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Research of the Enrichment of Ash and Slag Waste from Coal Combustion at Thermal Power Plants Using the Flotation Enrichment Method

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Abstract – *When burning coal, a significant amount of unburned or partially burned coal particles, called "underburning", turns out to be in the ash. The extracted underburning is a valuable component and can be used as a secondary fuel mixed with the main one, in the manufacture of fuel briquettes, as a rubber filler instead of graphite and a filler of electrically conductive concretes used in the construction of some elements of a nuclear power plant. Flotation is an effective method of extracting unburned coal particles. In this work, a flotation enrichment method has been proposed for the extraction of carbon concentrate from ash and slag waste from thermal power plants. The influence of the reagent regime, the size of the material, as well as the use of pre-activated ash and slag waste after the chemical activation process on the efficiency of flotation enrichment have been comprehensively studied. The phase composition and the morphology of ash and slag waste have been analyzed by using X-ray diffraction and scanning electron microscopy. Compared with the traditional method of flotation enrichment of ash and slag waste, the use of pre-activated ash and slag waste under optimal conditions has showed the efficiency of carbon extraction into carbon concentrate from 26.6 to 65%. The results of the experiments conducted by using the reagent mode of the kerosene collector 1500 g/t and the MIBK 50 g/t foamer are as follows: a carbon concentrate with a carbon content of 65% has been obtained, carbon extraction into the concentrate has been 37.6%, the yield has been 4.14% when using activated ash and slag waste.*

***Keywords**: Ash, Chemical Activation, Coal, Flotation, Carbon Concentrate*

Nomenclature

MIBK	Methyl Isobutyl Carbinol
SBX	Butyl Sodium Xanthogenate
ASW	Ash Slag and Waste

I. Introduction

Currently, there is an urgent issue in the world of processing ash and slag waste from coal combustion in thermal power plants. Coal rocks and ash and slag waste generated during coal mining and processing are the main industrial aluminosilicate wastes that cause concern to countries around the world due to their low level of use and negative environmental impact [1]. The annual output of ash-cinder from thermal power plants, from only burning of Ekibastuz coal, which is characterized by a high ash content (40-45%), is averaged 30 million tons [2].

The average content of Al_2O_3 in the ASW is from 25 to 30%, making it a potential alternative source of alumina and other valuable components [3] after bauxite, nepheline, alunite. The share of reserves of high-quality bauxite in Kazakhstan is limited [4], which affects the industrial production of alumina. However, for the same purposes it is possible to use non-toxic raw materials, for example ash and slag waste from the burning of Ekibastuz coal thermal power plants. Thus, the possibility of using ASW as a substitute or increasing the import of bauxite as a raw material in the production of aluminum seems feasible. The study of the possibility of using ASW as a substitute for mineral raw materials, especially with the complex use of useful components accompanying alumina, is of great interest. Recently, significant researches have been conducted on the processing of ash and slag waste in order to obtain valuable products [5]-[15]. Ash and slag wastes are used in the production of rare earth elements [16], the extraction of aluminum and scandium [17], in the production of bricks [18], in the production of zeolites [19], for the extraction of aluminum from activated ash [20], for the extraction of alumina by firing-electrolysis [21], for the extraction of lithium [22], for the preparation of sodium silicate solutions to obtain silicon nanoparticles [23], in the method of mechanical activation [24], in the synthesis of mesoporous silica nanoparticles [25]. Ash and slag waste is also used as granular filters for refining primary aluminum from impurities of vanadium and other non-ferrous metals [26], [27]. In [28], a resource-saving technology for processing ash and slag waste for sale as raw materials has been proposed. In [29], the authors have used ash and slag waste

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for preliminary chemical activation in a solution of sodium bicarbonate. The results of the authors' research have showed that after the application of the chemical activation process, the mineral and crystal structure of ash and slag waste changes. The positive results of the work have shown the effectiveness of complex processing of ash and slag waste in the processes of enrichment, leaching, sintering [30], [31]. In addition, [32] has developed a method of chemical activation of mineral raw materials. In the proposed method, due to the use of chemical activation, the phase composition of the raw material has changed. Chemical activation has been carried out with a solution of sodium bicarbonate ($NaHCO_3$) containing 120 g/dm^3 $NaHCO_3$ at a temperature of 120-150 °C. In [32, p. 314], studies have been conducted on the processing of difficult-to-process raw materials and waste from metallurgical production (ash and slag waste, slags, slimes). In [33], a new technology for processing low-quality gibbsite-kaolinite bauxites with preliminary two-stage enrichment has been proposed. The technology has consisted of using the process of chemical activation with sodium bicarbonate, which has made it possible to transform the phase composition of bauxites. As a result, raw materials suitable for the production of alumina by the Bayer method have been obtained. In [34], a technology has been developed for the enrichment of kaolinite clay from the Alekseevsky deposit using preliminary chemical activation. The results of [34, p. 135] have showed that the maximum yield of 79.36% Al_2O_3 has been obtained at a temperature of 150 °C with an increase in the duration of chemical activation. An analytical review on the technology of processing low-quality aluminum containing raw materials, concerning the study of the process of chemical activation of aluminum containing raw materials in a solution of sodium bicarbonate ($NaHCO_3$) in the works of the authors [32, p. 315; 33, p. 94; 34, p. 135] has showed the effectiveness of using this process for low-quality aluminum containing raw materials, including for ash and slag waste from thermal power plants with the transformation of phase compositions and a change in the mineral structure before desilinization of aluminum-containing raw materials. As a result of the conducted research [32, p. 315], [33, p. 94], [34, p. 135], positive results have been obtained on the extraction of silica into solution after the chemical activation process, as well as improved technological indicators of desilinization, enrichment, and sintering processes. When burning coal, a significant amount of coal residue, so-called underburning, remains in the ash and slag waste. The extracted underburning is a valuable component in the production of coal briquettes, which can then be used as a secondary fuel in thermal power plants.

One of the most effective methods of extracting underburning (coal residue) is flotation. The development of new types of cheap fuels, the creation of a technology for the integrated processing of man-made waste, along with a reduction in the specific consumption of materials (respectively, CO_2 emissions into the atmosphere), are urgent problems that need to be solved [35]. The purpose of this article is to study the method of flotation enrichment of ash and slag waste from thermal power plants, followed by the separation of enrichment tailings suitable for the production of alumina concentrate and commercial alumina, tailings for the production of building materials (ceramics) and carbon concentrate (underburning) suitable for further use in the production of coal briquettes. The possibility of using activated ash and slag waste in flotation enrichment is being considered.

The use of activated ash and slag waste during flotation enrichment will increase the efficiency of carbon concentrate extraction (underburning) by almost 2.5 times. A technological scheme of flotation enrichment using activated ash and slag waste has been developed, including chemical activation of ash and slag waste, grinding, sieve analysis, basic flotation, control flotation with re-purification of concentrate. As a result, carbon concentrate (underburning), enrichment tails, and re-cleaning tails are extracted. The optimal reagent regime for flotation enrichment of ash and slag waste is the kerosene collector – 1500 g/t; the MIBK foamer – 50 g /t; Carbon extraction (underburning) remained at the level of 65%.

