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Geo-economical Assessment of the Prospects for Processing Ash and Slag Waste of Coal-fired Power Plants of the Far Eastern Region of Russia

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Abstract

The prospects of further accumulation of waste in the form of ash and slag at power plants of the Far Eastern district are analysed. New approaches to disposal and recycling of waste (ash, slag) of pulverized coal-fired power plants are suggested. Main directions of ash and slag disposal are considered. Technical solutions for processing ash and slag in construction materials are presented. Availability of significant precious metals reserves concentrated in the waste of power plants of the Far Eastern district is ascertained. Technical and economic calculations confirming the effectiveness of precious metals obtaining when processing ash and slag of the pulverized coal-fired power plants are carried out.

Keywords: technogenic deposits, waste of power production industry enterprises, ash and slag waste, integrated processing of mineral raw materials.

INTRODUCTION

In the general problem of increasing accumulation of waste one of the key places both in the world and in Russia occupy ash and slag waste (ASW) of power production industry. According to the data of power companies, about 90 million tons of ash and slag waste is generated annually in thermal power plants (TPP) and boiler houses which burn solid fuel. The amount of accumulated ash and slag waste in Russia is 1,300 million tons [1]. The area of land contaminated by ash dumps of TPP exceeds 22 thousand hectares [2].

The global and Russian trends in amounts of ASW formation naturally follow changes in the coal consumption in power plants and boiler houses. It is evident that fuel balances by regions and individual countries have their own features, but in general, in the global fuel market takes place the growth of coal consumption in absolute and percentage indices [3].

The fuel balance structure of the Far Eastern economic region (FEER), according to the data of Institute of Economic Researches FEB RAS, differs significantly from the all-Russia [4]. If in the fuel balance of power plants of the European part of Russia, the Urals and Siberia, the coal fraction is 28%, and the gas fraction is 64% [2], the coal fraction in the structure of boiler and furnace fuel consumption of East UPS is currently 85% of primary energy resources [4]. Forecast data on the coal fraction in the total balance of FEER energy carriers, which includes oil, gas, hydro resources, renewable alternative energy sources, nuclear energy are shown in Table 1.

Table 1 - Coal fraction in the fuel balance of FEER [4]

Administrative territories of FEER	Coal in the structure of energy potential,%
1. Primorsky Territory	68
2. Khabarovsky Territory	65
3. Republic of Sakha (Yakutia)	62
4. Sakhalin Region	60
5. Amur Region	58
6. Magadan Region	24
7. Chukotka Autonomous District	56
8. Kamchatka Region, including Koryaksky AD	50
In total by FEER	56.5

The forecast of coal consumption for FEER for the period up to 2020 is prepared by "Energosetproject" Institute in Vladivostok (Table 2) [5].

For power plants of Primorsky Territory the main fuel remains to be local brown coal with a corresponding development of the coal industry. Based on the available data, there is every reason to claim that the coal consumption in power plants of Primorsky Territory and ASW formation amounts will not change significantly.

Table 2 - Forecast of maximum demand for coal in million tons [5]

Administrative territory of FEER	**2010**	**2015**	**2020**	**Growth for the period**
Primorsky Territory	16.7	17.5	17.8	1.07
Khabarovsky Territory	12.8	13.9	14.0	1.09
Amur Region	6.1	6.3	7.9	1.30
Magadan Region and Chukotka Autonomous District	2.2	2.4	2.4	1.09
Sakhalin Region	1.9	0.5	0.5	0.26
In total throughout FEER	39.7	40.6	42.6	1.07

Assessment of ASW formation amounts is expedient from both environmental and commercial point of view. The value of ash and slag waste as a raw materials resource bases for various sectors of industry is substantiated by numerous studies [2, 6, 7]. Considering the fact that the raw stock are constantly moving away from processing places - that is especially characteristic for the building industry - ASW can become an important source of raw materials for various sectors of industry. Therefore, the problem of processing ash and slag waste deserves particular attention.

RESEARCH METHODS

As research objects, ASW were studied from warehouses and landfills of TPPs of Khabarovsk, Birobidzhan, Primorsky Territory, and with less detail a number of other objects.

In the field study of ASW, the sampling of ash dumps and coals burned at TPP, the ash sampling in systems of transportation from furnaces (boilers) to ash dumps with the analysis of combustion and transportation technology were carried out. Testing ash dumps themselves was carried out by drifting in accessible places on a sparse network of mole-hole operations and pits with sampling therein by trench or bulk method.

