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Development of the Technology of a Simultaneous Untilization of Heterogenous Industrial Wastes for a Construction Materials Production

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Abstract

Nowadays a development of industry and technology reached levels, that allow to consider industrial wastes as valuable raw material for construction materials' production. The factor, which prevents from using many kinds of wastes, is a negative impact that they have on environment and people. However, technologies allowing a usage of a simultaneous utilization of wastes with a mutual neutralization effect are known from a practice. The aim of the presented research is the analysis of previous studies on the topic of a utilization of industrial wastes in construction materials and a development of methodological approaches to their simultaneous utilization with an obtainment of construction materials which can be competitive in comparison with analogues produced from natural raw materials. In the paper, methodological approaches to a utilization of heterogeneous industrial waste products and a production of construction materials with a low negative impact on environment are presented. The basis of methodological approaches comprises principles used in the best obtainable technologies. Developed theoretical basis passed approbation during the creation of the technology of a simultaneous utilization of blast furnace slags and waste products of soda production in construction materials manufacture. In case of a utilization of blast furnace slags in construction materials production there is an increased migration of heavy metals and water-soluble compounds. With an introduction of soda m wastes, which have an increased alkaline reserve, to construction materials' composition, water soluble compounds convert in marginally soluble and insoluble. The achieved result is a 2.5-3 times decreased migration of heavy metals in environment in case of contact with water both in acid and alkaline media.

Keywords: ecological safety, industrial waste products, blast furnace slag, road construction, construction materials, emission of heavy metals

1. Introduction

Nowadays, some technologies based on a utilization of a resource potential and other useful properties of homogeneous wastes of some industries instead of primary waste products and materials for an obtainment of target products with predetermined properties are widely used (Leontiev, 2013). At the same time, an important condition of an increase of an ecological safety and an effectiveness of industry is an implementation of the best available technologies (BAT) (Reich et al., 2003). A development and an adaptation of BAT provide the best solution of ecological, economic and social goals of industry (Brian Ellis 2005, V. Ibáñez-Forés et al 2013, Thomas B. Johansson et al 2005). A modernization of a production must proceed in a way that minimizes a strain on environment by a minimization of emission, generated unutilized wastes with a maximum implementation of a resource potential of an intermediate and a final industrial wastes (Motz and Geiseler, 2001).

Methodological approaches for a development of technologies of an implementation of a resources potential of homogenous wastes of various productions, which are based on an empirical researches and an analysis and a generalization of results of a treatment of such a wastes are known (Lind et all., 2001) (Young and Downey, 2008). At the same time, methodological approaches for a development of technologies of a simultaneous utilization of heterogeneous wastes with an aim of an implementation of their resource potential and their useful properties are not established so far. From practice it is known (Shekarchi et al. 2003, 2004), that during a simultaneous usage of that kind of waste, it is possible to obtain target products with predetermined consumer properties with a less expensive method and a minimal use of primary raw materials and energy (Mozt and Geiseler, 2000). These becomes possible as a result of effects, appearing during the process, such as: a mutual neutralization of ecologically dangerous components (Downey and Twidwell, 2008) and unfavorable properties of waste products, which influence consumer properties of products; an improvement of existing or an obtainment of new positive properties of target products; an intensification and an increase of an effectiveness of used stages of technology as a results of a summation, potentiation, synergy and emergence during an interaction of two or more heterogeneous waste products (Reuter et all., 2004) (Pugin and Vaysman, 2013).

Considering aforementioned and basing on a generalization of results of the personal long-term research in a simultaneous utilization of heterogeneous wastes with an aim to obtain of target products with a predetermined quality using a control of processes of their interaction with an utilization of their resource potential, we had developed methodological approaches for a selection and a development of technologies of a simultaneous utilization of heterogeneous waste products in construction materials production.

2. Materials and Methods

For a development of methodological approaches a complex ecological approach was used, in which along with complying with fundamental principles used in the best available technologies (a resource-saving, a priority of maximum effectiveness in an obtainment of a high level of environment protection, an economical affordability and a technical possibility of a realization on a production scale on a plant or a branch of industry in a whole) (Directive 96/61/EC), a priority of achieving of tolerable ecological risks during a life cycle of wastes (from the moment of their generation, an obtainment of target products by using their resource potential and other useful properties, an usage of target products by a customer, including ending of a life-cycle of target products and materials based on them) is provided (Directive 2008/1/EC).