II. Materials and Methods

The phase and chemical composition of the objects has been studied by using physicochemical methods of analysis. The following equipment has been used for this:

- mass spectrometer with inductively coupled plasma ICP-MS 7500cx from Agilent technologies (USA), in order to determine the content of chemical elements in the studied raw materials by the spectral method;
- X'Pert PRO X-ray diffractometer manufactured by PANalitical has been used to study qualitative, semi-quantitative phase analysis;
- Scanning electron microscope JSM-6390LV manufactured by JEOL Ltd. (Japan) with an energy-dispersive microanalysis system INCA Energy Penta FET X3 from OXFORD Instruments Analytical Limited (UK) has been used to study the topography and the microstructure of the surface of samples and specimens, qualitative and quantitative elemental microanalysis in a point area, constructing profiles of the distribution of elements along a given line, constructing maps of the distribution of elements in a selected area;
- In order to study the morphology of the surface of materials, a BX-51 microscope (Olympus, Japan) has been used;
- For photo visualization of the research objects during the experiment, a CANON EOS 80D device has been used;

In order to solve the problems posed in this research, the following methods have been used. When studying the effectiveness of the method of flotation enrichment of ash and slag waste from thermal power plants, the possibility of extracting carbon concentrate and aluminosilicate microspheres from ash and slag waste of the Eurasian Energy Corporation has been investigated. Flotation enrichment has been carried out on laboratory flotation machines of the Mekhanobr Tekhnika type with a chamber volume of 3.0 dm^3 [29]. Enrichment has been carried out at the initial size of ash and slag waste, with a chamber volume of 1 dm^3 and a sample weight of 150 g (T:L = 1/3) with pulp aeration of 10 dm^3/min, impeller rotation speed was 2500 rpm [29]. For research, samples have been taken from the ash dumps of the Euro-Asian Energy Company (EEC JSC) from the combustion of Ekibastuz coal. The chemical composition of the initial averaged ash sample, wt. %: is presented in Table I.

III. Results and Discussion

Sieve analysis has been used to determine the particle size distribution of ash and slag waste. Sifting has been carried out on a mechanical analyzer. The results of the sieve analysis of the sludge sample are given in Table II.

From the results of the sieve analysis of ash and slag waste it follows that the bulk is represented by the class -0.25 + 0.1 mm, whose amount is about 60.0%. The size distribution of unburned carbon makes it obvious that approximately 65.7% of the total is in the -0.25+0 fraction.

By taking into account all the known technologies for recycling ash and slag waste from thermal power plants, a technological scheme for processing has been proposed, including the operations of grinding and subsequent flotation of ash and slag waste. The study has confirmed that the most optimal grinding time can be considered 15 minutes. At the same time, the bulk of crushed ASW (96.67%) falls on a size of -0.25+0 mm, which makes them possible for processing by flotation.

In order to determine the possibility of extracting underburning (carbonaceous concentrate) from ash and slag waste using the main flotation method, staged experiments have been carried out.

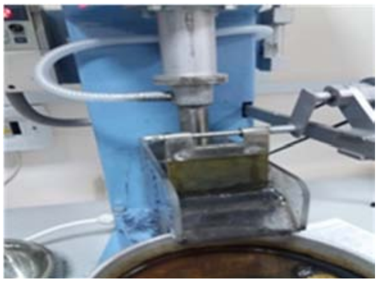


Fig. 1. Flotation machine "Mekhanobr Technika"

The amount of kerosene supplied to flotation enrichment has been selected based on literature data on coal flotation in industry [36]. Reagent mode of experiments performed:

- Mass of initial ash – 150 grams;
- Collector – kerosene – 1500 g/t;
- Foaming agent – pine oil – 50 g/t;
- Feed size – (-0.25+0.1 mm);
- Pulp density – 300 g/l;
- Flotation time – 5 min.

The results of the experiments on the separation of carbon concentrate from ashes are presented in Tables IV, V. The experiments carried out have showed the possibility of extracting underburned carbon dioxide (carbon concentrate) by using the flotation method. In order to achieve high rates of carbon concentrate recovery, cleaning operations and optimal reagent conditions are required. The analysis of the literature data shows that the most suitable particle size for flotation should be more than 71 µm [37]. In [38], particles of the non-magnetic fraction with a size of 71-100 µm have been used for flotation tests of ash. Kerosene has been chosen as the flotation collector due to its high efficiency and low cost [38]. MIBK has been used in flotation tests to prevent the coalescence of air bubbles [38, p. 8]. The use of the 40-71 µm fraction has ensured the extraction of unburned carbon by about 99%, while when using larger particles of 71–100 µm, the carbon extraction has not exceeded 83% [38, p. 9]. In order to increase flotation efficiency, pre-activated ashes have been used after chemical activation.

TABLE I
CHEMICAL COMPOSITION OF THE INITIAL AVERAGED ASH SAMPLE, %

Mass fraction of elements, %								
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	K_2O	SO_3	Na_2O
55,0	20,04	2,30	1,36	0,4	0,71	0,50	0,62	0,70

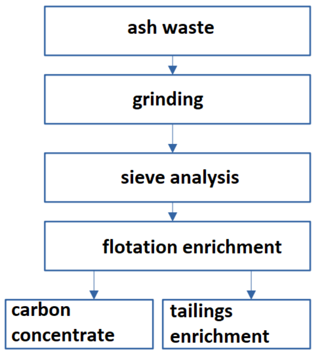


Fig. 2. Technological scheme for processing ash and slag waste from thermal power plants using the flotation enrichment method

TABLE II
SIEVE ANALYSIS OF ASH AND SLAG WASTE

Fraction class, mm	Class Outcome, %	Contents of elements, %				Element distribution, %				Distribution of unburned carbon, %
		SiO_2	Fe_2O_3	Al_2O_3	TiO_2	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	$C_{unburned}$
+1,0	11,7	44,59	12,22	16,92	0,96	11,77	13,6	9,88	11,4	2,0
-1,0 +0,25	10,4	43,79	8,36	20,56	0,92	10,26	8,3	10,67	10,0	7,38
-0,25 +0,1	57,5	44,24	8,98	20,65	0,98	58,0	49,0	59,2	58,3	24,92
-0,1 +0,056	13,6	43,14	14,63	20,23	0,92	13,21	18,9	13,72	13,0	36,91
-0,056 +0	6,8	44,35	15,68	19,31	1,11	6,76	10,2	6,53	7,3	28,79
Total	100					100	100	100	100	100

TABLE III
CHANGE IN PARTICLE SIZE DISTRIBUTION OF ASH AND SLAG WASTE FROM THERMAL POWER PLANTS DEPENDING ON GRINDING TIME

