ELECTRICAL RESISTIVITY MEASUREMENTS FOR WASTE DUMP CHARACTERIZATION

CHARAKTERYSTYKA SKŁADOWISKA ODPADÓW NA PODSTAWIE POMIARÓW ERT

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Abstract

The studies were conducted on smelter waste dump from zinc and lead processing located in Ruda Śląska in Southern Poland. The survey lines were situated at the bottom of the embankment where the part of waste dump was already exploited, and on the boundary between the waste dump and surroundings. The results of electrical resistivity tomography show that variation in electrical resistivity of waste depends on the location of waste within the dump. Electrical resistivity of waste varied from 150 Ωm to 8000 Ωm. The difference of the electrical properties of the waste is caused by their chemical, physical, physico-chemical properties (e.g. water content, compaction of waste, particle size distribution, chemical composition). Electrical resistivity contrast between waste and surroundings allowed to determine the thickness of the waste and the maximal depth of their depositions. Depth of waste deposition varied from 6 m to 8 m and established thickness of waste was 19 m.

Abstrakt

Studie byla provedena na skládkách odpadů z hutí, které vznikly ze zpracování zinko-olověných rud v Rudě Slezské (Polsko). Měřicí profily byly realizovány ve vytěžené části skládky a na hranici mezi skládkou a okolním prostředím. Výsledky elektroodporové tomografie ukazují variabilitu elektrického odporu na skládce v závislosti na místě měření. Elektrický odpor odpadů se pohybuje od 150 Ωm do 8000 Ωm. Rozdíly v elektrických vlastnostech odpadů jsou způsobeny různými fyzikálními, chemickými a fyzikálně-chemickými vlastnostmi (např. obsah vody, stupeň zhutnění odpadu, chemické složení, velikost částic). Kontrast elektrického odporu mezi odpady a okolním prostředím dovolil odhadnutí mocnosti skládkovaného odpadu (od 6 m až 8 m) a maximální hloubky jeho uložení (19 m).

Keywords

ERT, smelting waste dump, Zn-Pb waste, heavy metals, soil contamination

Klicova slova

Elektroodporová tomografia, skládky odpodů z hutí, odpady Zn-Pb, těžké kovy, znečistění půdy

1 Introduction

The areas of mining and smelting of non-ferrous metal, such as zinc and lead, carried out large-scale processing of ore flotation which generates significant amounts of waste. The environmental impact of deposition of these wastes is associated mainly with high amounts of heavy metals and iron sulfides. These compounds cause the pollution of air, soil, water and organisms especially in the vicinity of waste dump. In the Upper Silesian Region, devastated or degraded waste-land requiring reclamation are estimated for about 7 000 ha (Jarczewski and Ziorbowski, 2010) to 21 000 ha (UMWS, 2011).

Electrical resistivity of waste, just like in soils, depends on various factors, including heavy metal concentration, the nature of the solid constituents, water content, degree of the water saturation, electrical conductivity of the pore fluid and temperature.

Geoelectrical measurements were successfully used to investigate the properties of mining waste dumps from the processing of deposits of zinc, lead, iron and copper mines in the world by Bogoslovsky and Ogilvy (1970), Bérubé (2004), Mainali (2006). In Poland, the ERT measurements where conducted mainly on post-flotation wastes in Olkusz, Bytom, and Brzeziny Śląskie by Cabała et al. (2007); Cabała et al. (2008), Kondracka, (2013). Conducted researches indicate that different waste of Zn-Pb processing has different electrical, physical and chemical properties depending on the type of reclamation, but they conclude that the studied waste are characterized by relatively low electrical resistivity of waste (about 3 –80 Ωm). Furthermore, most of these studies were carried out in the area of high resistivity surroundings (sandy soils) and very low resistivity of waste.

In this paper we present the electrical measurements of waste stored on the clays. The aim of this study is to characterize the electrical resistivity of waste from Zn-Pb processing and to determine the possibility for using of geoelectrical methods to investigate the differentiation of wastes and their surroundings.

2 Area of investigation

The studies were conducted in Southern Poland on smelter waste dump of zinc and lead processing located in one of the most devastated cities in Upper Silesian Region - in Ruda Śląska (Fig. 1). The waste dump is located in the center of Wirek near residential buildings - near Nowary and Korczaka Street. The wastes were formed as a result of activity of Hugo Steelworks (1812 - 1932. It is assessed that about 1 860 000 m^3 volume of waste was stored on the

