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RESOURCE AND ENERGY EFFICIENCY CRITERIA OF RECYCLING TECHNOGENIC MATERIALS AND THEIR QUALITY ASSESSMENT

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Abstract: A methodology of FABA quality assessment from the viewpoint of an object for processing and recycling is offered based on an analytic study of an accumulation of patented technologic solutions. The practicability of using such methodology is rationalized. Examples of resource saving technologies are given, which have undergone semi-industrial and experimental industrial approbation. The reasons of practicability of extensive involution of technogenic waste present in artificial waste pile-ups, which contaminate the environment, into processing and utilization are explained. It is noted that resource efficiency characterizes the system of resource saving from the viewpoint of the degree of waste utilization and the quality of production obtained (while minimizing costs and environmental risks).

Criteria of resource efficiency of waste and secondary raw materials recycling are outlined: degree of waste utilization, technologic indicators of the processes used, characteristics of new products, specific energy consumption. Resource efficiency assessment is provided using the example of FABA utilization. Fundamental principles of FABA processing and utilization are given, as well as ways of improving their quality when used as a secondary raw material.

Keywords: technology, waste management, secondary raw materials

1. Introduction

Maximum reduction of the amount of landfilled unprocessed waste is one of the main tasks of resource saving.

Resource saving strategy sets the priority approach of maximally reducing materials expenditure and their secondary reuse.

Resource efficiency is a characteristic of the resource saving system from a viewpoint of degree of waste utilization and quality of the resulting product (while minimizing costs and environmental risks). Degree of waste utilization is the amount of resources for secondary material use obtained from waste, quantified as percentage of the total amount of generated waste of this type. Quality of the resulting product is determined by specific indicators of its industrial use [1].

The choice of a resource saving technology is determined by its technological indicators, characteristics of raw materials and final products, environmental soundness of the process and costs minimization. These technologic indicators are used to generally determine resource efficiency of solving the problem of waste and secondary raw materials use and recycling.

Technological criteria, which are a combination of the main process parameters examined below (α, β, ε, γ), correlate according to the formula $\gamma\beta=\alpha\varepsilon$, where the target function is extraction $\varepsilon = \frac{\gamma\beta}{\alpha}$ (on the condition that the content of useful component β in the final product must fulfill the requirements of the subsequent stage of waste utilization).

These technological criteria of resource efficiency of waste and secondary raw materials processing are:

- degree of waste utilization, %;

- technological indicators of the applicable processes (such as benefication, metallurgy, chemical treatment etc.): fraction of the target component in the raw material (α, %); extraction (ε, %); content (β, %); yield (γ, %);
- (if the product is used in construction industry) constructional and technical properties of the final product: compressive strength ($\delta_{compression}$, MPa); flexural strength ($\delta_{flexural}$, MPa); freezing tolerance (F, cycles); thermal conductivity (λ, $W{\cdot}K^{-1}{\cdot}m^{-2}$); water absorption (W, %);
- (for paper and pulp recycling industry) paper-forming properties of waste pulp and paper: breaking length, m; bursting strength, kPa;
- specific energy consumption, kWh/t (for raw materials, products).

2. Metod

Below the resource efficiency of a technology for power plant coal combustion (by)products – fly and bottom ash (FABA) is assessed.

Wherein a FABA technology is a combination of methods (operations) of FABA treatment in order to improve their quality as a secondary raw material (i.e. composition and fineness stabilization, extraction of useful components, removal of undesired components) with subsequent processing and utilization of enriched products (compliant with the requirements of resource saving as well as legal and technical documentation).

Many methods of FABA processing and utilization are available.

The most potential method of large-scale use of FABA given that it is thermally treated and can't be incinerated (and contains reactive oxides of calcium, silicon and aluminum, has low thermal conductivity) is therefore in the construction industry (this has been practiced since the 1930s) and in road construction. At the same time FABA is a potent source of new products. One ton of FABA can contain up to 90 kg of iron, 160 kg of aluminum, 10-30 kg of magnesium, 1-3 kg of titanium, 1 kg of rare metals [3].