Size class, mm	Output of a certain size class, % Time for grinding ash and slag waste from thermal power plants, min				
	0	5	10	15	20
+1,0	31,51	9,41	6,57	1,12	0,33
-1,0 +0,25	6,16	10,48	7,12	2,21	0,75
-0,25 +0,1	17,67	25,31	25,04	23,03	17,67
-0,1 +0,056	32,89	35,48	36,73	40,37	24,15
-0,056 +0	11,77	19,32	24,54	33,27	57,43
Raw material	100,0	100,0	100,0	100,0	100,0

TABLE IV
CHEMICAL COMPOSITION
OF ENRICHMENT PRODUCTS (CARBON CONCENTRATE)

№	SiO_2, %	Fe_2O_3, %	Al_2O_3, %	C, %
1	42,26	8,02	13,18	21,5
2	42,28	10,02	18,35	10,8

TABLE V
CHEMICAL COMPOSITION
OF ENRICHMENT PRODUCTS (ENRICHMENT TAILINGS)

№	CaO, %	SiO_2, %	Fe_2O_3, %	Al_2O_3, %	Na_2O, %	MgO, %	TiO_2, %	K_2O, %
1	2,477	50,52	4,01	23,52	0,435	0,792	1,1	0,54
2	2,417	54,21	9,98	23,78	0,43	0,847	1,1	0,58

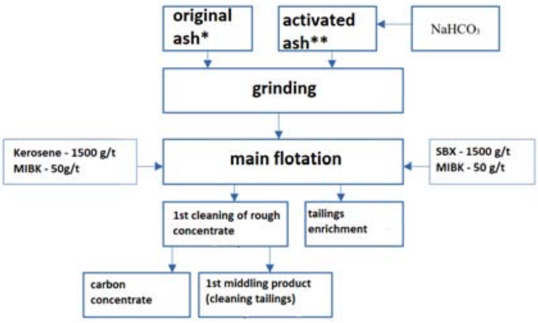


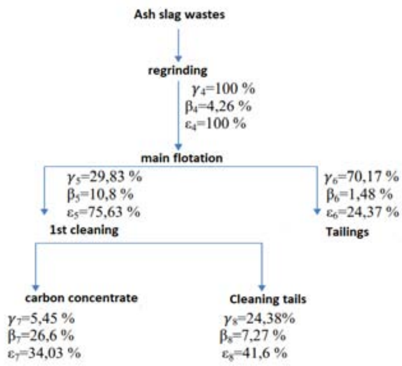
Fig. 3. Technological diagram of flotation enrichment of ASW

Four staged experiments have been carried out with different reagent regimes. When extracting the underburned material (carbonaceous concentrate), a main flotation scheme with concentrate re-cleaning has been used. As a comparative study, two samples have been taken on the original ash (without ash activation), as well as two samples of pre-activated ash [29]. Reagent mode for staged experiments:

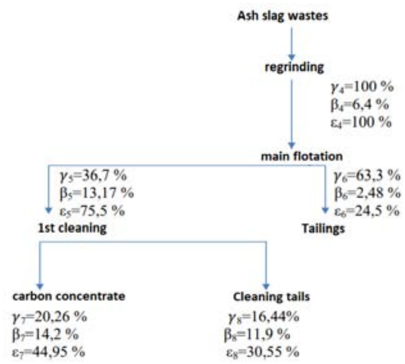
- Mass of initial ash – 150 grams;
- Collector – Kerosene – 1500 g/t;
- Foaming agent – MIBK – 50 g/t;
- Collector – SBX – 1500 g/t;
- Foaming agent – MIBK – 50 g/t;
- Feed size – (0.1 +0.056 mm);
- Pulp density – 300 g/l;
- Flotation time – 5 min;
- Cleaning time – 2.5 minutes.

As a result of the experiments using the reagent mode of a kerosene collector of 1500 g/t and a MIBK foaming agent of 50 g/t, a carbon concentrate with a carbon content of 65% has been obtained. The extraction of carbon into the concentrate has been 37.6%, the yield has been 4.14% at application of activated ash and slag waste. As a result of a series of staged experiments, qualitative and quantitative schemes for flotation enrichment of the ASW have been calculated and are shown in Figures 4, Figure 5 (where γ is the yield of the concentrate, β is the carbon content, ε is the extraction of carbon into the concentrate).

The resulting flotation enrichment products have been analyzed for the content of oxides of aluminum, silicon, sulfur, calcium, titanium, iron, sodium, phosphorus, and carbon, presented in Table VI. Micrographs have been obtained in backscattered electron mode at magnifications from X100 to X2500 [31]. The range of sizes of observed particles is from 1 to 150 microns. The samples represent various structures and irregular shapes of globules with a variety of morphological characteristics: ideal spheres with an intact smooth or perforated surface, hollow cenospheres, plerospheres (sample 46), aggregates of small spheres on the surface or in cavities and depressions of large globules. According to COMPO data, the particle size is on average 1-150 microns. The smaller the particle size is, the more spherical they are (Figure 6). According to COMRO data, the size of microspheres averages 0.5–5 µm. All the samples except sample No. 46 contain a large number of irregularly shaped particles with macroporous walls, perforated and relief surface. Sample No. 46 has a large number of globules of irregular spherical shape with a foam shell or a relief surface. When taking pictures of the mode of backscattered electrons in the sample No. 46, it is possible to see globules of a network structure.

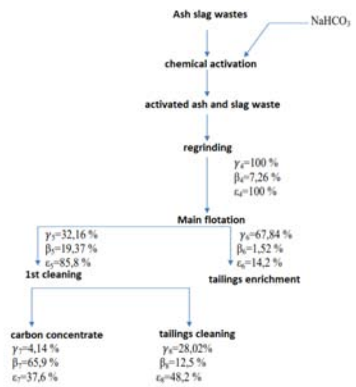


(a)

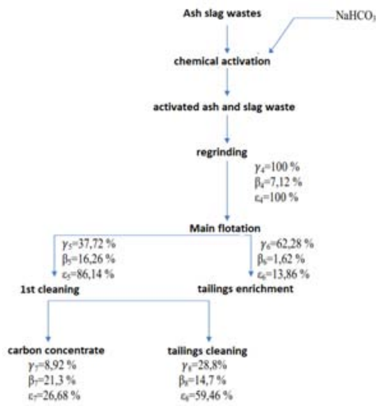


(b)

Figs. 4. Qualitative-quantitative scheme for flotation enrichment of ASW using various reagent modes (a) kerosene and MIBK, (b) SBX and MIBK



(a)



(b)

Figs. 5. Qualitative and quantitative scheme of flotation enrichment of activated ASW using various reagent modes (a) kerosene and MIBK, (b) SBX and MIBK

