 to 16.3% depending on the size of the initial coal ash particles. Carbon content was determined based on the mass loss of carbon concentrate in DSC-Tg. According to each fraction, the carbon content was determined to be 33.72%, 15.5%, and 54,63%. The TG line of mass loss of carbon concentrate is shown in Fig. 6. In addition, SEM images of carbon concentrate and mineral fraction after flotation are shown in Fig. 7.

In the carbon concentrate part (a), carbon particles are distinguished by porous and incompletely burned carbon particles. In addition, it contains a small amount of spherical mulitum particles. It can be assumed that particles of small-size mullite can pass through the concentrate section on the surface of large-size unburned carbon particles. The mineral part can be seen in spherical aluminosilicate compounds and irregularly shaped compounds coated with small amounts of iron minerals. In addition, as shown in many research works [26], since carbon in coal ash is in the form of soot, it is determined that particle sizes are in the nanoscale.

Figure 8 provides a brief technical diagram of the physical separation of iron concentrate and carbon concentrate from coal ash and the direct use of mineral parts for building materials.

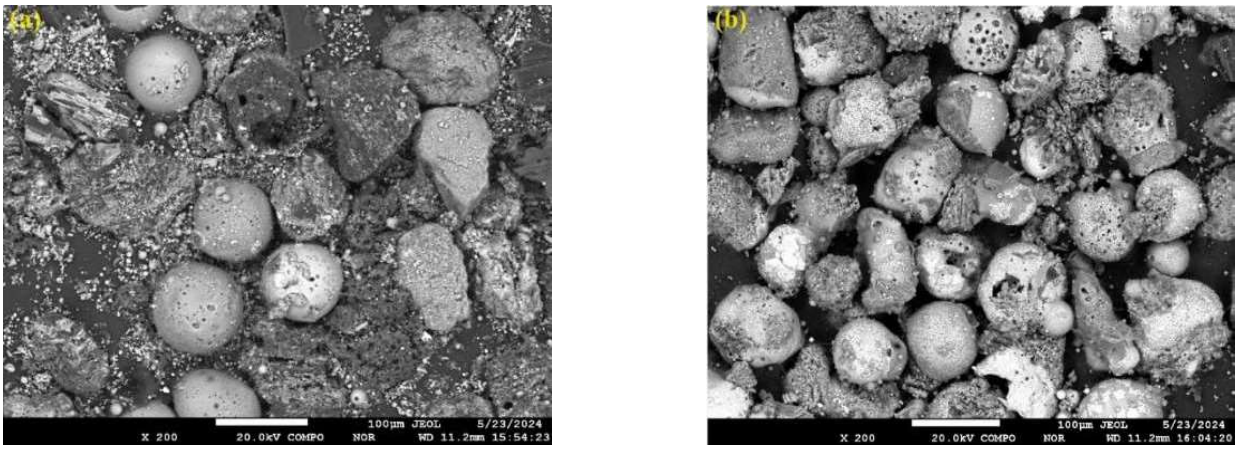

Fig. 7. SEM images of carbon concentration (a) and mineral particles (b) after flotation enrichment of CFA.

