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## Comparison of Geophysical and Geochemical Parameters of the Belovo Zinc Facility Dumps (Kemerovo Region) in the Process of Recultivation

To cite this article: S P Grakhova *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **459** 032050

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# Comparison of Geophysical and Geochemical Parameters of the Belovo Zinc Facility Dumps (Kemerovo Region) in the Process of Recultivation

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**Abstract.** The article presents the results of geochemical and geophysical studies of the Belovsky Zinc Plant reclaimed dumps (Kemerovo Region), which is located in the residential zone of the Belovo city. The relationship between the degree of neutralization of waste and electrical resistivity is established and described. For the first time at this facility, measurements were made by the induced polarization method. When analyzing the polarizability distribution (C, mV/V), it was found that not so much wet and warm zones with a high level of acidity are distinguished on the profiles of electrotomography as they are saturated with minerals with high electrical conductivity. This means that low resistivity values are associated with electronically conductive minerals with metallic conductivity. Thus, the assumption was made that the anomalies are associated with the introduction of coke into the dump, that is, an increased carbon content, which affects not only the resistivity profiles, but also the IP profiles.

## 1. Introduction

Slag dumps are a widespread type of industrial waste generated during the metallurgical processing of mineral concentrates. Currently, such dumps are attracting special attention: firstly, as a source of increased environmental hazard, and secondly, as a source of useful components and building materials [1].

Problem remediation is paid more and more attention every year. New ideas and justifications for ecological rehabilitation of the territory exposed to the negative impact of industrial facilities during the last century [2, 3, 4]

The dumps left over from the metallurgical enterprises of the Soviet era are an example of the irrational use of natural resources. Their processing is currently an urgent task, while the main condition is the integrated use of raw materials with minimal environmental damage. Often the costs incurred by the enterprise for the extraction and processing of ore resulted in the extraction of one valuable component, while the impurity elements went into waste. Currently, in some cases, such dumps can be considered as technogenic deposits and can be profitable for secondary processing due to high residual concentrations of valuable components. At the same time, slag dumps are a source of increased danger, since during metallurgical processing and subsequent storage of waste compounds of environmentally hazardous metals are transformed into mobile forms (sulfates, chlorides) that are intensively distributed in the environment. Combustion processes also contribute to this [5, 1].



The studied waste was stored in the territory of the former Belovsky Zinc Plant, which is located in the residential zone of the Belovo city (Kemerovo Region). [6]. Between 1950 and 1994, as a result of pyrometallurgical processing of sphalerite concentrate, about 1 million tons of slag containing high amounts of metals (Zn, Cu, Co, Ni, Pb, etc.), metalloids (As, Sb) were accumulated. The presence of coke dust (20%) remaining in the dump as a result of technological processes led to spontaneous combustion of the internal parts of the dump, which lasted more than 10 years. Combustion of the dump and, as a result, intense oxidation of the substance formed a kind of vertical zoning, characterized by three types of modified waste: burnt (or pyrometamorphic) waste, metamorphosed waste and slightly modified waste [7].

Acidic waters of drainage streams (pH 3-4) are of the  $\text{SO}_4\text{-Cl-Ca-Na}$  type, and slightly acidic waters of the Belovsky settling tank (pH 5.5) – are of the  $\text{SO}_4\text{-HCO}_3\text{-Cl-Ca-Na}$ -type with high salinity and high content of heavy metals, especially Cu and Zn. The main chemical forms of environmentally hazardous metals in the drainage flows and waters of the sump are aqua ions and sulfate complexes [6].

Technogenic soil pollution is maximally in the immediate vicinity of clinkers (60-fold excess of the regional background according to Zn), decreases at a distance of 300 m (17-fold excess) and remains even at a distance of 5 km (5-fold level) in control samples [8]. Although the concentrations of elements decrease along the wind rose trend they are elevated in comparison with background level even for a distance of about 250 m from the tailings dump. Thus, the total environmental damage amounted to \$156 million at the time of 2011, and could reach \$480 million by 2030 if steps are not taken in recycling and remediation of disturbed areas [9-12].

In 2013, Recycling LLC began reclamation of the dump with preliminary extraction of residual copper and noble metals (Au, Ag), neutralization of spent clinker with lime and then the creation of an environmentally friendly zone.

The aim of the study was to control the internal structure of the stacks of spent clinker and neutralized clinker by non-destructive methods to assess the formation and distribution of mineralized solutions.

The following tasks were solved:

- determination of the electrical resistivity of waste from the Belovsky Zinc Plant before and after neutralization;
- plotting a series of geoelectric sections of clinker dumps before and after treatment with neutralizing agents;
- creating a three-dimensional model of the waste body structure;
- assessment of the used technology effectiveness.

