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Methodological Approaches to Development of Ecologically Safe Usage Technologies of Ferrous Industry Solid Waste Resource Potential

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Abstract: At the present day in Russia the change of ferrous metals production technology results in the change of the chemical composition of solid waste from iron and steel works. Traditional approaches to waste recycling methods stop meeting the requirements of geoecological safety. The paper offers a methodology of usage of the ferrous industry waste taking into consideration a life cycle of the materials, which comprise the ferrous industry waste. New methodological approaches to evaluate the technologies of waste recycling have been developed. Complex selection criterion for usage technologies of ferrous industry solid waste resource potential is developed taking into consideration ecological, technological and economical factors. A technology of ferrovanadium waste utilization as a free-running material at a solid domestic waste landfill is shown. Data on vanadium migration activity to model mediums is represented. Distilled water and acetated-ammonium buffer were used as model mediums. A laboratory unit was offered to model vanadium migration to filtrate at the solid domestic waste landfill. The obtained data shows sorption capacity of solid domestic waste. Vanadium content in the filtrate of the laboratory unit equals to 0,057 mg/l., which is equivalent of satisfactory figure of maximum permissible concentration.

Key words: Ferrous metals • Maximum permissible concentration • Vanadium • Geoecological safety

INTRODUCTION

Iron and steel industry in Russia traditionally belongs to multi-waste works. As per data [1], the production of 1 ton of rolled steel results in 17 to 30 tons of waste. In 2011 iron and steel production and manufacture of ready-made steel products in the RF resulted in 186 mln.tons of solid waste. The main types of waste are slags, sludges and drosses. As per Leontiev L.I. data, there is more than 1 billion of waste [2] in disposals and sludge collectors of Russian iron and steel plants. This waste creates a significant ecological load on environmental compartments and its outstanding material resource is not used at its full.

A principal direction of iron and steel industry updating programs in Russia is the closure of distressed steel production in open-hearth furnaces and their replacement by modern electrical steel smelting furnaces. For the last 6 years, the share of open-hearth furnaces has reduced from 21% in 2005 to 6% in 2011. For the same period, the share of electrical steel increased from 19% in 2005 to 31% in 2011. Besides, it is expected, that in 2020 the share of electrical steel will be equal to 34% from the total steel output.

A significant part of ferrous industry solid waste contains a great quantity of ferrum; earlier after splitting and magnetic separation, it was used in blast furnaces on a par with iron ore. As the content of fresh output of nonferrous metals, in particular zinc, in solid waste increased, the blast furnaces are unable to use the waste on a par with natural ores due to formation of scar in blast furnace working chamber.

Mineral part of solid waste is traditionally used in construction industry. As per data [2], the Russian cement industry uses up to 7,4 mln.tons of iron and steel waste each year instead of natural materials during production of cement. Slag crushed stone is used in road construction, concrete and mineral wool production. Shift of iron and steel industry to modern technologies results in decaying activity of waste mineral part and unsteady chemical and phase composition of waste makes them unattractive for cement industry. High concentration of water soluble forms of metals in concrete, comprising the waste of ferrous industry, results in corrosion and

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operating life reduction of products and constructions on its basis. Negative environmental impact increases because of increased emission of heavy metals from materials, comprising ferrous industry solid waste, produced as per new technologies. High emission of contaminants from the waste limits its usage in agriculture. In European countries the problems of utilization and recycling of resource potential of iron and steel waste are also urgent [3-7].

That is why it is necessary to determine new methodological approaches to development of usage technologies of resource potential of ferrous industry fresh output solid waste, obtained at modern plants. Traditional methodological approaches, used previously to develop usage technologies for ferrous industry waste, did not take into account the waste whole life cycle. Consideration of waste negative environmental impact ended with inclusion of the waste to the new product or material (good) without considering the operation of the product (good) till the end of its life cycle. The significant migration possibility of hard metals from materials, produced on the basis of ferrous industry waste, shall be taken into consideration when selecting the technologies of usage. The life cycle analysis of waste, included to materials (products) together with the closing stage of product life cycle enables to consider its negative environmental impact in details.

At the present time there are no general methodological approaches for objective selection of usage technology of waste resource potential of ferrous industry considering the whole life cycle of the material and product, including utilization at the closing stage of life cycle. Decision analysis of such problems in allied sciences and technics showed that they use methodological approaches, based on complex criterion, including integral eco-social and eco-economic effects.