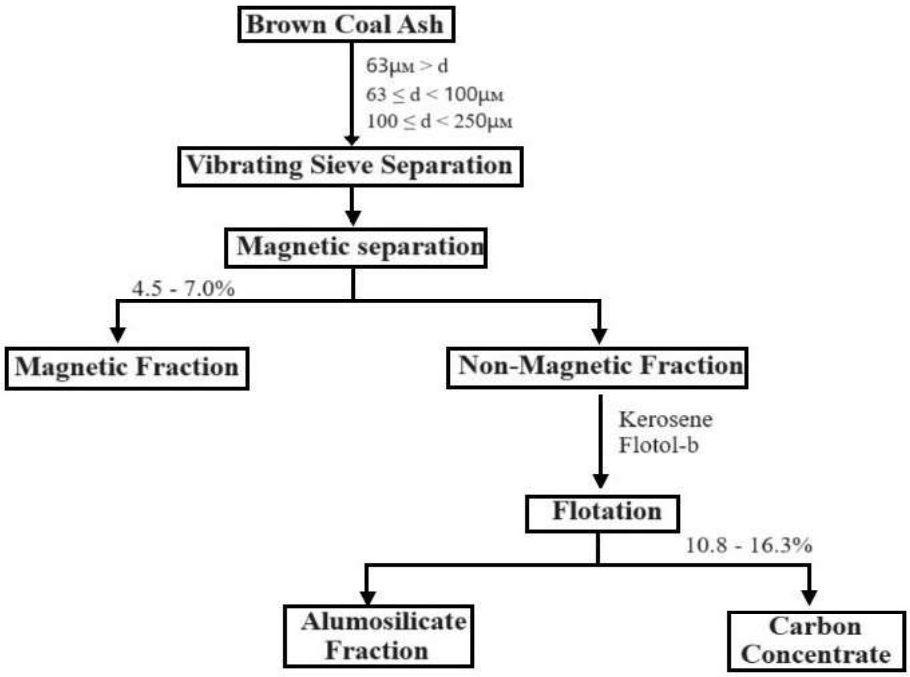

Fig. 8. Technological diagram of the CFA enrichment process of 2nd TPP in Almaty.

4. Conclusion

Iron and carbon concentrates were isolated and studied based on the physical separation process from CFA, Almaty's 2nd thermal power plant. The research work can be summarized as follows:

1. CFA was classified into different fractions using a vibrating sieve, and compositional analyses were made. It was shown that the proportion of iron concentrate increases with the increase in particle size;

2. With a magnetic separator, the iron concentrate was separated from the CFA in the range of 4.5-7% according to the particle size;

3. After flotation using kerosene as a collector, the carbon content of the concentrate is ~16.3% by mass. The carbon yield decreased significantly when the particle size was increased or when it was very low. This is because kerosene does not fully adhere to the carbon surface at higher sizes. In small sizes, this is due to the mineral part of the ash passing into the concentrate together with the folate reagents. Particle size between 63-100µm is optimal for carbon separation from CFA.

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Физикалық әдістерді қолдана отырып, жылу электр станциясының қатты қалдықтарынан темір және көміртекті концентраттарды бөліп алу

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АННОТАЦИЯ

Бұл зерттеу жұмысында, Алматы қалалық 2 – ші жылу электр станциясының көмір күлі негізіндігі ұшқыш қалдықтарды (ККҰҚ) физикалық байыту процестері зерттелді. ККҰҚ - ның магнетитті бөлігі мен көміртекті бөлігін бөліп алу үшін сәйкесінше, магнитті бөлгіш пен көбікті байыту әдістері қолданылды. Зерттеуде зертханалық магнитті бөлгіш кондырғысы көмегімен, әртүрлі фракциядағы күл қалдығынан, 4,49 - дан 5,57 массалық үлес мөлшерінде гематит бөлініп алынды. Көбікті байыту үшін көбіктік реагент ретінде арзан, әрі қол жетімді керосин мен flotol-b пайдаланылды. Көмір күлінің бөлшек өлшемдері 63-100μм аралығында, көбікті байыту арқылы көміртегінің мөлшері ~16,3 массалық үлеске дейін бөлініп алынды. Қалған көмір күлінің минералды бөлігі құрылыс материалдарының маңызды шикізаты болып табылады.

Түйін сөздер: Көмір күлі негізіндігі ұшқыш қалдықтар, гематит, алюмосликатты қосылыстар, магнитті бөлу, флотациялық байыту

Выделение концентратов железа и углерода из твердых отходов тепловых электростанций физическими методами

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АННОТАЦИЯ

В данном исследовании изучались процессы физического обогащения летучей золы угля (ЛЗУ) 2-й ТЭЦ Алматы. Для разделения магнетитовой и углеродистой частей золы угля использовались методы магнитного сепаратора и флотационного обогащения. В ходе исследования на лабораторном магнитном сепараторе из зольных остатков разных фракций выделен гематит с содержанием от 4,49 до 5,57% по массе. В качестве флотореагентов для флотационного обогащения использовались дешевые и доступные керосин и flotol-b. Размер частиц угольной золы составляет 63-100 мкм, количество углеродного концентрата ~16,3% по массе. Оставшийся минерал угольной золы является важным сырьем для строительных материалов.

Ключевые слова: летучая зола угля, магнитная сепарация, гематит, флотационное обогащение, угольный концентрат