Algorithmization methods were used; mathematical and physical modeling; verification of an obtained an experimental and a computational data by their approbation on a production scale and also a step-by-step logical approach in a decision making in order to obtain of predetermined consumer properties of construction materials.

As materials for the research, waste products of ferrous metallurgy (blast furnace slag) and soda production (sludge) were used. Chemical composition of granulated slag is presented in table 1. An average grain density of the slag is 2.46 g/cm^3.

Table 1. Chemical composition of blast furnace slag, %.

	MgO	CaO	TiO_2	SiO_2	MnO	Al_2O_3	FeO	V_2O_5	Cr_2O_3
min	5.4	21.8	7.1	25.06	0.4	8.4	0.9	0.17	0.07
max	13.5	33. 5	9.7	36.0	1.14	17.3	3.5	0.32	0.2

Hard remainder of soda production (sludge of calcium carbonate) in a dry form is a light-gray mass with density of 970 kg/m^3, which consists of particles of 0.1-0.2 mm diameter on 70-80%. Results of laboratory tests determined its composition with humidity roughly 60%: $CaCO_3$ 50-65%; $MgCO_3$ 20-25%; $Ca(OH)_2$ 4-10%; $CaCl_2$ 5-10%; $SiO_2 + Al_2O_3$ 5-10; $CaSO_4$ 3-9,5; SiO_2 0-4,9%.

3. Results

Method of our design, for a selection and a development of technologies of a simultaneous utilization of homogenous production wastes for a production of construction materials, presumes a necessity of an achievement of target properties during a realization of those technologies.

A set of those target parameters may be different, depending on aims, which have to be realized during a simultaneous utilization of wastes, initial conditions and restrictions (time related, resources related, social, economic, geographical), but in a whole they have to provide:

- A capability of an obtainment during a simultaneous use of wastes products of a predetermined quality, which have a status of market goods (materials, products), which have a demand on market and are capable to compete with analogues produced from primary raw materials;
- A compliance with a standard level of an industrial wastes treatment safety and an obtainment of an acceptable level of ecological risks during a simultaneous utilization of wastes on all stage of their

life-cycle, including ending of a life-cycle of produced by a final customer on their basis target products and materials;

- A technical possibility of a realization of a technology on a production scale (level of a plant or a branch of industry in a whole) with a predetermined full use of products' resource potential and other useful properties with a condition of a generation of residual amounts of non-utilizable remainders or secondary wastes not more than a level complying with requirements for low-waste resource-saving technologies;
- An affordability of technologies' realization in financial and economic respect (an acceptable level of capital expenditures, maintenance and other expenditures for a technology realization) considering a coverage of a part of expenses for technology functioning from sales proceeds of target products, an achievement of an ecology harm prevention by a reduction of a strain on an environment, ecological payments and other expenses arising from a decrease or an exclusion of discharges, an emission and dumping of a territory during a deposition of non-utilizable remainders of wastes and secondary wastes in environment;
- A social effectiveness complying with generally accepted criteria: social acceptability is an acceptable quality and conditions of labor; social stability – an exclusion of protest reactions of people and non-governmental organizations appearing due to risks taking place during technological realization (noise, smell, a visual impact, an appearance of pollutants in environment etc.) because of their acceptable (lower than an allowable maximum) standard level; an improvement of a social and an ecological image of a company; a creation of new jobs; an increase of payments to state budgets of all levels;

The basis of the proposed method consists of a step-by-step set of actions aimed at a development of industrial wastes resource potential utilization technologies.

Step 1 includes and expert evaluation of production wastes, possessing useful properties. A determination of physicochemical, mechanical and other properties of production's (consumption's) *waste i* which was determined on the basis of an expert and an analytical assessment for an implementation as a raw material for a target materials production. An assessment of a group of industrial wastes available for an industrial use in a certain economic region judging on physicochemical, mechanical and other properties with an assignment of an application field (construction, power engineering, chemical industry, metallurgy). An assessment is conducted by experts and acts as a recommendation.