So Krestovskikh T.S. introduces a "Generalizing criterion", which characterizes the economical effectiveness of waste usage variants through the integral social-ecological-economic factor. It comprises resource-providing effect from the increment of gross domestic product output and extension of the mineral resource base due to the increment of secondary resources value; ecological effect specified by prevention or reduction of the negative environmental impact of waste; social effect [8].

Mayorova L.P. [9] offers to use a factor "ecological property of technologies" as a main criterion for evaluation of industrial waste usage technologies. It includes the evaluation of: environmental load; environmental modifications under technological impact; correlation of technical and environmental capacities of the plant.

The full usage of such complex criteria for comparison of technologies is described in the paper of Bondarenko V.I. [10]. He mentions that when selecting the best available technology, it is possible to face with the strategy of anthropogenic load shift to other plants, implementing this technology. Technology selection shall be based on inventory analysis of not only production (technology), but also on pre-production processes, as well as the post-production ones, connected with waste utilization and recycling of the plant under study. When selecting the best technology, he offered to use the following principles: entity of natural environment; aggregation of environmental impact of all processes (technologies), relevant to implementation of the technology under study; uniformity of measurements based on specific impact indicators (elementary flows); total consideration of impact, connected both with input flows and the concerned technology; consideration of geographical location of the updated object, which characterize the impact, connected with supply of raw material, materials, parts and energy.

Alongside with this, the analysis of these papers showed that in selection of the technology the priority belongs to environmental protection without the proper consideration of economical acceptability and technical possibility of industrial implementation of this technology. Economical and technical components of such complex criteria are almost not used. It is important to point out that the analysis of the industrial waste life cycle is usually finished at the stage of waste usage without considering the following stages over the whole period of operation of the product, comprising this waste. That is why when developing the usage technologies for resource potential of ferrous industry wastes, it is necessary to pay attention to detailed development of economic attractiveness of the technology taking into consideration the life cycle of materials and products, comprising the waste, as well as marketing and logistics of usage of these products, obtained as per these technologies.

Considering all this, we developed a complex approach to selection of usage technology of solid waste resource potential of ferrous industry taking into account the analysis of its full life cycle. To make an optimal decision when selecting the usage technology of outstanding material resource from the waste of ferrous industry, we developed a selecting criterion, which includes the following main factors:

- Ecological safety during the waste whole life cycle - from its formation to utilization of materials (products), comprising this waste;
- Economical acceptability of extraction degree of the outstanding resource potential from waste;
- Technical possibility for industrial recycling of solid waste resource potential of ferrous industry;
- Minimization of non-utilized remnants, left in environment, after the implementation of the technology;
- Minimization of usage of primary energy sources and materials when implementing the technology;
- Marketing and logistics of realization (in demand at the market) of the new materials, produced from wastes.

We tested this methodological approach when reviewing the existing usage technologies of solid waste resource potential of the iron and steel industry and in development of new technologies of its usage at one of the iron and steel plant of the Perm Territory.

The Main Part: The iron and steel plant under study is a plant with full cycle of iron production (iron ore, cast iron, steel, ferroalloy industry). The main solid wastes are slags and sludges. Table 1 shows the chemical composition of the blast-furnace slag.

The waste of the blast-furnace process, accumulated previously, now is realized as crushed stone (fraction 5-20, 20-4-, 40-70) at the price from 200 to 400 rubles per ton, in particular, for road base filling and in concrete products. Slag goes through splitting and magnetic separation. Metal shots and slag with high concentration of ferrum are separated from the general mass and are forwarded back to the blast furnace or are sold as metal-concentrate (fractions 0-70, 0-250) at the price up to 1000 rubles per ton.

The analysis of this waste usage technology showed that it is economically accepted; the processing of one ton of slag costs 200 rubles, its realization costs up to 1000 rubles per ton. It proves its economical acceptability. Almost full waste resource potential is used, the number of non-utilized waste equals to zero. Road companies perform self-delivery of crushed stone up to their objects. There are almost no emissions to environment, when the waste is recycled; no more than 25kW per ton of the ready product is used from primary sources. In developed countries the widely used technology is to use slag as inert filling for asphalt and cement concrete, to use as a ballast for road construction is less popular. [11-17].

