

System of Industrial Waste Accounting and Recycling in Primorsky Territory, Russia in the Context of European Experience

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ABSTRACT

The analysis of Russian federal and regional waste-tracking systems was carried out. The volumes of generation of certain types of waste are presented for Primorsky Territory, which can serve as secondary resources for waste recycling industry. It was shown that ash and slag waste is one type of waste most easily drawn into the economic activity. The mineral and chemical composition of ash and slag wastes from thermal power plants of Primorsky Territory was investigated. The possibility of production of wide list of marketable products from ash and slag wastes was shown. Increasing of the profitability of ash and slag waste recycling by recovery of precious and rare earth metals was shown. A possible multi-stage scheme of complex ash and slag waste recycling is presented.

KEYWORDS

waste management; secondary resources; ash and slag waste (ASW); recycling; waste treatment industry.

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Introduction

In Russia waste recycling is not yet a part of the industry, in contrast with the European countries. Recycling of resources is not systematic; waste with valuable properties still mainly being landfilled. Moreover, landfill sites are insufficiently provided with protection systems, which may lead to environmental pollution. The distribution of European environmental safety standards is hampered by the lack of knowledge in the field of prevention and minimization of waste in production and consumption, and by underdeveloped system of economic incentives for environmental measures (Ulanova and

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Wünsch 2015). The priority issue in forming the waste recycling industry is state waste inventory system which is primarily formed by state waste inventory or regional waste ones.

Currently, the legal framework of waste management in Russia is the subject to significant changes both at federal and regional levels, corresponding to contemporary world and European experience. Decisions aimed at reuse of resources as business investment on the basis of private-public partnership are made. In Primorsky Territory this is implemented within the framework of the State program "Environmental protection of the Primorsky Territory" for 2013-2017 (On approval of the state program "Environmental Protection of Primorsky Territory for 2013-2017") an industrial park for waste recycling is being developed (Annual Report for 2014 on the implementation and evaluation of the state program "Environmental Protection of Primorsky Territory for 2013-2017).

The existing Russian system of state registration of waste management is insufficient to assess the resource value of waste as secondary raw materials, which significantly reduces the prospects for their processing. In European practice life cycle assessment (LCA) system that allows to create a hierarchy of effective secondary use of resources is widely used for the analysis of environmental aspects of waste management (Brogaard, et. al. 2014; Clavreul, et. al. 2014). The experience of European countries in improving the waste management system is already implemented in some regions of Russia (Starostina, et. al. 2014) and it can contribute to the integrity of waste inventory system. The informational system for running the Primorsky regional waste inventory developed at the Far Eastern Federal University (FEFU) (Litvinets, et. al. 2008) includes significantly greater scope of information (compared to the state inventory) necessary to assess the prospects for the development of waste recycling industry. However, this system suffers from disadvantages associated with inapt filling out of the forms of state waste management reports by the users of natural resources (Litvinets, et. al. 2014).

Waste recycling technologies used in Russia generate significant volumes of nonrecycled waste and prevent creating a system of reuse of same raw materials. The best European and Russian practices (Dornack 2015; Jamieson, et. al. 2015; Salhofer 2015; Salhofer 2008; Samorodkov and Zelinskaya 2012) provide new opportunities to waste recycling companies, greatly increasing the efficiency of production. The useful experience of implementing hazardous waste recycling technologies is presented in (Koumantakis, et. al. 2009; Mymrin, et. al. 2014; Valouma and Gidaracos, n. d.); it deserves being implemented in a number of enterprises of Primorsky Territory. The research of technologies for the recycling of ash dumps and ores tailings conducted at the FEFU (Ivannikov, et. al. 2015; Shamrai, et. al. 2015; Tarasenko, et. al. 2015) suggests the possibility of creating a cost-effective facility for recycling of these types of waste in the region.

Ash and slag waste generated from burning of coal at thermal power plants can be easily recycled and used in economic activities. This type of waste can be relatively easily recycled into marketable products; they contain significant quantities of commercially valuable components such as compounds of ferrous and non-ferrous metals, precious metals and rare earth elements (Panteleev, et. al. 1985). Chemical and mineralogical composition of ash and slag indicate that they should rather be considered enriched raw materials for various industries.

The aim of this work was to assess the available volumes of ash and slag waste in the Primorsky Territory, and technological feasibility and investment attractiveness of the recycling projects. The following studies were carried out: the generated volume of ash and slag waste in the region, their properties, material and elemental composition; available recycling technologies including the extraction of precious metals and rare earth elements; classification of possible marketable products produced from the waste; possible flowchart of complete recycling and use of waste.