## 2. Research methods

The material underlying this work was collected during the field seasons 2017 - 2019. Samples of waste (after metal extraction with acidic solutions) and neutralized (by adding lime) dumps were taken in sealed plastic bags and stored in a cool dark place.

The change in electrical resistivity as a function of moisture saturation was determined in laboratory conditions. Each 100 g dry sample (spent and neutralized clinker) was placed in a Miller resistivity meter, and the resistivity values were measured. Then, 1 ml of distilled water was added until a water mirror appeared on the surface of the sample. After each addition of water after 15 seconds, the resistivity values were measured.

The task of field geophysical research was to determine the geometry and structure of dumps using electrometomography method. The main difference between electrotomography and classical vertical electrical sounding is the use of multi-electrode electrical prospecting braids and full automation of measurements. The standard measurement procedure is a set of longitudinal lines 120 meters long, with a spacing step of 5 m. The distance between adjacent profiles was also 5 m (Fig. 1). The technology of three-dimensional electrotomography consists in software approximation of a series of

parallel profiles (in this case, 6 profiles) into a single system in the Res3DInv program (Geotomo Corp., Malaysia).

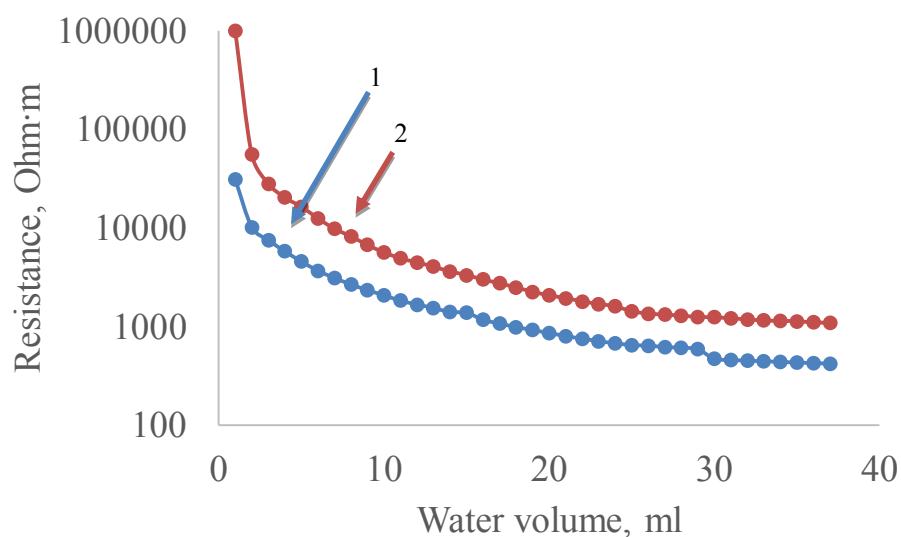


**Figure 1.** Panoramic view of the dump and the location of ET profiles.

Along with the determination of clinker resistivity, its polarizability was also measured - the property of rocks to create secondary electric fields under the influence of an external field. Minerals with electronic conductivity, metals and graphite are highly polarizable.