Samples were divided into three parts (sub-samples). One portion was subjected to spectral, atomic absorption and X-ray fluorescence analysis, the other was used as a small technology sample with determination in it useful components using laboratory technology researches and the third was washed on the tray or processed at a laboratory concentrator. Its heavy fraction was subjected to the mineralogical analysis, which was used for studying both ASW composition and obtained concentrates, determining the yield of precious metals and other products of enrichment.

Diagnostics of platinum group minerals (PGM), native minerals and alloys was carried out using micro-probe analysis at the Institute of Volcanology of the Far Eastern Branch of the Russian Academy of Sciences (FEB RAS). Individual samples were studied for the presence of PGM in Novosibirsk at the Joint Institute of Geology, Geophysics and Mineralogy of the Siberian Branch of the Russian Academy of

Sciences and in Vladivostok at the Institute of Chemistry FEB RAS and Far Eastern Geological Institute FEB RAS. In order to control the determination of precious metals, a portion of samples was subjected to fire assay tests.

The chemical composition of samples was determined by X-ray fluorescence analysis (XRF) method using Shimadzu EDX 800 HS spectrometer (tube with rhodium anode, vacuum) at a room temperature.

The content of precious and rare earth metals in ASW samples was determined by atomic absorption spectrophotometry (AAS) method. To determine Au, Pt and Pd content, samples were decomposed sequentially with HF + HNO_3 acid, followed by Te co-precipitation according to TsNIGRI-2005 procedure. To determine the content of Ag, samples were decomposed sequentially with HCl + HNO_3 acid. Measurement of Au, Pt, Pd and Ag content was carried out on the atomic absorption spectrophotometer Shimadzu 6800. Weighed portions of 2 g were used for the studies.

As an alternative method of determination of ASW gold content, the method of instrumental neutron activation analysis (NAA) was used on the compact NAA set-up with a radionuclide source of excitations based on ^{252}Cf developed at the Institute of Chemistry FEB RAS. For measurements of induced activity of samples the spectrometric system was used, made on the basis of the coaxial Ge detector GC2018 manufactured by Canberra company and data processing unit SBS-75. The program "Gamma analyser for semiconductor detectors," version 1.0 was used for processing of measurement results.

When carrying out mineralogical studies, the scanning electron microscope (SEM) JSM-6490LV (JEOL, Japan) was used, which was equipped with the energy-dispersive spectrometer (EDS) INCA Energy and System of microanalysis for wave dispersion spectrometer (WDS) INCA Wave. This X-ray micro-analyser with the electron probe allows carrying out the quantitative concentration determination analysis of a wide range of chemical elements (from B to U) in the range of 0.001 - 100 % by weight. Lateral locality is 2-5 um.

Concentrators of "Russian Klondike", "Itomak", "Knelson" companies, multifunctional concentrating plant of V.T. Kardash in FEFU (hereinafter MFP) designed for the extraction of fine gold were used for extraction of precious metals and ASW separation into components.

Studies of the possibility to use ASW for production of building materials and road construction were carried out in the city of Khabarovsk on a contractual basis by employees of "Building materials" departments of Far Eastern State University of Railway Engineering (FESURE) and Pacific State University (PSU).

For studies samples were taken from the following facilities:

1) Ash dumps of TPP-1 and TPP-2 were sampled in Khabarovsk. At the ash dumps pits and mole-hole operations were sunk throughout the network of 100x200 m and 100x200 m (depending on size), which were sampled by trench and tear method. At TPP-1 samples were taken from ash dumps No.1-3, at TPP-3 sampling was carried out from the ash dump No.1.
2) At Birobidzhan TPP ash dump No.1 with the size of 359x400 m and the depth of filling 8-10 m was sampled. The ash dump is defined by 27 run-off-mine

samples, 4 group samples and three small technological samples weighing 30-50 kg. ASW varieties, conveying pulp, coals burned at sampling time and coals of Ushumunskoye field located near and being under exploration.

3) In Primorsky Territory samples were taken from landfills of the following areas: city of Vladivostok, TPP-2; city of Artem, TPP; city of Bolshoy Kamen, TPP; city of Arsenyev, TPP; city of Partizansk, state district power station (SDPS); city of Luchegorsk, Primorskaya SDPS. 57 samples were taken in total.

For calculation of consolidated technical and economic performances of an enterprise for integrated ASW processing, the computer model was used which was designed for the rapid assessment of investment projects of various branches, scales and trends. "Al-Invest-Prim", version 5.0.