Materials and methods

In the analysis of waste management system the following information was used: generalized data of the Russian Federation state statistical reports for 2007-2014 (Environmental protection in Russia. 2014); data on waste management in the Primorsky Territory (annual reports on the environmental situation in the Primorsky Territory) for the period from 2010 to 2014; information from the automated database of Primorsky regional waste inventory for 2010-2012 (Litvinets, et. al. 2014); primary reports of 374 enterprises of the Primorsky Territory for the period from 2009 to 2013 in the form of statistical observation No.2-TP (waste) "Information on generation, use, neutralization, transportation and disposal of waste of production and consumption". The following activities have been carried out: expert evaluation of the credibility of information contained in the analyzed data, comparison of data from different sources, identification of available volumes of waste by types representing valuable secondary resources for waste recycling industry, including ash and slag waste of thermal power plants.

The research of ash dumps in the Primorsky Territory and the development of ash recycling technology were initiated by the authors in mid-1990-s at Thermal power plant-2 (TPP-2) in Vladivostok. In May 2015 and May 2016 57 samples of ash and slag with the total weight of 900 kg were taken from ash dumps of Artyom town TPP, Vladivostok TPP-2, Partizansk town regional power station, and Primorskaya regional power station. The samples from each power plant were averaged and used for the analysis of macro- and microelement composition, as well as for the content of precious metals and rare earth elements.

Macro element content of the chemical composition of ash (SiO_2 , Al_2O_3 , Fe_2O_3 , MgO , CaO , K_2O , Na_2O) is defined as a mandatory feature of coal for supply in accordance with state standards. The results for different coals were repeatedly tested by both consumers and various researchers. Our data coincide with the certified values and the results of previous studies.

The analysis of microelement composition of coal ash samples was carried out at the Institute of Chemistry (IC) of the Far Eastern Branch of the Russian Academy of Sciences (FEB RAS) using neutron-activation analyzer with californium excitation source (^{252}Cf) and energy dispersive X-ray fluorescence spectrometer EDX-800HS. The content of precious metals and rare earth elements was determined at the Far Eastern Geological Institute (FEGI) of FEB RAS by atomic absorption spectrometry using chemical and assay concentration on spectrophotometer Shimadzu AA-6800. The morphological types of gold and platinum group alloys were analyzed by photographs taken using Leica-E stereoscopic microscope with digital camera in transmitted and reflected light.

The results of analyzes were compared with the stock data of the regional units of the Russian Ministry of Natural Resources, IC, FEGI and Institute of Mining FEB RAS.

Based on the analysis of material and mineralogical composition of ash and slag waste the possible range of their use in production of marketable products was determined. The technologies for production of fuel elements, building materials, raw materials for steel industry, recovery of precious metals and rare earth elements were considered. When selecting the best technologies for recycling of individual components of ash and slag waste the emphasis was made on the common technological processes that could minimize costs for integrated waste management, make the recycling a cost-effective process.

Results and discussion

According to data of Rosprirodnadzor over 35 billion tons of waste were accumulated in the Russian Federation by the beginning of 2014 (Environmental, 2014), and the annual volume of waste generation amounted to 5168.3 mln tons. According to the statistical reports, during the period of 2007-2014 the main method of waste management was dumping of waste, both newly generated and accumulated during the previous period. The level of waste use virtually remained unchanged within the range of 40-50% of the total annual waste generation volume. The functions of information and analytical support of the state waste management system are also assigned to the state inventory of waste of production and consumption managed by Rosprirodnadzor. At the moment the following information can be received from the inventory: the types of waste, its origin, hazard class for the environment, as well as the component composition; waste disposal sites included in the state register; technology for use and treatment waste of various types listed in the database. However, even a cursory analysis of the data raises many questions. It is difficult to find logical explanation to more than two-fold reduction of waste volumes in the category "Production and distribution of electricity gas and water" from 58-70 mln tons in 2007-2011 to 24-28 mln tons in 2012-2014. Generation volumes of several types of waste in the category "Other types of economic activity", with the range from 710 to 16.9 mln tons (more than 40 times!) are puzzling. The information on the dynamics of management of waste of production and consumption in Primorsky Territory in 2010-2014 also raises a number of questions which cannot be answered rationally.