TABLE VI
CHEMICAL COMPOSITION OF PRODUCTS OF FLOTATION ENRICHMENT OF ASH AND SLAG WASTE FROM THERMAL POWER PLANTS, %

Enrichment products	Contents of the main elements, %								
	Al_2O_3	SiO_2	S	CaO	TiO_2	Fe_2O_3	Na_2O	P_2O_5	C
Carbon concentrate-1	13,18	42,26	0,083	2,134	1,103	5,02	0,456	0,332	26,6
Carbon concentrate-2	15,190	37,569	0,347	2,204	0,986	4,959	0,360	0,224	14,2
Carbon concentrate-3	11,208	32,847	0,097	2,160	0,927	2,785	0,331	0,132	65,9
Carbon concentrate-4	18,35	42,28	0,070	2,105	1,041	6,086	0,324	0,221	21,3
Enrichment tailings-1	23,377	41,361	0,072	2,693	1,237	7,47	0,533	0,341	1,48
Tailings enrichment-2	24,091	45,102	0,145	2,800	1,163	8,541	0,342	0,436	2,48
Tailings enrichment-3	23,360	41,086	0,066	2,692	1,100	9,045	0,496	0,367	1,52
Tailings enrichment-4	23,970	42,379	0,087	2,924	1,143	8,231	0,538	0,376	1,62
Cleaning tails (microspheres)-1	23,438	42,600	0,293	2,122	1,210	5,697	0,263	0,357	7,27
Cleaning tails (microspheres)-2	23,296	46,355	0,396	2,471	1,191	6,470	0,458	0,292	11,29
Cleaning tails (microspheres)-3	22,910	47,425	0,381	2,496	1,105	4,795	0,326	0,392	12,5
Cleaning tails (microspheres)-4	22,442	47,106	0,422	3,200	1,149	5,731	0,548	0,238	14,7

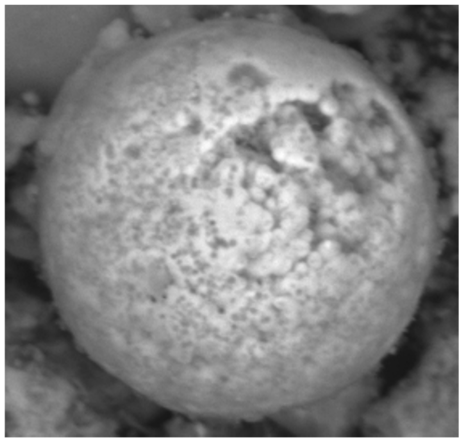


Fig. 6. Sample No. 40, ×500

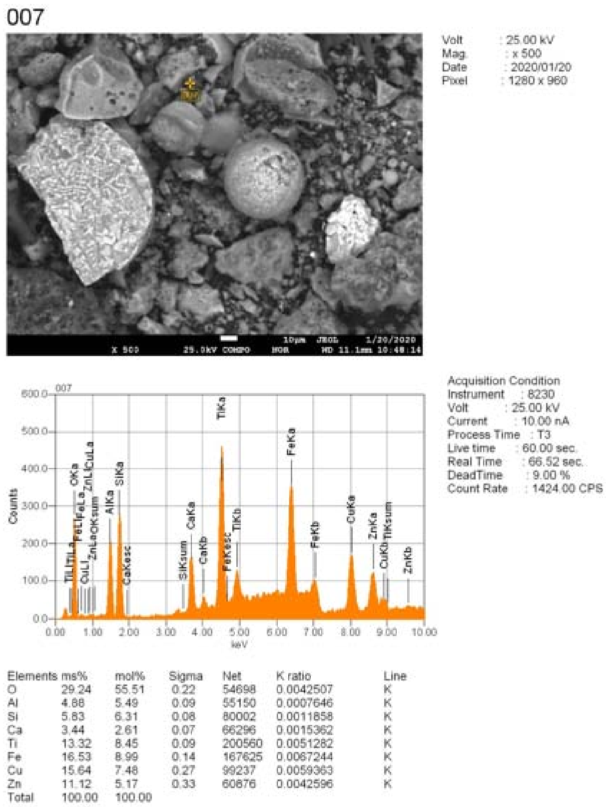


Fig. 7. EDS analysis of sample No. 40

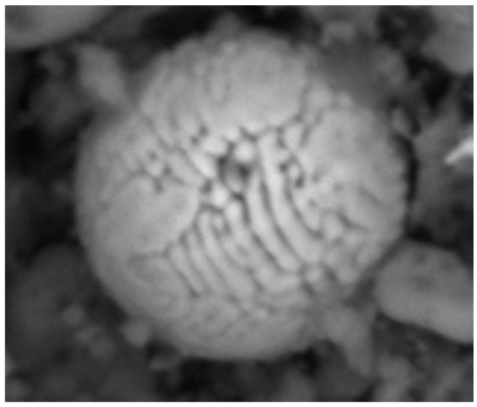
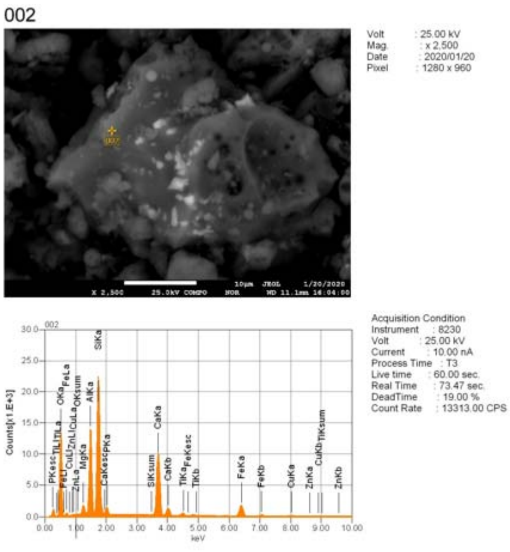


Fig. 8. Sample No. 44, ×500



Elements	ms%	mol%	Sigma	Net	K ratio	Line
O	55.53	71.15	0.40	2764950	0.2541689	K
Mg	1.24	1.04	0.15	356321	0.0059893	K
Al	9.91	7.53	0.13	3775293	0.0619112	K
Si	16.94	12.37	0.14	6568161	0.1151617	K
P	1.33	0.88	0.16	416175	0.0120582	K
Ca	10.43	5.33	0.17	4265626	0.1169160	K
Fe	4.63	1.70	0.35	974022	0.0462199	K
Total	100.00	100.00				

Fig. 9. EDS analysis of sample No. 44

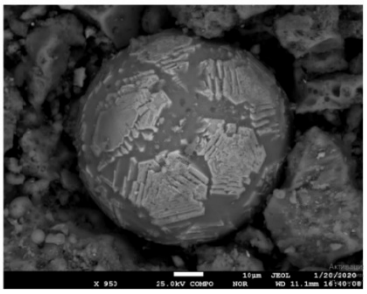
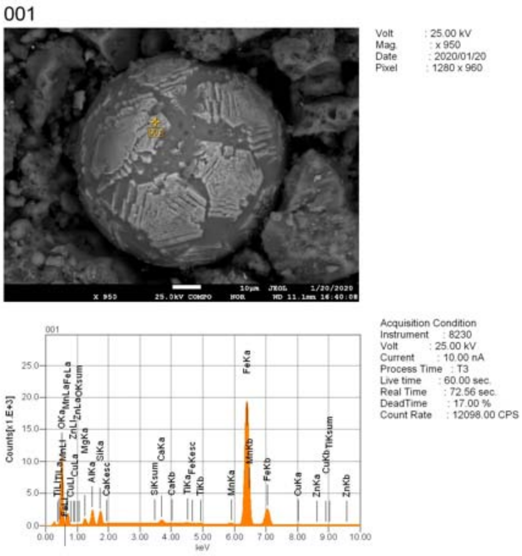