RESULTS AND DISCUSSION

ASW storages should be categorized as technogenic raw stock of put-up demand. Chemical and mineralogical composition of ash and slag waste indicates that it is more correctly to consider them as enriched raw materials for various industries. Ash and slag waste are mainly environmentally harmless, preservative properties of ash and slag waste allow using them for landfill and disposal of others, including hazardous waste. ASW are relatively easily processed into saleable products, contain commercially significant quantities of valuable components, such as compounds of ferrous and non-ferrous metals, precious metals and rare earth elements [5, 8, 9, 10, 11].

At examined TPP the coal combustion takes place at temperature 1,100-1,600°C. At combustion of the organic coal portion volatile compounds are produced in the form of smoke and vapour, and the incombustible mineral portion of a fuel escapes in the form of solid ash residues forming dust-like mass (ash), as well as lumpy slags. The amount of solid residues for bituminous and brown coals ranges from 15 up to 40%.

At combustion of atomized fuel small and light particles are whirled with flue gases, and they are called flue ash. The particle size of the flue ash ranges from 3-5 up to 100-150 um. The amount of larger particles usually does not exceed 10-15%. Flue ash is caught by ash collectors. At TPP-1 in Khabarovsk and Birobidzhan TPP ash collection is wet on scrubbers with Venturi tubes, at TPP-3 and TPP-2 in Vladivostok - dry on electrostatic precipitators.

Heavier ash particles settle on sub-fireboxes and are fused into lumpy slags representing aggregated and fused ash particles ranging in size from 0.15 up to 30 mm. Slags are ground and removed with water. Flue ash and pulverized slag are removed at first separately, next they are mixed forming a mixture of ash and slag.

In the composition of ash and slag mixture, besides ash and slag there are always present particles of unburned fuel (incomplete burning), the amount of which is 10-25%. The amount of a flue ash, depending on the type of boilers, fuel type and its combustion regime can be 70-85% by weight of the mixture, 10-20% of slag. Ash and slag pulp is removed to the ash dump via pipelines.

Averaged ASW chemical composition of examined TPP is shown in Table 3.

Table 3 - Limits of the average content of main ASW components

Component	Average content %		Component	Average contents %	
	From - to	Average		From - to	Average
SiO_2	51 - 60	54.5	CaO	3.0 - 7.3	4.3
TiO_2	0.5 - 0.9	0.75	Na_2O	0.2 - 0.6	0.34
Al_2O_3	16 - 22	19.4	K_2O	0.7 - 2.2	1.56
Fe_2O_3	5 - 8	6.6	SO_3	0.09 - 0.2	0.14
MnO	0.1 - 0.3	0.14	P_2O_5	0.1 - 0.4	0.24
MgO	1.1 - 2.1	1.64	POI	5.8 - 18.8	10.6

The content of impurity elements in ASW samples from TPP in Khabarovsk, according to the data of the spectral semi-quantitative analysis of individual and group samples, is shown in Table 4. Industrial value represents Au and Pt, according to the maximum values Yb and Li are approaching this.

Table 4 - The content of impurity elements in ASW samples from TPP in Khabarovsk, g/ton

Element	TPP-1		TPP-3		Element	TPP-1		TPP-3	
	Average	Max.	Average	Max.		Average	Max.	Average	Max.
Ni	60	100	30	60-80	**Ba**	1,000	3,000	900	1,000
Co	5	100	5	10	**Be**	4	10	2.5	6
Ti	3,000	6,000	3,000	6,000	**Y**	45	100	20	40
V	80	200	80	100	**Yb**	5	10	1	3
Cr	80	2,000	60	600	**La**	-	100	-	60
Mo	1	8	1	-	**Sr**	200	800	100	1,000
W	-	40	-	-	**Ce**	-	300	-	300
Nb	8	20	10	20	**Sc**	10	30	8	10
Zr	200	600	400	800	**Li**	60	300	-	-
Cu	55	100	30	100	**B**	200	300	100	300
Pb	20	100	45	80	**K**	8,000	30,000	7,000	10,000
Zn	60	200	40	100	**Au**	0.07	25	0.07	6
Sn	1	40	1.5	8	**Pt**	0.05	0.50	-	0.20
Ga	15	30	20	30					

According to the data of mineralogical analysis, dominant minerals in the studied ASW samples are meta- and orthosilicates, as well as aluminates, ferrites, alumoferrites, spinels, dendritic clay minerals, oxides: quartz, tridymite, cristobalite, corundum, γ-alumina, calcium oxide, magnesium and others. Are often noted, but in small quantities, ore minerals - cassiterite, wolframite, stanin and others; sulphides - pyrite, pyrrhotine, arsenopyrite and others; sulphates, chlorides, very rarely fluorides. As a result of hydro-chemical processes and weathering processes in ash dumps, secondary minerals appear - calcium, Portlandite, iron hydroxides, zeolites and others.