Alongside with life cycle analysis of the materials, produced from the waste, we found out, that in operation of the road surfacing from slag crushed stone, hard metals migrate from the slag crushed stone to the soil and ground waters. When used in acid soils, concrete structures, based on slag crushed stone instead of the natural filling, become the source of hard metals, which actively migrate from the material, when the concrete structures are humidified. It results in concrete corrosion and product life cycle reduction [18, 19]. It proves that under evaluation of life cycle of the material, comprising waste, impacts negatively on environment with loss of consumer properties. It is necessary to consider the whole life cycle of the waste (waste formation-product manufacture-product operation-closing of product life cycle).

On the plant under study, ferrovanadium is produced in electrical furnaces by alluminium-silico-thermal way for many years. Slag standard of alluminium-silico-thermal way is 6,6 t per ton of produced vanadium. The final slag has a chemical composition, shown in table 2.

At the present time the waste is located in flood-plain of Vilva and Chusovaya as a disposal on unprepared ground. Soil and water bodies are contaminated [20, 21].

Table 1: Chemical composition of the blast-furnace slag (average), %

SiO_2	CaO	Al_2O_3	FeO	MgO	TiO_2	MnO	V_2O_5
29,4	31,4	14,9	1,52	11,8	8-11	0,6	0,14

Table 2: Slag chemical composition (%).

V_2O_5	SiO_2	CaO	MgO	Al_2O_3	P
0,11±0,03	30,4±0,5	54,4±0,7	11,4±0,4	2,7±0,21	0,013±0,004

Table 3: Grain-size composition of ferrovanadium slag

Mesh size, mm	2	0,63	0,315	0,14	0,08
Full mesh residue of slag, %	3	32,0	83,0	97,0	99,0

Slag is a dusty mass of white-grey color with specific surface up to 300 m^2/kg. Grain-size composition of ferrovanadium slag is shown in table 3.

For this industrial waste at different times some technologies for the potential usage were developed. In particular, technologies for its usage as an inert filling in cement grouts, cleaning agents, low-level bound material for grouting in road construction. However, having engineering possibilities to implement these technologies for resource potential usage, no one technology was implemented. Firstly, because of economical inexpediency (absence of market) and also due to lack of driving force for recycling of these slags into new materials; besides, the plant was not interested in opening of non-core waste recycling.

When developing the new technology for resource potential usage of ferrovanadium slag, we used a complex criterion of technology selection, taking into consideration the whole life cycle of the produced material.

Our analytical investigations of ferrovanadium slag showed that in its physical properties the slag has a homogenous structure, well-compacted, not combustible, inert in relation to biological objects and can be used as a filling material for intermediate insulation at solid domestic waste landfill (SDW). A laboratory analysis of physical-chemical properties, as well as a biotest, showed that ferrovanadium slag belongs to IV hazard class for environment. It was determined that slag has a homogenous structure with fraction diameter less than 250 mm. Due to its structure, it prevents landfill working medium from birds, rodents and moisture. A dominating component in slag is calcium oxide, which, on reaction with water, develops to hydroxide (lime), characterized by disinfectant, antiparasitic and deodorant action. Slag has also magnesium oxide, which has antacid, adsorbing and detoxifying action. Fresh output slag with minimum technological conversion (metal shots extraction by magnetic separation) can be used as a material for filling SDW layers and recultivation of disturbed soil.

To use slag after technical conversion as a material for filling and technical recultivation, it was necessary to evaluate the ecological properties of the application technology of these materials during the whole life cycle. When using the materials, consisting of the waste, one of the adverse affects on environmental compartments is the emission of hard metals from the material. Vanadium oxide within slag is one of the hazardous elements. Its maximum permissible concentration (MPS) in ambient waters of potable, cultural and general water consumption equals to 0,1 mg/l. Vanadium brings great and long-term harm to environment and population health when got into water bodies in concentrations, exceeding the maximum permissible ones.

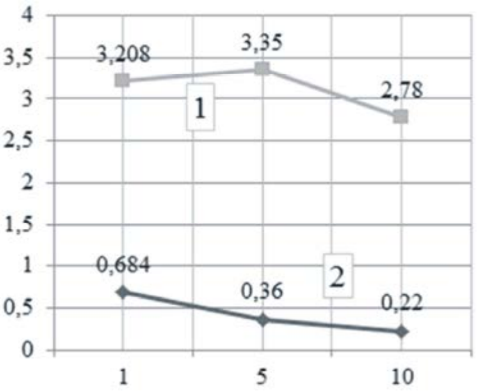

Fig. 1: Time dependency of vanadium quantity in model mediums.