The data of the state statistical reports includes practically no information on waste as secondary resource, which is necessary for the development of waste recycling industry. The current waste-tracking system has a number of important disadvantages: incomplete information on volumes of generated waste; incorrect application of terms "use" and "treatment" by users of natural resources; the lack of information on technologies for recycling of secondary resources in waste inventory. The information on technologies is incomplete; there is no data on the resources consumed, secondary products and waste received, indicators of environmental and economic evaluation of the effectiveness of the use of technology.

An informational system for running the regional waste inventory was developed at the Far Eastern Federal University (FEFU), distinguished by significantly greater scope of information (compared to the state inventory),

including data necessary to assess the prospects for the development of waste recycling industry (Table 1 (Litvinets et al., 2014)).

Table 1 The main types of waste in Primorsky Territory in 2009 according to the regional waste inventory, thousand tons

Type of waste	Waste treatment procedures		
	Generation	Use	Disposal
Ash and slag from thermal power plants	1844	11	1830
Mine tailings	1622	180	1442
Wood waste	322	135	17
Oil emulsion and oil products was	9	2	Under 1

The main volume of waste generated in Primorsky Territory subject to reuse consists of ash and slag, ore tailings, solid municipal waste, paper and cardboard waste. Technologies for recycling of these types of waste are of greatest interest.

The statistical evaluation of chemical composition of ash and slag waste at Vladivostok TPP-2 using coal from 17 deposits in Siberia and Russian Far East is presented in Table 2 (Ivannikov et al., 2015).

Table 2 Statistical parameters of chemical composition of ash and slag waste at Vladivostok TPP-2

Quartiles of empirical distribution function	SiO ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ %	CaO %	MgO %	K ₂ O %	Na ₂ O %
Minumum	37.0	17.5	4.0	2.0	0.5	0.2	0.1
Quartile 0.25	51.0	23.0	5.0	4.0	1.0	0.6	0.5
Median	53.8	25.0	6.5	5.5	1.5	1.5	1.0
Quartile 0.75	57.0	30.0	10.4	7.2	2.0	2.3	1.0
Maximum	66.0	36.5	19.0	15.0	3.0	20.0	10.0

As it is shown in Table 2, they are composed by 98-99% of free and bound into chemical compounds oxides of silicon, aluminum, iron, calcium, magnesium, potassium, sodium. The following microelements are found in the ash: boron, molybdenum, germanium, gallium, uranium, arsenic, vanadium, mercury, zinc, lead, nickel, cobalt, fluorine, etc. The chemical composition of ash may vary considerably depending on the deposit where fuel originated from, but on average, for a single TPP, chemical composition can be considered stable for practical application judging by the median.

A variety of chemical and mineralogical composition of ash and slag waste assumes a wide spectrum of use. The construction industry may be one of the major consumers of ash materials. Several ways to use ash and slag waste in construction industry are resented in Figure 1.

The technologies for production of some building materials were tried and tested together with the Far Eastern science and research institute for construction; they have passed pilot tests in production conditions at enterprises of Primorsky Territory (Ivannikov et al., 2015). Other useful components that can be obtained from ash and slag waste are compounds of iron which can serve

as raw material for steel industry; aluminum compounds - raw materials for non-ferrous metallurgy. Underburning from ash can be used as raw material for manufacture of fuel briquettes.

In addition, ash and slag waste can be considered an object for the recovery of precious metals and rare earth elements. In order to assess this possibility, we have determined the elemental composition of ash and slag waste at TPPs of Primorsky Territory with the emphasis on the content of rare earth and precious metals (Table 3).

Table 3. The content of rare earth and precious metals in ash and slag waste at TPPs of Primorsky Territory

Thermal power plants	Elements, gpt						
	Ga	Ge	V	Li	Zr	Au	Pt
Artyom town TPP	40.0	3.3	112.0	-	320.0	-	-
Vladivostok TPP-2	49.9	4.0	800.0	50.0	-	0.2-2.5	0.2-
Primorskaya regional pov station	28.0	1.9	128.0	54.0	104.0	0.2-2.3	-