From ASW components the practical interest in the ash represent precious metals, rare and trace elements, iron-containing magnetic concentrate, secondary coal, aluminium silicate hollow micro-spheres and the inertial mass of aluminosilicate composition.

Carried out studies have shown the presence of gold in a substantial part of studied samples, so the average content of Au in slag samples taken directly at TPP in the city of Khabarovsk, was 1.93 g/ton (18 samples), and in some samples reached 15 g/ton. Content of Au in the flue ash – 0.152 g/ton (12 samples). Carried out ASW study at TPP of Primorsky Territory showed the presence of gold in 29 samples from 57 samples in amounts from 0.2 g/ton to 3.8 g/ton.

Gold in ASW is mainly thin and dust-like, is represented by grains, more rarely cloddy aggregates with the grain size of 5-40 um, rarely larger. According to the data of sieve analysis, the increase in the mass fraction of gold in the most thin size categories is noted. In a number of samples, the content increased in the most large size categories too (due to intergrowths). Maximum dimensions of gold grains 0.5x1.0 mm were met in individual samples in intergrowths with quartz. Shapes of gold grains are irregular, whimsical, dendrite-like, plate-like with rounded and uneven contours, conchoidal, lumpy, wireline, hackly, spherical and drop-shaped.

Carried out analysis made it possible to detect the individual grains of platinum group metals in ASW test samples. Among the grains of platinum group metals according to the results of the analysis are distinguished: ferrous platinum, containing 85-95% Pt, 9-12% Fe and minor additives of Cu, rarely Ni and Si; ferrous platinum with iridium (Pt - 75-90%; Ir – 1-1,5%; Cu up to 1 %; Fe - 9-12% and additive of Rh and Ru); osmium platinum-iridous (Os – 80-90%; Pt – 0,5-15%; Ir – 10-12% with additive of Fe – up to 0.5%); iridium ferrum-platinum-osmious (Ir – 50%; Pt – 15-25%; Fe – 1-3%; Os –20-25%). Admixture of Ru and Ru (0.2-1.0%) is sporadically observed in insignificant amounts (up to 0.6%).

Iron-containing magnetic concentrate obtained from ash and slag waste consists for 70-95% of spherical magnetic aggregates and scale. Other minerals (pyrrhotine, limonite, hematite, pyroxenes, chlorite, epidote) are present in an amount of individual grains to 1-5% by concentrate weight. Besides, rare grains of platinum group metals, as well as alloys of iron-nickel-chrome composition are sporadically observed in the concentrate. The iron content in the concentrate ranges from 50 to 58%. The composition of the magnetic concentrate from ASW of TPP-1 in Khabarovsk: Fe - 53.34%, Mn- 0.96%, Ti – 0.32%, S - 0.23%, P - 0.16%.

At technological research of ASW samples by flotation method, there was incomplete burning of coal. It consists of unburned coal particles and by-products of its thermal processing - coke and coal char. It is characterized by increased calorific power (> 5,600 kcal) and ash content (up to 50-65%). After addition of a heavy fuel oil the incomplete burning can be used as a fuel for TPP or for production of fuel briquettes. The yield of this fraction amounts to up 10-15% by weight of processed ASW. Dimensions of coal particles are 0-2 mm, rarely up to 10mm.

Aluminosilicate hollow micro-spheres represent dispersion material put together by hollow micro-spheres with sizes of 10 to 500 um (Fig. 1). Bulk density of the material is 350-500 kg/m^3, specific - 500-600 kg/m^3. Main components of the phase-mineral composition of micro-spheres are aluminosilicate glass phase, mullite, chrystalline silica. Hematite, feldspar, magnetite, hydrous mica, calcium oxide are present in the form of additive. Predominant components of their chemical composition are silicon, aluminium, iron. Possible are micro-additives of various components in amounts below the threshold for toxicity or industrial significance.

