Technological aspects of waste incinerator slag processing

E V Kolodezhnaya¹, I V Shadrunova¹, M S Garkavi²

¹Research Institute of Comprehensive Exploitation of Mineral Resources of the
Russian Academy of Sciences, 4 Kryukovskiy dead end, Moscow 111020, Russia
²Company "Ural-Omega", 89/7, Lenina ave, Magnitogorsk 455037, Russia

E-mail: kev@uralomega.ru

Abstract. Incineration is a modern global trend in the disposal of combustible solid waste. When burning garbage, solid incombustible residues are formed – slags containing aluminum, copper, zinc and lead, in quantities many times higher than the maximum permissible concentrations of these elements in soils. The material composition and morphostructural features of the material were analyzed to determine possible areas of use and ways of utilization of waste incineration plant slags. As a result of microprobe researches forms of finding of ecologically controlled elements in slag are established. Test results of slag concentration by gravitational methods and results of magnetic separation are given. Based on the studies, a basic outline of slag product processing is proposed.

1. Introduction

The search for areas of use and ways to dispose of man-made waste is directly related to the issues of conservation and protection of the environment. Today, the issues of solid waste disposal (MSW) are acute for all countries of the world. In total, more than 550 million tons of municipal waste is generated annually in developed countries. [1-3]. The removal of combustible household waste to specialized landfills will solve the issue only in the short term, Garbage dumps occupy areas of the land Fund that become unsuitable for introduction into economic circulation due to the penetration of harmful substances into the soil. Evaporation and decomposition processes put a great strain on the environment of the region as a whole [4-7].

Solid waste incineration is performed in units of special designs that take into account the specific properties of combustible waste. Combustion is carried out without additional fuel input at a temperature of up to 900 °C. During incineration, a solid residue is formed in the form of slags, the mass of which is 20 – 30% of the mass of waste received for incineration. Slags contain heavy metal compounds, of which the main ones are aluminum, copper, zinc and lead [8]. To reduce the negative impact of this material on the environment during storage, it is necessary to process slags.

On technological lines, the slags are crushed, iron is removed from them and then they are dispersed along the border of 3 mm. Material larger than 3 mm contains more non-ferrous metals and is further processed. Slags of 0 – 3 mm fraction are tailings of slag processing and are sent to the landfill for burial [9-14]. These tailings reprocessing slags from waste incineration plants contain such harmful impurities such as compounds of copper, lead and zinc. Reducing the mass fraction of these metals in tailings would reduce the risk of this material and consider other options for its utilization [15].
When choosing a method of recycling slags, a significant advantage of using them as secondary resources is a reduction in the disposal area at the landfill. However, this is only feasible if the established rules governing waste management are met. In the countries of the European Union, hazardous waste lists are mainly used to indicate hazards. There are also levels classifying wastes as hazardous on the basis of activity type as a result of which they are formed or the properties of substances (a total of 14 properties). There are two waste classifications in Russia: "Sanitary rules for determining the hazard class of toxic waste of production and consumption" (SP 2.1.7.1386-03) and approved in 2001 by the Order of the Ministry of Natural Resources of the Russian Federation "Criteria for classifying hazardous waste as an environmental hazard class." In essence, classifications do not have fundamental differences, since the hazard class is established by toxicity, but such duality distorts information. Primary indicators are MPC of chemical elements of water, atmosphere, soil, etc.

2. Object and research methods

Material represents loose powder of fineness less than 0.5 mm. The particle size distribution of slag defined on the laser analyzer is presented in table 1.

| Size (mm) | Vol Under (%) |
|-----------|---------------|
| 0,02      | 0,0           |
| 0,06      | 3,2           |
| 0,16      | 63,9          |
| 0,3       | 92,5          |
| 0,6       | 98,8          |
| 1,2       | 99,8          |

Results of the analysis showed that in material there are no particles less than 0.065 mm in size. The humidity of initial material was 0.2%, bulk density – 920 kg/m³.

In the magnetic analysis of material, the mass of magnetic fraction was 16.7%.

The element composition of material is determined by X-ray fluorescent method on a x-ray power dispersive spectrometer of ARL QUANT’X of the Thermo Scientific company.

The phase composition of material is defined on the x-ray PRO MPD X Pert diffractometer according to methodical instructions NSOMMI No. 191 "The Radiographic Quantitative Phase Analysis (RQPA) with use of a method of the internal standard".

The X-ray spectral microanalysis with the electron probe (XSMA) was carried out on the electron probe JXA-8100 microanalyzer of Jeol equipped with wave spectrometers and the power dispersive Link Pentafel attachment.

Gravity enrichment of the material was carried out in air and water. The air classification of the material was carried out in the cascade-gravitational classifier CG manufactured by Ural-Omega. Classifier is intended for separation of loose materials in air flow by size or density with possibility of separation boundaries adjustment. The starting material was classified in a cascade-gravity classifier (CG) to obtain two products: "large" and "small."

The separation of the material in the aquatic environment was carried out on the laboratory table concentrator and spiral concentration, to obtain light and heavy fractions.

3. Results and discussion

The selection and justification of technology for processing natural and man-made raw materials is based on complete, objective and reliable information about the material composition of the material. When predicting qualitative and quantitative indicators of slags from the combustion of combustible
waste, information about the actual composition, structure, morphostructural characteristics, and technological properties is now one of their main tools [16-18].

The established regularities of the slag structure, phase composition, physical and physico-chemical properties make it possible to adapt traditional methods of enrichment to the processing of slags, increase the efficiency and economic attractiveness of processing [19-22].