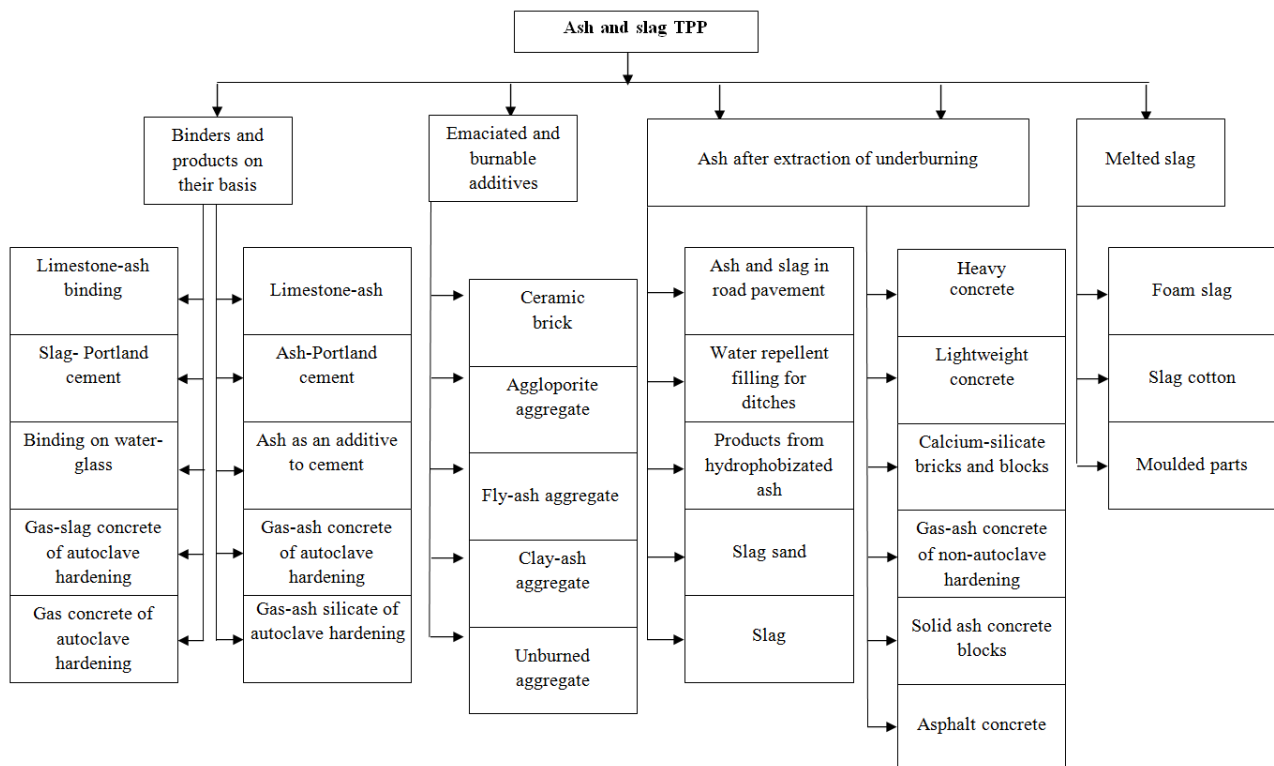
The research of metallurgy technology for extraction of precious metals from ash and slag waste was successfully conducted in the laboratory of reuse of resources at the School of Engineering, FEFU. Precious metals in technogenic waste of energy-producing enterprises are characterized by complex morphology; they are represented by small, thin and fine sized fractions; they have dust-like, plate-like, scaly, dendritic forms (Ivannikov et al., 2015). A pilot production unit is currently at the last stage of development.

Taking into account the peculiarities of chemical composition, a three-stage variant of the recycling of ash and slag waste was developed. The first stage is raw material stage. At this technological conversion ash and slag waste is divided into fractions and purified from underburning and iron oxides. At this stage commercial output with sustainable liquidity is already produced: high-energy fuel, iron concentrate, and sand. The second stage includes extraction of valuable concentrate components. The third stage is production of construction materials, including materials for road and cement industries. Upon implementation of the proposed integrated technology for recycling of ash and slag waste almost 100% of it become useful components in the production of marketable products (Figure 2). An estimated 28-38% can be used in the manufacture of building materials, 20-25% is concentrates of iron and aluminum, up to 20% - raw material for cement production, and about 10% of the volume can be the production of fuel briquettes from incomplete combustion. Marketable products are fine sands and coarse slag with a volume fraction of 10% each. The obtained data make it possible to prepare an investment project for recycling of ash and slag waste of thermal power plants at Primorsky Territory.