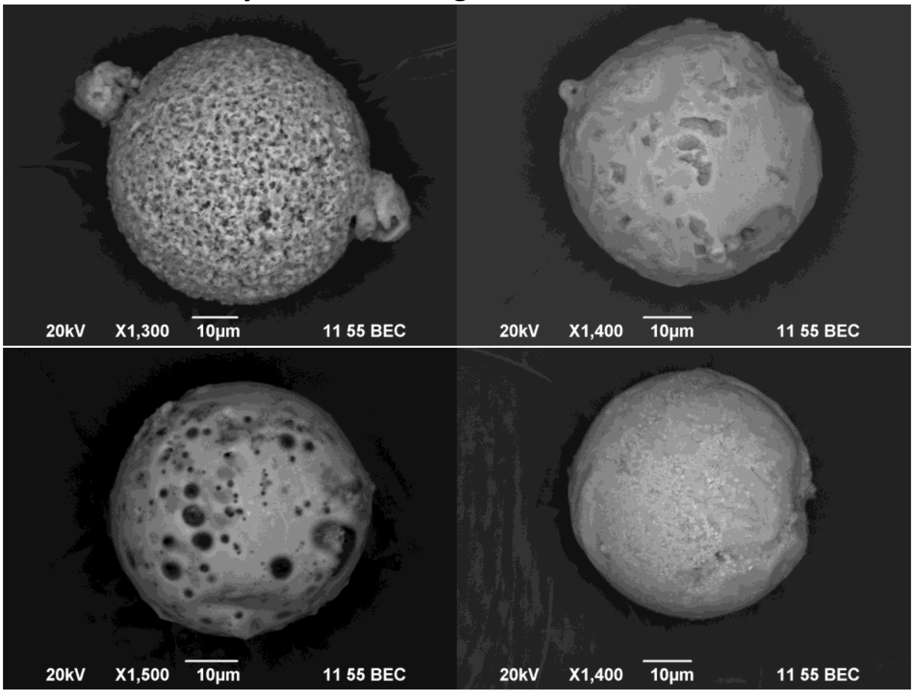

Fig. 1 – Micro-spheres from ASW photographed under a scanning electron microscope

Due to the regular spherical shape and low density, micro-spheres have properties of the excellent filler in the most diverse products. Promising directions of the industrial use of aluminosilicate micro-spheres are production of spheroplastics, road-marking thermoplastics, grout mixes and drilling fluids, thermal insulation radio-transparent and lightweight building ceramics, heat-insulating non-fired materials and heat-resistant concretes [12-14].

The inertial mass of the aluminosilicate composition amounting to 60-70% by ASW weight is obtained after extraction from the ash of all above mentioned concentrates and commercial components. In terms of composition it is close to the overall ash composition, but it will contain an order less iron, as well as harmful and toxic components. Its composition is mainly aluminosilicate. Unlike flue ash, it will have finer uniform grain-size composition (due to regrinding at extracting heavy fraction). By environmental and physical and chemical properties it can be widely used in the production of building materials, construction and as fertilizer - ground limestone substitute.

Taking into account features of the chemical composition, the three-stage variant of ASW processing organization was developed. The first stage is raw material processing. At this technological conversion ASW are fractionated, cleaned of unburned carbon and iron oxides. Commodity products with stable liquidity - high-energy fuel, iron concentrate and sand are produced already at this stage. The second stage is the extraction of concentrates of valuable components. The third stage is the production of building materials and products, including materials for road and cement industries. When implementing proposed integrated technology for ASW processing, almost all 100% become commercial components in the production of saleable products. According to conducted estimates, 28-38% can be used in the production of building materials, 20-25% - concentrates of iron and aluminium, up to 20% - raw materials for cement production, about 10% of the amount can be the production of fuel briquettes from incomplete combustion. Saleable products are fine-grained sands and coarse-grained slag with a volume fraction of 10% each. The obtained data allow proceeding preparation of the investment project for ash and slag waste processing of thermal power plants.

Based on obtained results, the scheme of integrated processing of ash and slag waste, providing environmentally safe and non-waste processing of TPP ASW with a positive economic effect was proposed [15].

The advantage of integrated ASW processing, compared with mono-technologies, lies in combining highly profitable technologies of extraction from ASW of precious (gold, platinum) metals with technologies of ASW bulk processing in raw materials for metallurgical, construction, road, cement industries and building products. At the same time, one of advantages of ASM integrated processing is the possibility to control properties of materials and, as a consequence, increase of their commercial value and growth of sales volumes.