Fig. 10. Sample No. 46, ×950



Elements	ms%	mol%	Sigma	Net	K ratio	Line
O	30.62	57.97	0.17	2245555	0.2073004	K
Mg	1.74	2.17	0.18	242549	0.0040943	K
Al	2.96	3.33	0.14	590214	0.0097201	K
Si	2.38	2.57	0.13	591095	0.0104079	K
Ca	0.65	0.49	0.12	227965	0.0062748	K
Ti	0.41	0.26	0.14	118777	0.0036078	K
Fe	61.24	33.22	0.23	11094826	0.5287159	K
Total	100.00	100.00				

Fig. 11. EDS analysis of sample No. 46

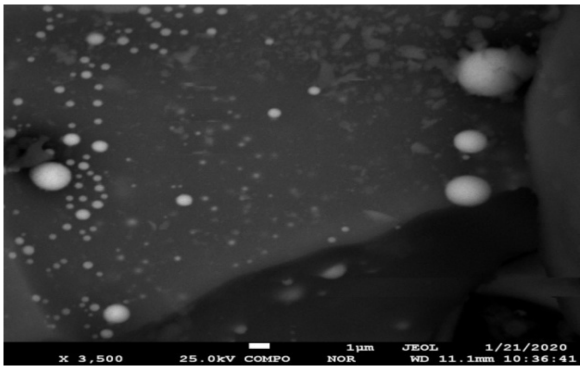
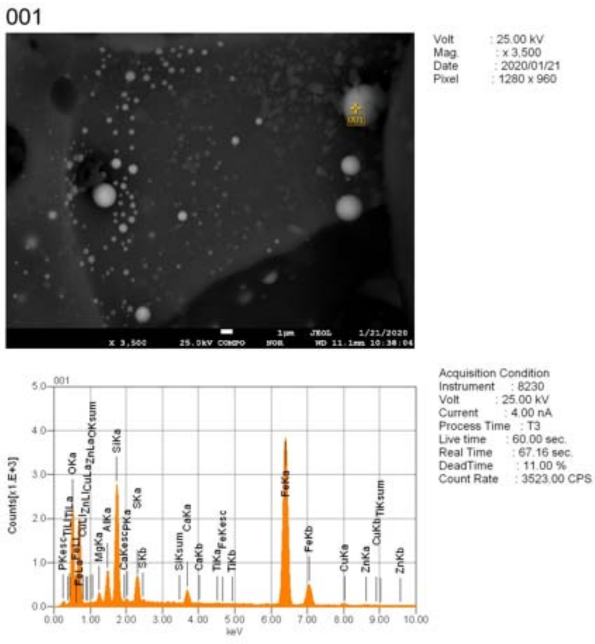


Fig. 12. Spherical microspheres. Sample No. 46, ×3500



Elements	ms%	mol%	Sigma	Net	K ratio	Line
O	30.79	54.67	0.19	472971	0.2619650	K
Mg	1.32	1.54	0.14	54139	0.0054830	K
Al	3.51	3.69	0.12	202914	0.0200495	K
Si	11.69	11.83	0.11	817748	0.0863888	K
P*	0.35	0.32	0.11	22508	0.0039294	K
S	2.98	2.64	0.09	221151	0.0305303	K
Ca	1.33	0.94	0.11	115223	0.0190284	K
Ti*	0.09	0.05	0.13	6187	0.0011275	K
Fe	46.75	23.78	0.22	2163271	0.6185082	K
Cu*	0.76	0.34	0.43	21365	0.0091086	K
Zn*	0.43	0.19	0.52	10422	0.0051976	K
Total	100.00	100.00				

Fig. 13. EDS analysis sample No. 46, ×3500

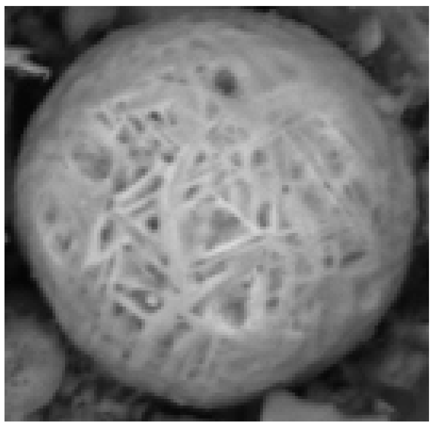


Fig. 14. Sample No. 46 × 250

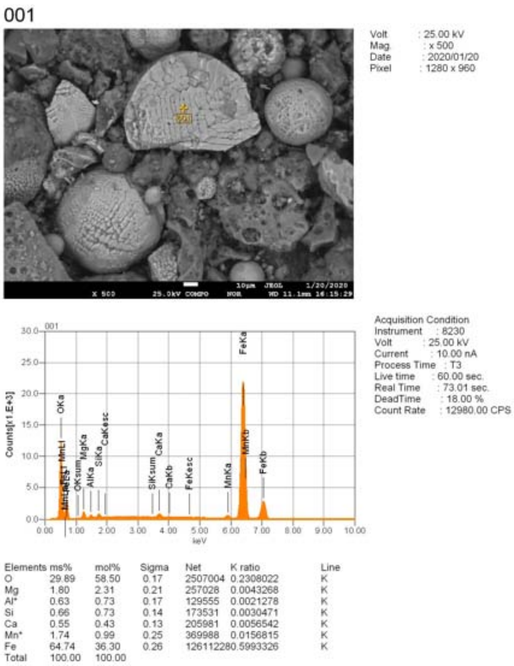


Fig. 15. EDS analysis sample No. 46, ×250

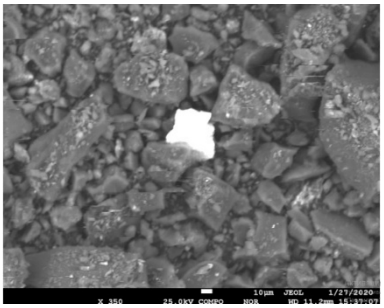


Fig. 16. Carbon concentrate, ×350

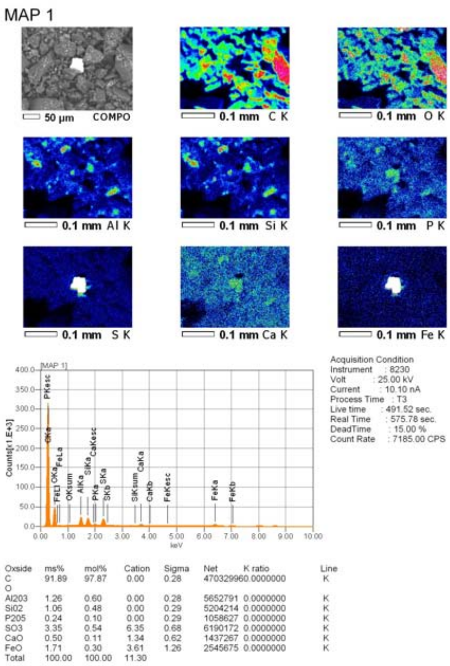


Fig. 17. EDS analysis of carbon concentrate, ×350

Energy dispersive analysis of the spectrum of samples (EDS analysis) from the surface of microspheres has showed that the main elements of microsphere shells are Al, Si, Ca, Fe, K, S, Ti, Mg, Mn, Cu, Zn and O [31, p. 75].