The advantage of complex recycling of ash and slag waste, compared to mono-technologies is in combining highly profitable technologies of extraction of precious metals (gold, platinum) from ash and slag with large-capacity technologies for recycling of ash and slag into raw materials for metallurgy, construction, road-building, cement industries and into building products. Simultaneously, one of the advantages of complex recycling of ash and slag is

the ability to control the properties of the materials and, as a consequence, increase their commercial value and sales volumes. An ash and slag recycling complex may be a part of a TPP and make a single economic unit, or it can operate as an independent company. A combined scheme when an energy company transfers (sells) pre-prepared ash and slag materials to the recycling company seems the most correct one.

Figure 1: Main areas of ash and slag waste usage in the construction indust



Distribution of ASW products for complex processing

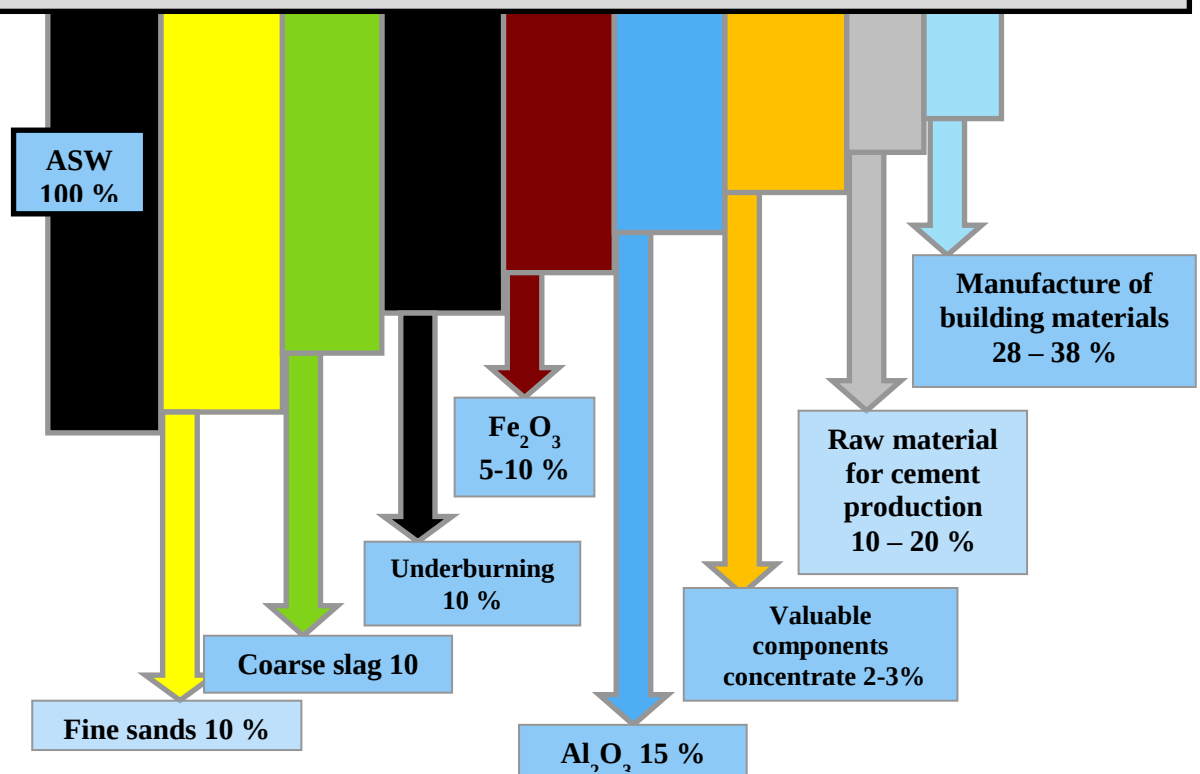


Figure 2: Estimated distribution of ASW technology processed products for complex processing

Conclusion

The state system of statistical tracking of waste management in the Russian Federation requires changes aimed at keeping useful properties of waste as a source of secondary resources, at serving the interests of the developing waste recycling industry.

Over 1.8 mln tons of ash and slag waste are generated annually in Primorsky Territory; they can be used as raw materials to produce marketable products. The production of building materials, fuel briquettes and iron-containing concentrates has undergone pilot production tests. A pilot production unit for extraction of precious metals from ash and slag waste is currently at the last stage of development. A three-stage technology for complex recycling of ash and slag waste with virtually 100% use of waste as secondary raw materials is presented.

The presented data on ash and slag waste generation volumes, technologies for its recycling into marketable products are a good basis for creating an investment project on the development of ash and slag recycling company for the newly created industrial park for waste recycling in Primorsky Territory.

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