Step 2 consists of an assessment of a resource potential of *waste i*, a determination of possible technologies of its implementation, a detection of a technical and an economic possibility and a practicability of an extent (fullness) of an extraction of its resource potential for an obtainment of products of a predetermined quality. During the realization of block 2 technological solutions (thermal, chemical, mechanical method etc.) are determined which allow to extract a resource potential from wastes and to specify the list of possible target products which are in demand on market (cement concrete, asphalt concrete, gravel for roads' construction, pavement tiles etc.). Additionally, a social significance of technology undergoing an adoption and obtained target products are taken into account.

Step 3 is detecting a possibility of exceeding allowable limits ecological risks, which are appearing during the process of a production of specified construction materials from *waste i* and usage by a consumer during their life-cycle. Possible ecological risks are established which exceed tolerable limits appearing during the realization of specified technological processes in a process of specified construction materials production from *waste I* and their use by a consumer. Migration of heavy metals from construction materials into environment (soil, water) can be considered among them.

Step 4 includes a selection of a production waste, which is capable, in a case of a simultaneous use with *waste I*, to provide neutralization (a decrease to a tolerable level) of a possible negative effect on ecology and people during processes of a production and use of a target product with specified consumer properties.

Step 5 selects (develops) technological process of a simultaneous utilization of wastes with an aim of a production of construction materials of specified quality with a compliance with ecological, economic, social and other restrictions (an industrial and an ecological safety, an economic affordability, a technical possibility of realization, a social acceptability and stability, a competitiveness on market in comparison with products of the same class produced from primary materials).

During the realization of steps 1 – 4 complex criterion indexes were developed which include following main components – ecological, economic, technical, social, which numerical values are determined considering specified restriction in context of particular conditions of objects' functioning where technologies of a simultaneous utilization of heterogeneous wastes are applied.

Ecological components allow to assess ecological risks and a compliance with ecological standards. Economic components define a value of expenses necessary for realization of a considered technology, changes of raw materials price in the world and target products which are obtained. Technical components define a technical possibility of a realization of technological processes at typical plants of an industry branch.

During the realization of step 5 we implemented IDEF0 – standard method of a functional modeling of a technology development procedure adapted for solving tasks of a simultaneous utilization of wastes.

4. Discussion

Developed methodological approaches for a selection and a development of technologies of a simultaneous utilization of industrial wastes were approbated on a case of ferrous metallurgy wastes (blast furnace slags) and wastes of soda production (sludges –sediments of calcium carbonate) during a simultaneous utilization as a mineral components in a manufacturing of target products – cement concrete and asphalt concrete. Those heterogeneous wastes are situated in Perm Krai and pertain to an economic area.

As a result of experimental studies in the laboratory and in the field it was established that blast furnace slags after a primary magnetic separation in order to extract big metal inclusion and a secondary magnetic separation after crushing to a specified size established for gravel, sand and mineral powder materials were obtained which physicochemical properties complying with requirements for traditional primary materials – gravel, sand and mineral powder.

At the same time, it was established that in case of a direct contact between these materials and water (especially acidic waters) emission of mobile forms of heavy metals, salts of vanadium, manganese and iron, from them is possible (Pugin et all., 2012).

Results of studies allowed to establish that, in case of putting mineral components of blast furnace slag in denser media during a production of cement concrete and asphalting concrete, a 2.5-3 times decrease of emission of heavy metals into environment during a contact with water occurs. In their consumer properties cement concrete remains competitive in comparison with mixes made with natural raw materials.

In case of a simultaneous utilization of gravel, sand and mineral powder with sludge wastes of soda production during the production of cement concrete products, due to alkaline reserve of the sludge, vanadium, manganese and iron salt conversion into immobile forms occurs, which provides a multiple decrease of their emission into environmental objects (see fig.1).