ASW processing system can be a part of the TPP and constitute with it one economic entity. But in a situation when there is no installations of preliminary ash and slag conditioning on TPP, and this situation is typical for thermal power plants of the Far East of Russia, the system can operate as an independent enterprise on dump ASW. The most correct seem to be the combined scheme when an energy company sells to a processing enterprise slag materials, preliminary prepared for processing, and ASW, not subjected to the preparation, simply passes to the system.

A functional flow diagram of the integrated ASW processing was developed for ash dumps of Vladivostok TPP-2. All technological conversions, both in the set and by individual process stages, can be used for virtually any power plant ash dumps. When developing the scheme, it was supposed to solve two main tasks - to ensure production economic effectiveness and organize bulk processing of the industrial waste. This scheme is shown in Fig.2.

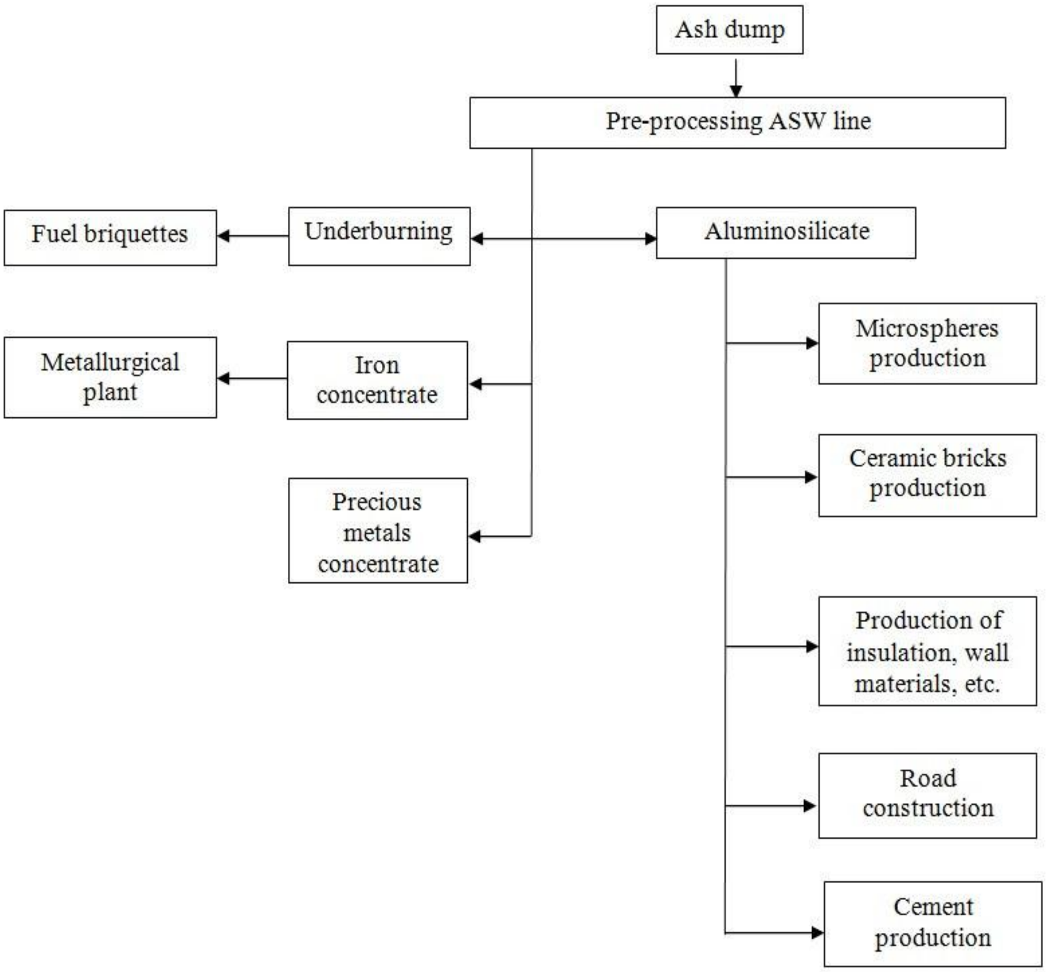

Fig. 2 - Functional flow diagram of the integrated processing of dump ASW

Some building materials, tried out in conjunction with the Far Eastern Research Institute for Construction production technologies, have passed pilot production test under production conditions of Primorsky Territory enterprises [16]. The multidisciplinary scientific and applied work for involvement of ash and slag waste of thermal power plants of the Russian Far East in production and economic sphere was performed. The following activities were implemented during the researches:

- technologies of production from ASW of building materials and products with improved characteristics were developed and tried out under conditions of existing plants of Primorsky Territory ;
- detailed design of the plant for production of building materials from ASW was developed and approved;
- marketing researches of-building materials market for the city of Vladivostok were performed;
- basic technical solutions for reconstruction of the ash-handling system of Vladivostok TPP-2 were developed in order to obtain conditional raw materials;

- ash handling system of Vladivostok TPP-2 was equipped with the installation for withdrawal of the dry ash from electrostatic precipitators of boilers;
- low-power technological lines for the production of wall materials, foundation blocks, roof tiles, paving stones were operated at Vladivostok TPP-2;
- plot of land for construction of a plant for the production of building materials and products from ASW was allotted in the area of TPP ash dumps;
- concept of cost-effective, 100%, integrated processing of ASW was developed.

Carried out works allowed the following results:

- possibility of organizing selection of conditioned ash and slag materials of different fractions under conditions of operating TPP without disturbing the ash-handling technological process of a power station;
- possibility of successful entry in the current market of new building products from ash and slag waste of power production industry is shown;
- positive economic effectiveness of building materials production from ASW is proved in practice;
- possibility of complete recovery of ASW from the operating power plant is shown;
- possibility of recycling the other waste using the flue ash, for example paper, wood waste, liquid radioactive waste of the Pacific Fleet is shown.

Up to date, the land plot area occupied by "DGK" OJSC ash dumps only is 311 hectares, 43,167,000 tons of ash and slag waste are accumulated, annual ASW yield is 774,000 tons, including by power plants (Table 5):

Table 5 - Characteristics of "DGK" OJSC ash dumps

Power plant	The area of land plots occupied by ash dumps, ha.	Accumulated ash waste, thousand tons	Annual ASW yield, thousand tons
Partizansk SDPS	59	8,275	53
Artyemovsk TPP	145	16,534	289
Vladivostok TPP-2	1. Surface of ash dumps - 104; 2. With due account for the hydraulic engineering structures - 153.	18,358	432 (prior to conversion to gas)

Based on obtained data on chemical and mineral composition of ASW of Russian Far East and conducted works for involving ASW in production and economic sphere, the calculation of technical and economic indices of the workshop for integrated ASW processing, using the line for production of precious metals concentrates, was conducted (Table 6). The calculation was made provided ASW selection from operating hydraulic ash handling systems (for example, Vladivostok TPP-2). The gold content in ASW was taken as 0.6 g/ton, the amount of processed ASW was taken as 180 thousand tons per year.

Table 6 - Consolidated technical and economic indices of the workshop for integrated ASW processing taking in account the line for production of precious metals concentrate

No. item	Indices	Unit	Values
1.	Annual amount of processed ASW	ton	180,000
2.	Capital expenditures	thousand roubles	45,000
3.	Specific capital expenditures for 1 ton of ASW	thousand roubles	0.250
4.	The term of plants installation	year	1 − 1.5
5.	The period of production activity, accepted for the calculation of economic indices of the line after line commissioning to the nominal capacity. Start of production activity is linked to the reconstruction of hydraulic ash-handling system	year	4
6.	Annual production of commercial products, including:		
	- gold-containing concentrate with gold content of 600 g/ton	ton	180
	- platinum-containing concentrate with platinum content of 600 g/ton	ton	240
7.	Annual cost of products	thousand roubles	58,424
8.	Annual operating costs	thousand roubles	30,000
9.	Balance annual net income	thousand roubles	28,424
10.	Net annual income	thousand roubles	19,897
11.	Risk-free norm of discounting	%	13
12.	Capital expenditures discounted to the end of the accounting period, at the risk-free discount rate	thousand roubles	27,607
13.	Net discounted profit for the accounting period, (NPV)	thousand roubles	61,464
14.	Profitability index (PI)	unit	1.71
15.	Internal rate of return at the risk-free discount rate of 17% (IRR)	%	27.5
16.	The payback period of capital investments: - statistical - discounted	years	 3.77 2.89
17.	Profitability for the accounting period	%	82
18.	Life cycle of process lines	years	Not limited

Change of the project payback period at other changes of ASW processing amount and other precious metals content in the original raw material is shown in Fig.3-4.