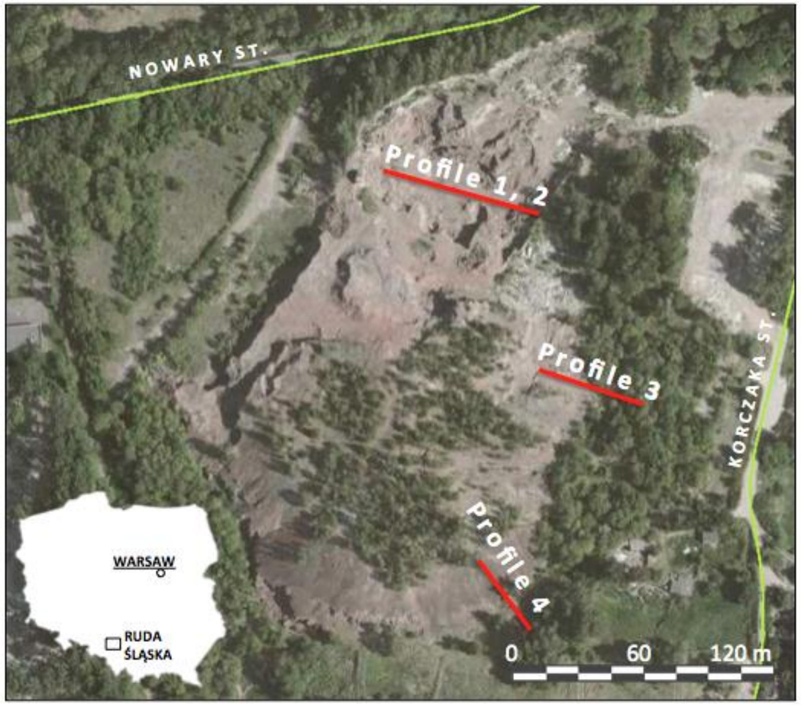

Fig. 1 Area of investigation and location of electrical resistivity tomography (ERT) profiles (red lines) on the studied waste dump.

area of 8.5 ha. The wastes are characterized by red and brown color and varied with physical properties depending on the depth (Jonczy, 2006) and localization on the waste dump. A part of the waste dump was exploited for the use in the road construction, what gave us the opportunity to explore the deepest parts of embankment. Part of the waste dump, especially southern and eastern part, is covered by vegetation. Rest of it is very rarely covered by the spontaneous succession, what may cause an aeolian transport of waste.

Jonczy (2006) indicated that piled up wastes are characterized by high concentration of heavy metals, especially: Zn (6 270 – 83 700 ppm), Pb (5 340 – 29 385 ppm), As (2 560 – 17 400 ppm), Cu (166 – 1 859 ppm) and Cd (32 – 262 ppm). Acid pH (5.7 – 6.0) and high permeability of waste increase heavy metals migration outside the waste dump (Jonczy, 2006). The highest mobility of heavy metals was established for As, Pb, Zn, Ni and V (Warchulski, 2014).

High concentrations in the vicinity of waste dump: Pb (136 – 867 ppm), Cd (2 – 8 ppm), Cr (16 – 33 ppm), As (2 – 33 ppm) and Zn (276 – 1 485 ppm) indicate that the waste causes the soil pollution in that area (Mzyk, 2003).

The area of the investigations is situated in the Upper Silesian Coal Basin. The Carboniferous coal formation is covered by the Pleistocene deposits represented by clayey sediments, sometimes with thin interbeds of sands or gravels which underlain the waste dump.

3 Methods

The electrical resistivity tomography (ERT) using electrical imaging system LUND (ABEM) were carried out in the area of studied waste dump. The system consisted of 41 electrodes. Three different electrode spacings - 2 m (profile 1), 1.5 m (profile 3), 1.2 m (profile 2, profile 4), depending on the area conditions and depth recognition, were used. Different electrode spacings gave the maximum penetration depth of approximately: 14 m, 12 m and 8 m respectively. The Wenner-Schlumberger electrode configuration was used in order to combine accurate horizontal coverage of the ground, good depth penetration and good signal-to-noise ratio (Loke and Barker, 1996). The obtained data were processed in RES2DINV. The interpretation program calculates the true resistivity and true depth of the ground from the inputted data file using Jacobi matrix calculation and forward modeling procedures. The topographic data was loaded in datasets before inversion for all profiles.

The survey lines were situated at the bottom of the embankment (Fig. 2A) where the part of waste dump was already exploited (parallels profiles: 1 and 2) and on the boundary between the waste dump and its surroundings (profile 3, profile 4) – Fig, 2B. Location of profile lines is presented on Fig. 1.

Fig. 2 Location of the ERT profiles on the part of waste dump partly exploited (A) and on the boundary between the waste dump and surrounding clayey soils (B)

4 Results

Electrical resistivity of examined waste dump characterized its different structure (Fig. 3, Fig. 4). The results of electrical resistivity tomography show that the variation in electrical resistivity of waste depends on the location on the waste dump. Profile 1 and 2, carried out in the exploited part of the waste dump show that the waste are characterized by high electrical resistivity 250 Ωm to 8000 Ωm. However the lower electrical resistivity of waste is observed in the near surface layer (depth of 1 m to 4 m - on profile 2 and 1 respectively). The high resistivity layer is observed on the depth of 2 m and has a thickness of about 5 – 6 m.

So high electrical resistivity is not observed in the profiles conducted on the slope of waste dump (Fig. 4). The electrical resistivity varied from 150 Ωm to 1 200 Ωm, but higher resistivity layers are observed only sporadically (Fig.4).