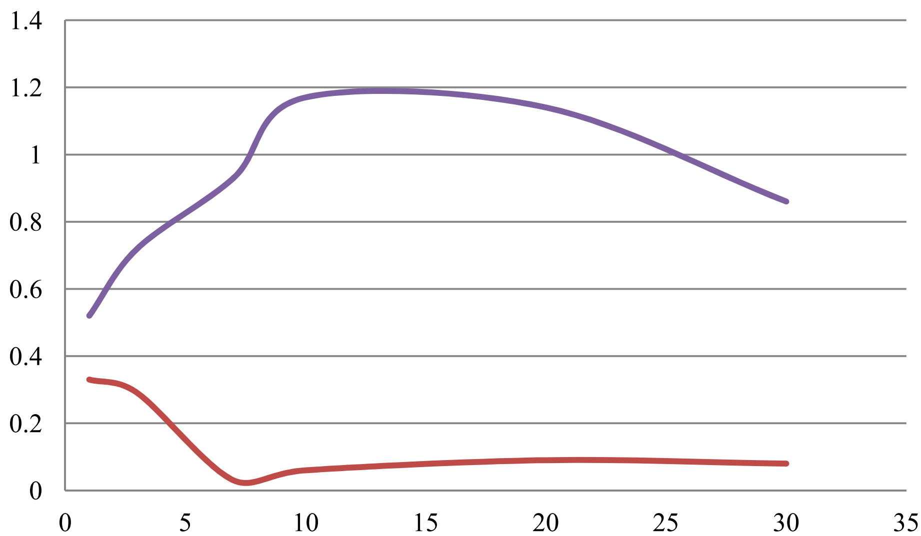

Fig.1. Migration of Vanadium ions (mg/l) from concrete to ammonium-acetate buffer (pH=4.8) during 30 days. Red line – contents of wastes of soda production is 10%, blue line – without soda production wastes

It was experimentally established, that in case of contact of cement concrete of a designed composition, which was made from a mineral component of blast furnace slag and sludge of soda production, with surface and subsurface waters with pH in range of 4.8-11.3 no emission of vanadium, manganese and iron in significant concentrations was found (Pugin, 2013).

A simultaneous use of a mineral component of blast furnace slag and wastes of soda production for a manufacture of cement concrete products such as cement concrete blocks and pavement tiles, emission of vanadium decreases in 2-3 times, manganese in 3-4 times, iron 4-5 times.

It is necessary to point out, that for an assessment of ecological danger of construction materials, which composition contains industrial wastes, the main factor is an assessment of a migration activity of chemical elements (Proske et all., 2013), (Shekarchi et all., 2003, 2004), which in the presented study was also considered the main critical factor.

Researchers previously studied the topic (Stengel and Schießl, 2014), (Qasrawi et al., 2009) proposed a simultaneous utilization of a certain industrial wastes, however, these were of an isolated character. The most common methodological approaches close to those developed by us, are presented in the studies (Shekarchi et al., 2003, 2004), (Chen, 2010) and reflect an achievement of the same goals with those designated in the presented study.

It is also necessary to note, that some researchers (Shi, and Qian 2000) (Wu et al., 2007) reasonably state the necessity of a simultaneous utilization of wastes for a decrease of ecological risks during construction materials production. Construction materials are used for prolonged time and in direct proximity to people.

5. Conclusion

For the first time, the methodology is proposed, which comprises simultaneous utilization of heterogenous waste products during manufacturing of a target product – a construction material.

The technology of a simultaneous utilization of two heterogeneous wastes (blast furnace slags) for a cement concrete production that we designed is ecologically safe, technically realizable on a production scale, economically affordable and complies with fundamental principles of the best available technologies. At the same time, a decrease of heavy metals emission is achieved, particularly, vanadium emission decreases in 2-3 times, manganese in 3-4 times, iron 4-5 times.

The approbation of methodological approaches of technologies of a simultaneous utilization of heterogeneous industrial wastes, that was carried out showed, that the approaches possess a general character and a decrease of ecological danger of wastes utilization is achieved.

The development of methodological approaches of a simultaneous utilization of industrial wastes as raw materials will allow to decrease capital expenditures of companies and to decrease a negative influence on an environment. In compliance with that method in Perm Krai technical requirements for pavement tiles production based on two industrial wastes – blast furnace slags and soda production sludge - were developed. In future, it is planned to organize a production of concrete fence form the same wastes.

It is necessary to note, that there are some restrictions on an implementation of the developed method of wastes utilization. Particularly, it is impossible to implement that method with wastes of highly toxic elements (cadmium, arsenic etc.) or radioactive elements. Authors presume that an implementation of construction materials comprising highly toxic elements can harm people and environment because of a long period of use and possible chemical degeneration of bonds between elements constituting a material.

The main direction of a further research is an expansion of a list of materials produced from industrial wastes without a decrease of consumer properties and also a selection of heterogeneous wastes allowing to achieve synergy effect in case of their use on one technological cycle for constructions materials production.

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