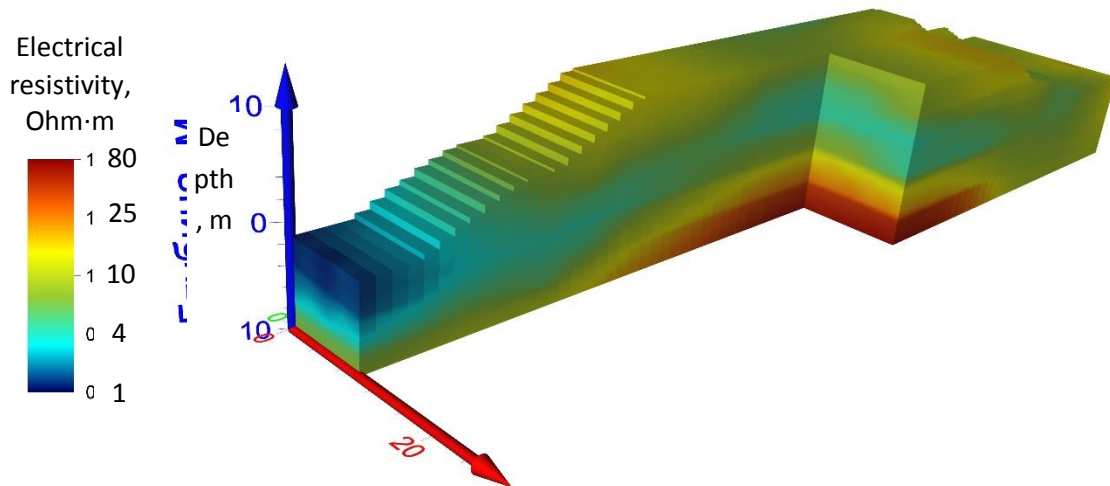
### 3. The results

The change in the resistivity values of spent and neutralized clinker samples is inversely proportional to the moisture saturation of the substance. It is important that the neutralized clinker is characterized by higher resistivity values than the spent clinker in the entire humidity range (Fig. 2). This indicates that using electrical prospecting methods it is possible to detect, firstly, areas that have not undergone neutralization, and secondly, the contouring of flooded lenses inside the pile stack. It should be noted that identical resistivity values are determined in the spent clinker with a low ratio of "solid - water" and in the neutralized clinker with a higher ratio, which creates some uncertainty in the interpretation of field measurements. Therefore, geophysical data were certified by the geochemical characteristics of the substance.



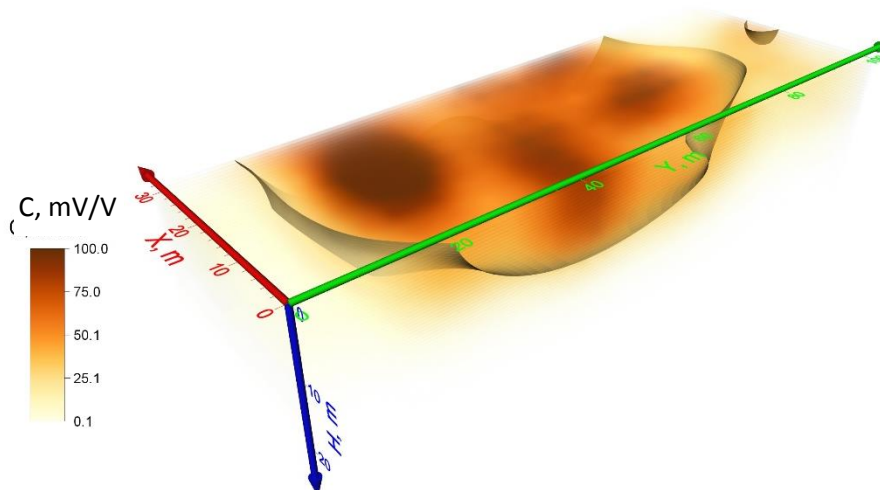
**Figure 2.** The graph of the water saturation sample resistivity: 1 – before, 2 – after watering.

Field geoelectric measurements of the neutralized clinker stack indicates that the clinker as a whole has an abnormally low resistivity (Fig. 3). At the same time, the low-resistance zone is clearly shown on the 3D-model, indicating the presence of an irrigated lens with highly mineralized solutions. Probably, such zoning can form due to the incompleteness of the neutralization reaction inside the stack.



**Figure 3.** Three-dimensional resistivity distribution model in a neutralized clinker.

An analysis of the polarizability distribution ( $C$ , mV/V) showed that not so much “acidic”, wet and warm zones are distinguished on the profiles of electrotomography, but rather saturated with minerals with increased electrical conductivity (Fig. 4), probably copper sulfates. This means that low resistivity values are associated with electronically conductive minerals with metallic conductivity. It can be assumed that the anomalies are associated with the presence of residual alloys, which are characteristic of pyrometallurgy waste. Although it is possible, that coke can influence the polarizability of the substance, the content of which in the dump remains rather high, despite the combustion process.



**Figure 4.** Three-dimensional model of IP anomaly in a spent clinker.

After repeated measurements of the apparent resistivity at the site of the clinker treated with the reagent, zones appeared in which neutralization processes are actively taking place with the release of heat. Thus, it becomes obvious that control over the state of stored neutralized clinkers is necessary,

the development of non-invasive methods for their control using electrical intelligence becomes an urgent task. Further monitoring is planned depending on the seasons of the year, as well as daily observations.

#### 4. Summary

Comparison of geochemical and geophysical data on objects of this type is justified. An experiment was conducted, which showed that the resistance of the samples before and after treatment with milk of lime differ at least twice. Which gives us reason to believe that the method of electrotomography is applicable for monitoring the processes of neutralization of clinkers in production.

Then, according to the field studies results, two geophysical methods were combined - ET and IP, which made it possible in one case to find wet zones (ET), and in the second case, to determine the conductive solid minerals. Thus, when confirmed by geochemical data in the complex, we have the opportunity to talk about those zones that are more mineralized - at least compare, localize neutralized zones.

In a first approximation, we have developed a method that allows outlining and characterizing the neutralized zones in the clinker. Which subsequently makes it possible to evaluate the efficiency of the technological process by non-invasive methods.

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### **Acknowledgments**

This work supported by the basic research project No. 0331-2019-0031.

The authors thank the management of Recycling LLC and personally K.I. Cherny for help in field works organizing and conducting, as well as valuable recommendations when writing a work.