According to EDS analysis, the average elemental composition of the microspheres is given in Table VII. It should be noted that the composition of microspheres is very heterogeneous for all samples, and this heterogeneity is also manifested for particles of the same sample with the same morphological characteristics. Figure 18 shows the EDS spectrum of the same morphology of microsphere particles of sample No. 42. Globules with shells can also be seen, similar to the crystallization structure of molten metal. Figure 19 shows the chemical composition of sample No. 42. The area marked with a yellow square may suggest the content of phases resembling fayalites, magnetite, gortonolite, ferrite, spinel, ganite or pre-eutectic silumins. Based on the quality of the flotation enrichment products obtained, their further direction can be determined:

- *Carbon concentrates* 3: it can be used as raw materials for pulverized combustion at thermal power plants in the form of fuel briquettes.
- *Cleaning tails* 3 (microspheres): GOST 28584-90 Refractories and refractory raw materials can be used in the oil industry, construction, ceramics, plastics, automotive industry.
- *Tailings of enrichment* 3: it can be used as raw materials in the production of alumina by the alkaline method and will be the object of our further research.

TABLE VII
EDS 500 MAPB (WT.%)

Element	Sample No. 40	Sample No. 42	Sample No. 44	Sample No. 46
O	47,27	49,66	50,77	44,59
Mg	0,44	0,29	0,32	0,72
Al	6,56	7,13	8,33	7,79
Si	9,92	11,95	14,05	13,11
S	0,77	0,06	-	-
K	0,14	0,26	0,31	0,21
Ca	1,36	0,97	1,35	2,26
Ti	0,39	0,29	0,56	0,36
Mn	0,29	0,13	-	0,92
Fe	8,93	3,37	2,49	29,20
Cu	0,58	0,60	0,64	0,46
Zn	0,47	0,44	0,52	0,38
Total	100,00	100,00	100,00	100,00

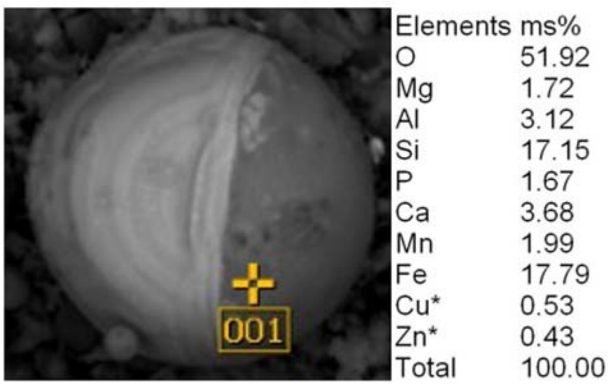
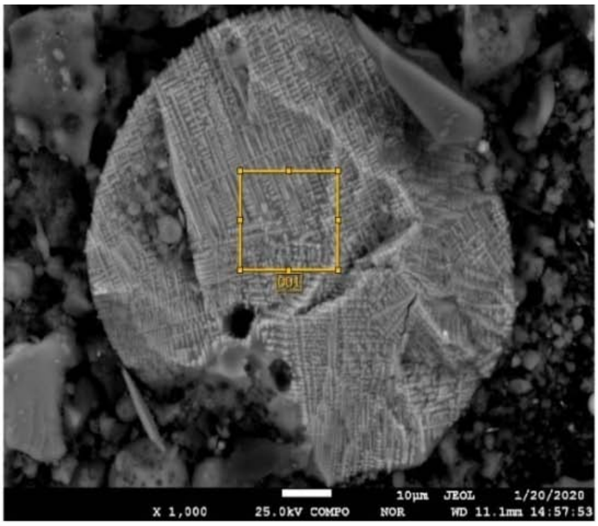
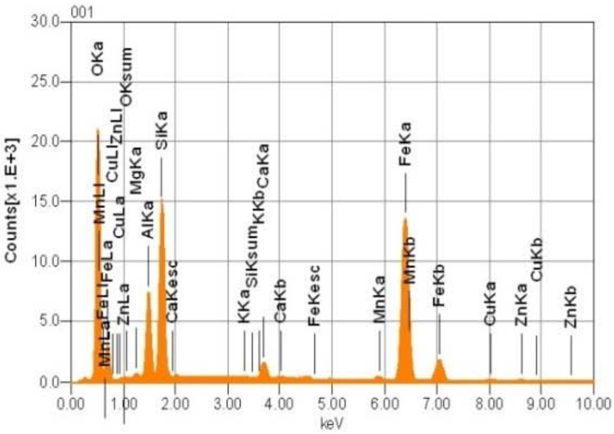


Fig. 18. Samples No. 42, ×650





Elements	ms%	mol%	Sigma	Net	K ratio	Line
O	46.42	69.16	0.23	4174344	0.3733804	K
Mg*	0.33	0.32	0.20	73762	0.0012064	K
Al	5.99	5.29	0.16	1922259	0.0306732	K
Si	11.55	9.80	0.15	4267647	0.0728083	K
K*	0.08	0.05	0.15	37229	0.0010259	K
Ca	1.30	0.77	0.16	589129	0.0157119	K
Mn*	0.94	0.41	0.31	242430	0.0099831	K
Fe	32.37	13.82	0.32	7658798	0.3536303	K
Cu*	0.53	0.20	0.62	77600	0.0053429	K
Zn*	0.49	0.18	0.76	61553	0.0049573	K
Total	100.00	100.00				

Fig. 19. Sample No. 42, ×1000

Then the resulting products will be used in the production of ceramics, in the production of coal briquettes, in construction, and the resulting enrichment tailings will be directed to the production of alumina concentrate by hydrometallurgical method with further extraction of alumina and other valuable components.

IV. Conclusion

Based on the results of the conducted research, the following conclusions can be made:

1. Experiments on the separation of carbon concentrate (underburning) from ash and slag waste by flotation enrichment have shown that the most optimal separation of carbon concentrate (underburning) is achieved with the use of activated ash and slag waste;
2. As a result of the experiments conducted by using the reagent mode of the kerosene collector 1500 g/t and the MIBK 50 g/t foamer, a carbon concentrate with a carbon content of 65% has been obtained; carbon extraction into the concentrate has been 37.6%, the yield has been 4.14% when using activated ash and slag waste;
3. Electron microscopy of ash and slag waste after flotation enrichment has showed that the samples represent various structures and irregular shapes of globules with a variety of morphological features: ideal spheres with an intact smooth or perforated surface, hollow cenospheres, plerospheres (sample 46), aggregates of small spheres on the surface or in cavities and depressions of large globules. According to SOMRO, the particle size averages 1-150 microns. The smaller the particle size is, the more spherical they are. Moreover, energy dispersion analysis of the sample spectrum (EDS analysis) from the surface of microspheres has showed that the main elements of the shells of microspheres are Al, Si, Ca, Fe, K, S, Ti, Mg, Mn, Si, Zn and O.