In order to improve the quality of FABA as a secondary raw material, methods of enrichment have to be used. A technologic possibility (and economic feasibility) has been proved for FABA separation via benefication methods into magnetic fraction (yield is 5-10%mass., iron content 35-50%, germanium 10 g/ton, 80% fineness –0,1+0,05 mm), light fraction which contains microbeads (yield is 2%, density 0.3-0.5 $g{\cdot}cm^{-3}$) and non-magnetic fraction (yield is 90%, 70% fineness –0,05 mm) which is a raw material for construction industry (and other industry branches) [4].

The main technologic indicators which characterize the process of benefication (separation) are *extraction*, *content* and *yield*. They allow to evaluate the efficiency of a given technology and compare it to the other technologic processes dedicated to solving similar tasks.

Extraction Ɛ of the component into the separation product is a ratio of the mass of the component in the separation product to the mass of the component in the initial raw material.

Content β of the component in the separation product is a ratio of the mass of the component in the separation product to the mass of the separation product.

Yield γ of the separation product is a ratio of the mass of the separation product to the mass of the initial raw material.

Indicators of separation are usually expressed in percentages (less commonly in decimal quantities).

Products and half-products (waste fractions) obtained after separation (of FABA in particular) must be compliant with the applicable valid standards and requirements of a specific manufacturing process to which they will be sent.

To examine a specific example .

One ton of FABA is sent for separation. The material is transported on the conveyor belt with suspended magnetic separator installed above it.

One ton of FABA contains 5% of iron (50 kg).

As a result of magnetic separation magnetic fraction in the amount of 25 kg is obtained; represented by ferrous metals (20 kg) and impurities (5 kg).

Determination of indicators of separation:

$$Ɛ= \frac{20\,kg}{50\,kg}\text{x}100\%=40\%;\ \beta = \frac{20\,kg}{25\,kg}\text{x}100\% = 80\%;\ \gamma = \frac{25\,kg}{1000\,kg}\text{x}100\% = 2.5\%.$$

The numeric values of technologic indicators allow to make conclusions about efficiency of the separation process (whether these indicators are good or bad).

Extraction: the indicator value of 40% was achieved with the maximum possible of 100%. Large losses of ferrous metals which are left in the non-magnetic fraction indicate that single-step magnetic separation is insufficient, at least one more step is required (introducing one more separator into the processing scheme).

Content: 80% is a high indicator, but according to the applicable Russian state standard (GOST) the content of iron in magnetic fraction for municipal waste benefication has to be not less than 97% (therefore secondary cleaning is required).

Yield: 2.5% is an acceptable indicator which shows that a part of iron compounds was separated from the main bulk of waste (yield of magnetic separation tailings is 100%-2,5%=97,5%; and in case of FABA processing these tailings are an optimized product which can be used in construction industry).

Since FABA is a multicomponent system, the most important indicator is comprehensiveness of raw material usage.

The indicator of the comprehensiveness of FABA usage is a number of components which are extracted into quality products.

3. Results and Discussion

Rational and comprehensive processing of FABA ensures extraction and obtaining of resource valuable components and materials, as well as compliance with valid and applicable norms of secondary raw material utilization.

According to the research by the Kuzbass State Technical University and the Thermal Physics Institute of the Siberian Branch of the Russian Academy of Sciences, using non-magnetic (ferrous metals removed) fraction of FABA allows to lower the cement consumption by 30%. Using FABA in cement manufacturing without removing ferrous compounds leads to a decrease of mechanic and technologic indicators of cement, an increase of setting time [5].

Another unfavorable impurity of FABA is unburned carbon. Different technologic of unburned carbon removal from FABA (flotation, gravitation etc.) are compared using the following technologic indicators: yield of coal concentrate (usually ~20%) and its carbon content (usually 70-80%); coal content in tailings no more than 5%. A technology with higher indicators is chosen.

In order to compare the technologies of enriched FABA utilization in construction industry and road construction (such as manufacturing of concrete, cement, binders, cement clinker etc.) constructional and technical properties of the final products are examined: strength characteristics, normalized water content, flowing property, non-consolidation etc (basic quality indicators of the resulting products) [6].