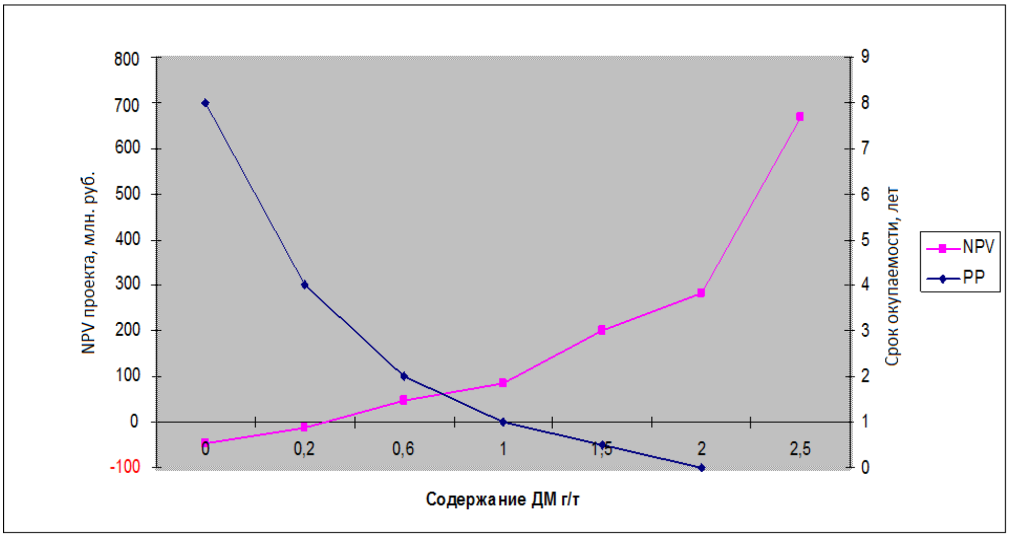

Fig. 3 - Diagram of risk diversification. NVP, PP of the workshop for integrated ASW processing depending on precious metals content at constant volume of processing

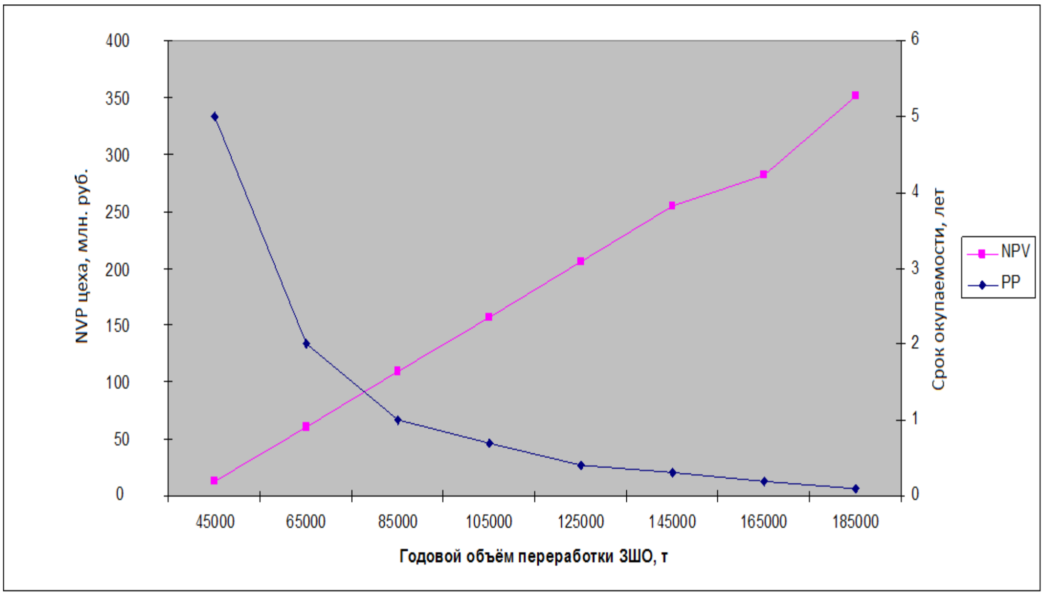

Fig. 4 - Diagram of risk diversification. NVP, PP of the workshop for integrated ASW processing depending on ASW processing amounts at precious metals content at the rated gold content of 0.6 g/ton

CONCLUSIONS

Obtained results confirm the possibility of complete, cost-effective processing of ash and slag waste of power production industry.

High economic effectiveness of ASW processing is achieved due to the extraction of valuable components, in particular the concentrate of precious metals, iron-containing concentrate unburned carbon and incomplete burning of coal.

The problem of ASW bulk recovery is solved by the production of building materials and products from the aluminosilicate residue.

Integrated processing allows reduction of the payback period of the cost for development of production for ASW processing to 3 - 4 years.

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