Energy dispersion analysis has revealed that the composition of microspheres is very heterogeneous for all the samples, and this heterogeneity is also manifested for particles of the same sample with the same morphological characteristics.

Based on the experiments conducted on flotation enrichment, the application of the obtained products has been determined. The cleaning tails will be used in the production of ceramics and construction. The enrichment tails will be used in the production of alumina concentrate and commercial alumina, and the resulting carbon concentrate (underburning) will be used in the production of coal briquettes.

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References

[1] Zhang, T., H. Yang, H. Zhang, P. Zhang, and R. Bei. Aluminum Extraction from Activated Coal Gangue with Carbide Slag. *Journal of Analytical and Applied Pyrolysis*. 2022. 163:105504. doi: https:// doi.org/10.1016/j.jaap.2022.105504

[2] Bayandy Dikhanbaev, Aristan B. Dikhanbaev, Ibray Sultan, Artur Rusowicz. Development Of Hydrogen-Enriched Water Gas Production Technology By Processing Ekibastuz Coal With Technogenic Waste, *Archive Of Mechanical Engineering* Vol. Lxv 2018 Number 2. doi: 10.24425/123022

[3] Bakirov A.G., Abdulina S.A., Zhunusov A.K. Investigation of the chemical and mineralogical composition of ash and slag wastes of the Eurasian Energy Company, *Bulletin of D.Serikbaev EKSTU*. -