Using FABA for purification of slightly contaminated discharge water is possible (fly ash – a part of FABA – has adsorptive properties). The quality of purification is assessed by the changes in composition of discharge water from the viewpoint of lowering the content of various contaminants [7].

Another proven way of using FABA is manufacturing of granulated fertilizers (which improves the productive capacity of acidic soil). At the same time soil chalking with an ameliorant derived from waste can be viewed as environmental and resource saving technology since its usage allows to lower the consumption of nitrogenous and phosphorous fertilizers.

As can be seen from the above, technologies are compared taking into account the specifics of the branch usage of the final products.

Regardless of the type of waste which is being processed, the raw materials composition in the feed of a thermal process must be optimized by the criteria of energy saving and environmental safety:

- thermal utilization of waste should be performed for enriched combustible fraction with specific fineness (determined by a given process) and calorific capacity which don't contain resource valuable and dangerous components (spent dry galvanic elements, expired mercury-containing devices etc.);
- calorific capacity of a mixture of wastes (like solid municipal waste) which is to be incinerated is in the range of 2000-3000 kcal/kg (which ensures that the process is stable and autogenic);
- unburned carbon content in slug is not more than 0.3% (requirements for unburned carbon content);
- slug hazard class not lower that IV.

Main ways of improving energy efficiency of waste processing:

- completeness of waste combustion (unburned carbon yield minimization);
- sound preparation of waste for thermal processing (i.e., briquetting, ballast removing etc.);
- extraction of unburned carbon from ash (its briquetting and use as fuel);
- fullness of heat recovery for heat generated in thermal processing of waste:

  - for instance, through heat of molten slug during processing of dusty metallurgy waste into clean metallized ingots;
  - through obtaining more efficient energy carriers, for instance in a so called "adiabatic" process of waste gasification;
- energy saving through improving the main manufacturing technology:
  - tin sulfide sublimation is low in power consumption and can be applied as a technology of extracting tin from low metal content smelter slugs;
  - 30% of energy can be saved using a technology of processing industrial waste into hydraulic binders based on special physical treatment and using efficient chemical additives;
  - technology of extracting nanoparticles of carbon from carbonaceous material is low in power consumption (due to using a feedstock of waste which has undergone high energy treatment during the process of aluminum electrolysis);
- crushing spent tires with addition of rubber devulcanizer.

Introducing such wastes into the industrial cycle is largely tied to their resources, composition, degree of technological usage and readiness of waste for processing and utilization, the demand of obtaining new products [8].

Based on the foregoing, the scientific approach for implementing policy in resource saving and resource efficiency is based on determination of cause-effect relationships between regular waste generation (meaning their properties, quantity and quality) and practicability of their recycling and utilization (considering priorities for investment). Systems of waste management are created in order to protect the environment and ensure rational use of natural resources (taking into account one of the basic principles: it is preferable to conserve the energy contained in waste by using it as a secondary raw material as opposed to incinerating it and utilizing the energy generated by that) [9].

Introducing large-tonnage wastes into the industrial cycle requires valid and reliable information about not only the available resources, but also the quality of the secondary raw materials and possible methods of their processing and utilization, which in turn necessitates organized testing of storages and landfills of technogenic materials and conducting large-scale experimental research (similar to new mineral deposits), which is a complex and laborious task, which takes time and resources to be completed. (Assessment of the resources available in mineral deposits is done in conjunction with examination of their enrichability, that is, their ability to be processed using existing technologies).

In order to save time and reduce costs, as well as to increase comprehensiveness and reliability of research a methodology of technogenic waste quality assessment and their possible utilization methods was suggested, based on analytic study of an accumulation of patented technologic solutions, which are dedicated to recycling technogenic raw materials generated as a result of processing mineral deposits and derivatives thereof (in a chain of manufacturing various products which have lost their consumer properties with time) [2,6].

To justify the viability of applying such methodology:

- patented technologic solutions are obtained experimentally using actual samples of industrial waste, thus identifying not only the possibilities of using a given technology, but also precising the composition of wastes as objects of recycling;
- experiments can be regarded as crosscutting: they are conducted by various researchers and solve different tasks;
- patented technologies of secondary raw materials reuse are resource saving solutions and therefore can be viewed as innovative offers;
- in case the conducted experiments were successful on a larger scale (i.e., semi-industrial) the technology can be recommended for practical implementation and used as a starting point for engineering.