The chemical composition of the slags is shown in table 2. The main eco-controlled components are Al, Si, Zn, Ca, Cu and Fe. These elements are present in the form of independent metal grains (metallic aluminum) and alloys (brass), as well as in the form of inclusions in the composition of iron oxides (hematite) and aluminum silicate (helenite).

### Table 2. The chemical composition of an input material.

| Chemical element | Mass concentration (%) |
|------------------|------------------------|
| Si               | 25.9                   |
| Ca               | 14.9                   |
| Fe               | 3.2                    |
| S                | 0.6                    |
| Al               | 8.9                    |
| Ti               | 0.8                    |
| Mg               | 1.5                    |
| Cl               | 0.2                    |
| K                | 0.9                    |
| P                | 0.2                    |
| Zn               | 1.7                    |
| Cu               | 1.1                    |
| Mn               | 0.1                    |
| Cr               | 0.1                    |
| Pb               | 0.4                    |
| Ni               | 0.1                    |

Photo mineralogical studying of samples showed that material mainly consists of the isolated grains of the main phases having complex structure. Cluster or multiple grains are not established (figure 1).

![Figure 1](image1.png)  
**Figure 1.** Optical-mineralogical study of the material. a) S1, S2, S3, S6, S7 – silicates of variable composition, S4, S5 – metal part Cu-Zn; b) S1, S3 – metal Al, S2 – metal part Al-Cu, S4 – alumina, S5 – metal part Al-Zn, S6 – metal part Cu-Zn, S7 – metal Pb, S8 – metal Zn.

The distribution of Cu, Zn, Pb and Al in the material phase particles is determined by x-ray spectral microanalysis with an electron probe (RSMA).
The presence of particles representing an alloy of copper and zinc in approximately equal proportions was found in the slags. These particles contain fine lead inclusions of 10 – 15 microns in size (mass fraction Pb 75 – 79%). The presence of veins of metallic aluminum with a thickness of no more than 1 – 2 microns was found in the zinc particles. Particles of metal aluminum have dendritic impregnations of two types: Cu-Al compound (in the ratio 1:1) and Su-Al-Fe compound (in the ratio 1:6:3) (table 3).

**Table 3. Composition of inclusions in aluminum particles**

| Chemical element | Mass concentration (%) |
|------------------|------------------------|
|                  | Spectrum 1 | Spectrum 2 |
| Mn               | 0,09       | 1,50       |
| Fe               | 1,31       | 28,26      |
| Co               | 0,11       | 0,08       |
| Al               | 47,04      | 59,77      |
| Si               | 0,10       | 0,29       |
| Ni               | 0,06       | 0,10       |
| Cu               | 50,37      | 7,48       |
| Zn               | 0,27       | 0,62       |
| As               | 0,59       | 0,50       |
| Pb               | n/o        | 0,63       |

Grains of phases, mainly consisting of iron, are characterized by a very variable chemical composition and a variety of structure. These particles are a silicate-ferrous mass with inclusions of iron oxides and metallic iron. This type of grain contains Cu 0.1–1%, Zn 0.1–0.5%, Ni 0.1 – 0.2% and Pb 0.2–1%. Grains of the silicate phase have a simpler and more uniform structure.

During elemental mapping of the sample, it was found that Pb and Sn are distributed almost evenly across all phases, and Cu, Zn and Ni are mainly associated with metal grains.

As the most contrasting separating feature of slags is their grain density, it was recommended to conduct technological tests on the gravitational-magnetic enrichment of this material. Tests were carried out on gravity separation of material in air on cascade-gravity classifier and in water on table concentrator and spiral concentration (table 4).

**Table 4. Results of slag enrichment.**

| Product                                             | Mass output (%) | Mass concentration (%) |
|-----------------------------------------------------|-----------------|------------------------|
|                                                     |                 | Al        | Zn     | Cu     | Fe     | Pb     |
| Raw material                                        | 100,00          | 8,96      | 1,75   | 1,14   | 3,18   | 0,44   |
| Classification in the cascade-gravity classifier (KG)|                 |           |        |        |        |        |
| "Large" product                                     | 16,60           | 12,80     | 2,86   | 3,10   | 3,99   | 1,10   |
| "Small" product                                     | 83,40           | 8,20      | 1,53   | 0,75   | 3,02   | 0,31   |
| Classification on the screw separator                |                 |           |        |        |        |        |
| Heavy fraction                                      | 13,40           | 5,64      | 8,60   | 5,53   | 4,60   | 2,06   |
| Light fraction                                      | 86,60           | 9,47      | 0,69   | 0,46   | 2,96   | 0,19   |
| Classification on the concentration table            |                 |           |        |        |        |        |
| Heavy fraction                                      | 9,80            | 5,56      | 7,09   | 6,20   | 4,10   | 1,51   |
| Light fraction                                      | 90,20           | 9,33      | 1,17   | 0,59   | 3,08   | 0,32   |
4. Conclusion
Air classification of the material in CG increases the mass fraction of Al, Zn, Cu in the "large" product. The yield of the "large" product was 16.6%.

Magnetic separation of the "large" and "small" CG products allows to isolate a total of 16.1% of the magnetic product with a mass fraction of Fe in 12%. When developing the flowchart of enrichment, it is advisable to conduct first magnetic separation of the starting material to obtain an iron-containing material in the magnetic product, and then conducting air classification of the non-magnetic product to isolate non-ferrous metals into a "large" product CG. The non-ferrous metals Al, Zn, Cu, Pb are converted to a non-magnetic product.

The hydro classification of the starting material makes it possible to separate Al from Cu, Zn, Pb. Therefore, it is advisable to enrich non-magnetic products of dry processing of the material on table concentrator and spiral concentration.

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