Vanadium migration from ferrovanadium slag to model mediums was investigated. For vanadium migration modeling two mediums were used: a neutral one - distilled water (Fig. 1 - curve No.2) and an acid one - acetate-ammonium buffer with pH 4,8, what is true to acid residues (Fig. 1 - curve No.1).

The results in fig. 1 show that vanadium migrates from slag and its concentration exceeds the maximum permissible ones even in 10 days. During the experiment it was determined that in one day vanadium flexible form in aqueous media shifts to slightly soluble combination vanadat, which sedimentates, being a suspended matter. Considering this, it was supposed that if it is used as a filling material, SDW layer adsorbs vanadium and its concentration in SDW landfill filtrate reduces.

In fig. 1 time intervals are set along the axis of abscissa in days; vanadium quantity in extract is shown along the axis of ordinates in mg/kg.

To investigate slag impact on vanadium quantity in SDW landfill filtrate, we designed and produced an experimental unit, which allows to model filtrate formation. An experimental unit is shown in fig. 2.

1 – container with distilled water; 2 – shutoff and control valves; 3 – supply pipeline; 4 – irrigation compartment with bottom perforation; 5 – bracket; 6 – filling material MP-1; 7 – SDW layer; 8 – mesh; 9 – splitter; 10 – return pipeline; 11 – shutoff valves; 12 – container; 13 – tower.

In laboratory unit the location of SDW was maximally close to real conditions. The height of SDW layer and filling material was equal to 2 and 0,25 meters respectively.

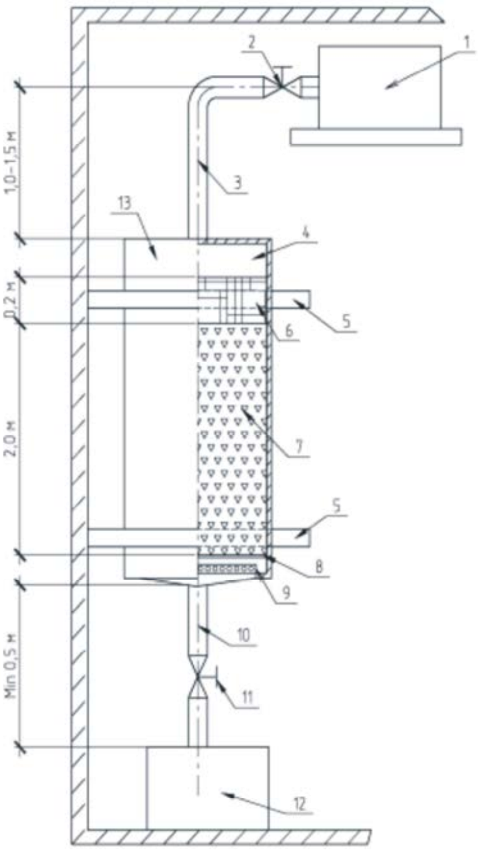

Fig. 2: Experimental unit.

SDW morphological composition was taken as per investigations of The Chair of Environmental Protection of Perm National Research Polytechnic University for the city, where iron and steel plant is located.

To model the atmospheric fallouts to the surface of the SDW landfill, distilled water was supplied from the top to the slag layer. It was supplied from the top of the container through the irrigation device in an average quantity of fallouts for Perm district (600 mm).

To model the most unfavorable weather conditions, i.e. the period of peak fallouts, the whole water volume was regularly supplied during 24 hours.

Filtration was carried out during 24 hours, then the collected filtrate showed that vanadium concentration was equal to 0, 057 mg/l, i.e. just in 24 hours of filtration vanadium concentration in the filtrate reduced below the MPC.

Thus, it was modeled the whole life cycle of the waste from its formation up to finishing of its life cycle as a layer of filling material in the working body of SDW landfill in Chusovoy city.

As a result, the developed technology of filling material production allowed a plant to shift the waste to the category of materials with low economic consumption and allowable environmental impact during the whole life cycle of the new material. Logistics analysis (delivery up to consumption place, loading and unloading work) of filling material at Chusovoy landfill showed that the delivery from the waste formation place up to consumption place is low-cost, so this technology can be determined as economically acceptable. A consumer of the materials from the waste and SDW landfill are also interested in getting this filling material.

CONCLUSION

Approbation of the developed methodological approaches to selection of usage technology of ferrous industry resource potential showed that they allow to implement the waste application technology with allowable ecological impact taking into consideration the life cycle of the new material and economical attractiveness for the plant.

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