Below is a list of new resource saving technologies which have been tested on semi-industrial and experimentally industrial scales:

- technology of recycling finely dispersed wastes of electrolytic aluminum manufacturing containing carbon and fluorine (millions of tons of such waste are accumulated on slimy landfills);
- technology of recycling dusts of secondary lead and paste of lead batteries;
- technology of combined processing of cuprous slug and copper anode slime;
- technology of steel smelter slug and ferrous sulphate disposal (derived from regeneration of spent etching medium);
- technology of extracting magnetic fraction from FABA;
- technology of FABA's complex recycling, extraction of valuable components and unburned carbon;

- technology of pyrite cynder recycling;
- technology of phosphogypsum recycling (combined with extracting valuable components, incl. rare earth metals);
- technology of obtaining high strength artificial gypsum stone.

Analysis of patented technologic solutions indicates that technogenic fields of large tonnage waste in the Russian Federation have been practically studied and considered to be serviceable. All approbated technologic solutions can be assumed to be resource efficient. Therefore, the problem of waste, stemming from the methods of its solving, is refocused to be a problem of secondary raw materials as a part of the resource saving issue. It is extremely important that introducing many types of secondary raw materials into the industrial cycle is based on using experimentally tested technologic solutions and that technologic and investment risks are reduced to the minimum.

On the whole, extracting valuable components from raw materials with subsequent utilization of the remaining part in the construction industry is basically a rational solution of the resource saving and improving resource efficiency problems (strategic planning).

4. Conclusions

Based on the foregoing, the analytic study of an accumulation of patented resource saving solutions of various technological tasks, which is used in this paper, is an effective method to evaluate quality of technogenic raw materials and its readiness for introduction into the industrial cycle. This approach is also the most informative and well-grounded method of evaluating the soundness of concepts of solving the problem of secondary raw materials and creating applicable market conditions to recycle and use waste in a given region, to minimize environmental and investment risks, and it can also be used as a method for expert assessment in determining environmental and economic efficiency and practicability of recycling technogenic raw materials, and in implementation of sound environmental industrial policy.

Practicability of extensive involution into processing and utilization of large tonnage waste as technogenic raw materials concentrated in artificial waste landfills which contaminate the environment, is explained by the following reasons:

- the necessity of solving the problem of waste is dictated by the regulatory documents;
- environmental requirements (there is approximately 2 billion tons of FABA, over 3 billion tons of ore-mining and smelting waste and other wastes which contaminate the environment are accumulated in the Russian Federation; the formation of landfills is associated with withdrawal of land from beneficial use); environmental problems in and of themselves do not pose an interest to the market, but at the same time a part of a new product's competitiveness is related to its environmental characteristics (eco-efficiency);
- FABA and slugs are finely crushed thermally processed and incombustible product (they contain reactive calcium, silicon and aluminum oxides, possess low thermal conductivity); the properties of many wastes determine their potential usefulness for the construction industry and road construction;
- many wastes contain valuable components (compounds of iron, microbeads, rare and rare earth metals, precious metals, etc.).

Actions to be taken on a state level:

- legal requirement that all enterprises must maintain records of waste management and provide data on it to authorities;
- state support of marketing products which contain secondary raw materials;
- placing restrictions on using primary raw materials or products therefrom, if similar materials or products using secondary raw materials are available;
- preferential taxation of enterprises which perform activities of waste management;
- discounted fares on transportation of raw materials obtained from waste;
- soft loans for the purposes of creating the infrastructure of waste utilization.

Unfortunately, as of now such large tonnage wastes as FABA and phosphogypsum are mainly practically used only for manufacturing construction and road materials, significantly less commonly as agrochemicals and almost never as raw materials for extraction of valuable components, especially metals (incl. those which are strategically important).

The analysis of an accumulation of patented technologic solutions proves that FABA and phosphogypsum, which generate large landfills, can be reused, and characterizes their broad technologic possibilities as object of processing.

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