2019. – No. 2. – pp. 25-29.
[4] Akhmadiyeva, N.; Abdulvaliyev, R.; Gladyshev, S.; Kassymzhanova, A. Hydrochemical Method for the Production of Alumina from Nepheline Using Effective Calcium Reagents. *Processes* 2024, 12, 1355.
doi: https://doi.org/ 10.3390/pr12071355
[5] Panda, S. S., & Jena, B.. Yield behaviour of two-way reinforced concrete fly ash brick slab. In eds. Bibhuti Bhusan Das, Salim Barbhuiya, Rishi Gupta, Purnachandra Saha. *Recent Developments in Sustainable Infrastructure* (2021), (pp. 405–414). Springer.
[6] Apua, M. C., and B. D. Nkazi. Leaching of Coal Fly Ash with Sulphuric Acid for Synthesis of Wastewater Treatment Composite Coagulant. *Canadian Metallurgical Quarterly* 2022, 61 (3): 309–331.
doi: https://doi.org/10.1080/00084433.2022.2044689
[7] Cao, P., G. Li, H. Jiang, X. Zhang, J. Luo, M. Rao, and T. Jiang. Extraction and Value-Added Utilization of Alumina from Coal Fly Ash via One-Step Hydrothermal Process Followed by Carbonation. *Journal of Cleaner Production* 2021, 323:129174.
doi: https://doi.org/10.1016/j.jclepro.2021.129174
[8] Fan, X. L., J. L. Xia, D. R. Zhang, Z. Y. Nie, Y. P. Liu, L. J. Zhang, and D. Y. Zhang. Highly- Efficient and Sequential Recovery of Rare Earth Elements, Alumina and Silica from Coal Fly Ash via a Novel Recyclable ZnO Sinter Method. *Journal of Hazardous Materials* 2022, 437:129308.
doi: https://doi.org/10.1016/j.jhazmat.2022.129308
[9] Gao, X. B., Q. S. Zhou, Y. L. Wang, T. G. Qi, L. T. Shen, G. H. Liu, Z. H. Peng, and X. B. Li. Coal Fly Ash Resource Utilization: Structure of Siloxy Group of High-Modulus Sodium Silicate Solution. *Process Safety and Environmental Protection* 2023, 171:396–404.
doi: https://doi.org/10.1016/j. psep.2023.01.022
[10] Huang, Q. P., X. B. Li, T. G. Qi, Z. H. Peng, G. H. Liu, and Q. S. Zhou. Dynamic Expansion Experiment of Efficient Separation of Aluminum and Silicon from Coal Fly Ash. *The Chinese Journal of Nonferrous Metals* 2022, 32:173–182.
doi: doi.org/10.11817/j.ysxb.1004.0609.2021-36669
[11] Li, X. B., P. Wang, H. Y. Wang, Q. S. Zhou, T. G. Qi, G. H. Liu, Z. H. Peng, Y. L. Wang, and L. T. Shen. The Alkaline Leaching Behavior of Silica Solid Solutions in the Product Obtained by Roasting the Mixture of High-Alumina Coal Gangue and Hematite. *Journal of Sustainable Metallurgy* 2022, 8(4):1853–1865.
doi: doi.org/10.1007/s40831-022-00615-8
[12] Rezaei, H., S. Ziaedin Shafaei, H. Abdollahi, A. Shahidi, and S. Ghassa. A Sustainable Method for Germanium, Vanadium and Lithium Extraction from Coal Fly Ash: Sodium Salts Roasting and Organic Acids Leaching. *Fuel* 2022, 312:122844.
doi: https://doi.org/10.1016/j.fuel.2021.122844
[13] Valeev, D., I. Kunilova, A. Shoppert, C. Salazar-Concha, and A. Kondratiev. High-Pressure HCl Leaching of Coal Ash to Extract Al into a Chloride Solution with Further Use as a Coagulant for Water Treatment. *Journal of Cleaner Production* 2020, 276:123206.
doi: https://doi.org/10.1016/j.jclepro. 2020.123206
[14] Wang, P., H. Liu, F. Zheng, Y. Liu, G. Kuang, R. Deng, and H. Li. Extraction of Aluminum from Coal Fly Ash Using Pressurized Sulfuric Acid Leaching with Emphasis on Optimization and Mechanism. *Jom* 2021, 73 (9): 2643–2651.
doi: https://doi.org/10.1007/s11837-021-04801-z
[15] Wang, H. Y., X. X. Zhang, C. Liu, and L. T. Shen. Comprehensive Extraction of Silica and Alumina from High-Alumina Coal Gangue (HACG): Hematite Involved Roasting − alkaline Leaching − bayer Digestion Process. *Journal of Sustainable Metallurgy* 2021, 7 (4): 1686–1698.
doi: https:// doi.org/10.1007/s40831-021-00433-4
[16] Wu, L.; Ma, L.; Huang, G.; Li, J.; Xu, H. Distribution and Speciation of Rare Earth Elements in Coal Fly Ash from the Qianxi Power Plant, Guizhou Province, Southwest China. *Minerals* 2022, 12, 1089.
doi: https://doi.org/10.3390/min12091089
[17] Shoppert, A.; Valeev, D.; Loginova, I. Kinetics of Aluminum and Scandium Extraction from Desilicated Coal Fly Ash by High-Pressure HCl Leaching. *Metals* 2023, 13, 1994.
doi: https://doi.org/10.3390/met13121994
[18] Yusop, H.; Suhatril, M.; Abdul Hamid, M.A.H.; Zainal, F.; Fauzan, M.d.; Yapandi, M.F.K.; Abbas, N.A. Usage of Coal Fly Ash and Bottom Ash from Ash Ponds for Bricks and Precast Concrete Blocks-A Review. *J. Sustain. Civil Eng. Technol*. 2022, 1, 50–62.
[19] Panda, L.; Dash, S.; Kar, B.; Panigrahi, S.; Mohanty, I. Alkaline Hydrothermal Synthesis of Zeolite from Class F Coal Fly Ash. *J. Solid Waste Technol. Manag.* 2021, 47, 674–681.
[20] Liu, C.-J.; Zhao, A.-C.; Ye, X.; Zhao, Z.; Yang, X.-R.; Qin, Y.-M.; Zhang, T.-A. Kinetics of Aluminum Extraction from Roasting Activated Fly Ash by Sulfuric Acid Leaching. *MRS Commun*. 2023.
[21] Shi, Y.; Jiang, K.; Zhang, T. Cleaner Extraction of Alumina from Coal Fly Ash: Baking-Electrolysis Method. *Fuel* 2020, 273, 117697.
[22] Rui, H.; Zhang, L.; Li, L.; Zhu, L. Solvent Extraction of Lithium from Hydrochloric Acid Leaching Solution of High-Alumina Coal Fly Ash. *Chem. Phys. Lett.* 2021, 771, 138510.
[23] Aphane, M.E.; Doucet, F.J.; Kruger, R.A.; Petrik, L.; Van Der Merwe, E.M. Preparation of Sodium Silicate Solutions and Silica Nanoparticles from South African Coal Fly Ash. *Waste Biomass Valor.* 2019, 11, 4403–4417.
[24] Ji, H.; Mi, X.; Tian, Q.; Liu, C.; Yao, J.; Ma, S.; Zeng, G. Recycling of Mullite from High-Alumina Coal Fly Ash by a Mechanochemical Activation Method: Effect of Particle Size and Mechanism Research. *Sci. Total Environ.* 2021, 784, 147100.
[25] Yadav, V.K.; Amari, A.; Mahdhi, N.; Elkhaleefa, A.M.; Fulekar, M.H.; Patel, A. A Novel and Economical Approach for the Synthesis of Short Rod-Shaped Mesoporous Silica Nanoparticles from Coal Fly Ash Waste by Bacillus Circulans MTCC 6811. *World J. Microbiol. Biotechnol.* 2023, 39, 289.
[26] A. B. Kuandykov, A. G. Bakirov , A. K. Zhunusov, P. O. Bykov. Grain filters from ash ekibastuz are used for refining first aluminum. *Science and Technology Of Kazakhstan*. ISSN 2788-8770. №4, 2022.
doi: https://doi.org/10.48081/KOZV9746
[27] Bykov P., Kuandykov A., Zhunusov A. Refining of Primary Aluminum from Vanadium, *Defect and Diffusion Forum*. 2021 (410) 405-410.
[28] Bergenzhanova, G., Sakitzhanov, M., Olzhabayeva, K., Rasmukhametova, A., Sultanova, L., Analysis of the Chemical Composition of Ash and Slag Waste from Solid Fuel Combustion for Sale as Raw Materials, (2023) *International Review of Mechanical Engineering (IREME)*, 17 (2), pp. 57-62.
doi: https://doi.org/10.15866/ireme.v17i2.23166
[29] Bakirov, A., Abdulina, S., Zhunusov, A., Oleinikova, N. Preliminary Chemical Activation of Ash Waste with Release of Carbon Concentrate. *Chemical Engineering Transactions*. 2021 (88) 973–978.
[30] Bakirov A.G., Abdulina S.A., Zhunusov A.K., Bulenbaev M.J. Technology of processing ash and slag waste of thermal power plants by sintering, *Proceedings of the University of Karaganda Technical University*. – 2022. – No. 4. – pp.103–107.
[31] Bakirov A.G., Abdulina S.A., Zhunusov A.K., Ibraeva G.M. Study of aluminosilicate microspheres from ash and slag waste of the Aksu State District Power Plant using Ekibastuz coal, *Bulletin of EKSTU named after D. Serikbaev*. – 2020. – No. 4. – P.72 – 77.
[32] Kenzhaliev B.K., Abdulvaliev R.A., Gladyshev S.V., Dyusenova S.B., Omarova S.A., Imangalieva L.M. Method of chemical activation of mineral raw materials, B.K. Kenzhaliev, R.A. Abdulvaliev, S.V. Gladyshev, S.B. Dyusenova, S.A. Omarova, L.M. Imangalieva, *Materials of the XXIII International Scientific and Technical Conference "Scientific foundations and practice of processing ores and man-made raw materials"*. – Yekaterinburg, 2018. – pp. 314-316.
[33] Modification of the phase composition of low-grade gibbsite-kaolinite bauxites Abdulvaliyev R.A., Dyussenova S.B., Manapova A.I., Akcil A., Beisenbiyeva U.Zh., *Complex Use of Mineral Raw Materials*. – 2021. – № 2. – P. (317).
[34] Abdulvaliev R.A., Gladyshev S.V., Dyusenova S.B., Imangalieva L.M. Enrichment of kaolinite clay of the Alekseevsky deposit / R.A.Abdulvaliev, S.V. Gladyshev, S.B. Dyusenova, L.M. Imangalieva, *Collection of abstracts of the XIV International conference dedicated to the 40th anniversary of the Institute of Chemistry and Chemical Technology of the Siberian Branch of the*

Russian Academy of Sciences. – Krasnoyarsk: Siberian Federal University, 2021. – pp. 134-136.

[35] A. Grzebielec, A. Rusowicz, and A. Szel ̨agowski. Air purification in industrial plants producing automotive rubber components in terms of energy efficiency, *Open Engineering*, 7(1):106–114, 2017. doi: 10.1515/eng-2017-0015

[36] Yang, L.; Zhu, Z.; Li, D.; Yan, X.; Zhang, H. Effects of particle size on the flotation behavior of coal fly ash, *Waste Manag*. – 2019. – Volume 85. – P. 490–497.

[37] Valeev D., Kunilova I., Alpatov A., Varnavskaya A., Ju D. Magnetite and Carbon Extraction from Coal Fly Ash Using Magnetic Separation and Flotation Methods. *Minerals*. - 2019. – Volume 9(5), 320. – P. 1–13. doi: https://doi.org/10.3390/min9050320 10.3390/min9050320

[38] Yang, L.; Li, D.; Zhu, Z.; Xu, M.; Yan, X.; Zhang, H. Effect of the intensification of preconditioning on the separation of unburned carbon from coal fly ash, *Fuel* 2019. – Volume 242. – P. 174–183.

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