5 Discussion

Electrical resistivity of waste varied from 150 Ωm to 8000 Ωm depending on the location of their deposition. Relatively higher resistivity values of waste were observed on profile 1 and 2: 250 Ωm to 8000 Ωm (Fig. 3) and relatively lower values: 150 Ωm to 1 200 Ωm on profile 3 and 4 (Fig. 4). The difference of the electrical properties of the waste is caused by their physical and physico-chemical properties what is connected with their ability to retention of water. The water content is one of the major factors of ground properties, which affect the electric conduction and may cause the high differences of recorded electrical resistivity. The waste with low electrical resistivity (Fig. 2) is a fine-grained loose material, what causes the decrease of measured electrical resistivity due to the magnitude of the specific surface (Fukue et al., 1999). The waste with very high electrical resistivity characterize with coarse-gained material, consolidated and very dry resemble in the texture of rocks. The type of deposition and remaining the waste under the pressure of about 20 m of waste had an influence on the waste properties and probably affected on the observed properties of waste.

The differentiation of electrical properties of waste is also related with chemical and mineralogical composition. The changes

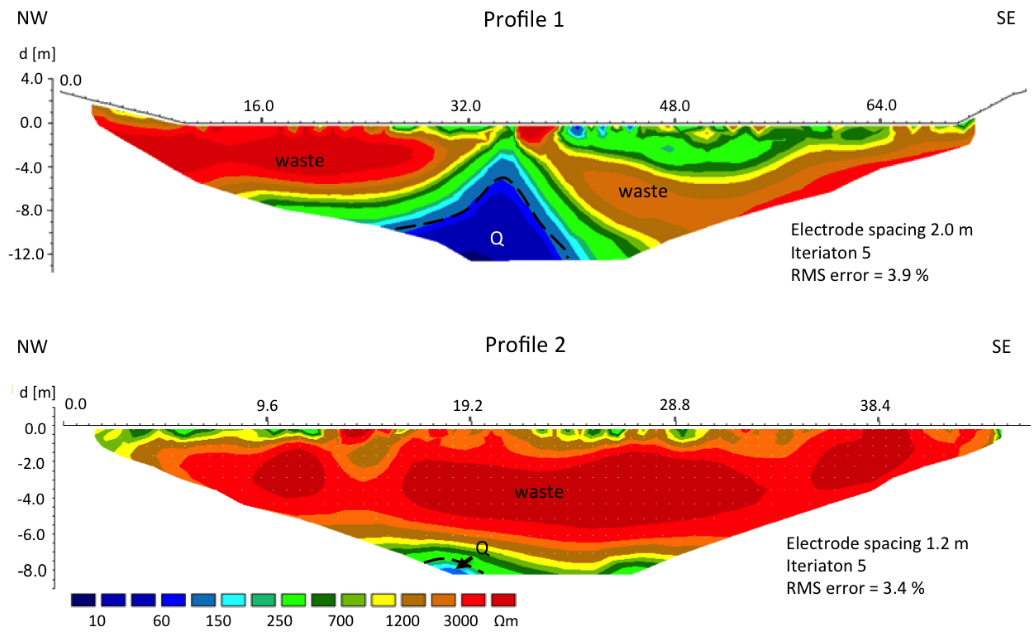

Fig. 3 The electrical resistivity variations of waste (the bottom part of the embankment) and the Quaternary deposits represented by clayey sediments (Q) on two parallels profiles with different depth recognition. Black dashed line represents the base of the waste dump

are connected with the hypergenetic processes, which occur in the waste dump (Chodyniecka and Haber, 1995) and with the weathering processes of the near surface layer of the waste. Studies carried out by Jonczy (2006) indicate that the minerals of waste are preserved with different degree depending on the resistance to weathering and contact with migrating solutions.

Comparing the results from Ruda Śląska with Bytom and Piekary Śląska (Kondracka, 2013) different structure of embankment can be seen. In postflotation waste it was shown that the electrical resistivity decreases with the depth (Kondracka and Wiśniewska, 2011). In Ruda Śląska, we observed the opposite situation - the resistivity is increasing with depth (Fig.3). The difference can indicate that different processes occurred inside the embankment waste. The differences are probably caused by the chemical composition of waste and their physical properties what affect the transport of water, conditions to mineral transformation and heavy metal release and should be farther examined.

The difference between clayey sediments with relatively low electrical resistivity (10 – 60 Ωm) and relatively high resistivity (150 Ωm – 8 000 Ωm) of waste allowed to determine the thickness of the waste and the maximal depth of depositions. Thickness of the waste varied from about 6 m (Fig. 3) to 8 m (Fig. 4). The total thickness of the waste dump was established for 19 m based on the ERT and GPS measurements.

Contrast between electrical resistivity of waste and geological settings can be used to monitor direction of soil pollution using geoelectrical methods. This contrast can be seen not only in the sands (in case with low electrical resistivity of waste) but also in clay (in case with high electrical resistivity of waste) where the high electrical resistivity difference between deposit material and geological structure exists.

The performed researches proved that the ore processing leads to formation of different waste with different physical, physicochemical and chemical properties what is reflected in the various electrical resistivity studies. The smelting waste characterized with much higher electrical resistivity (150 Ωm to 8000 Ωm) than the floatation or the

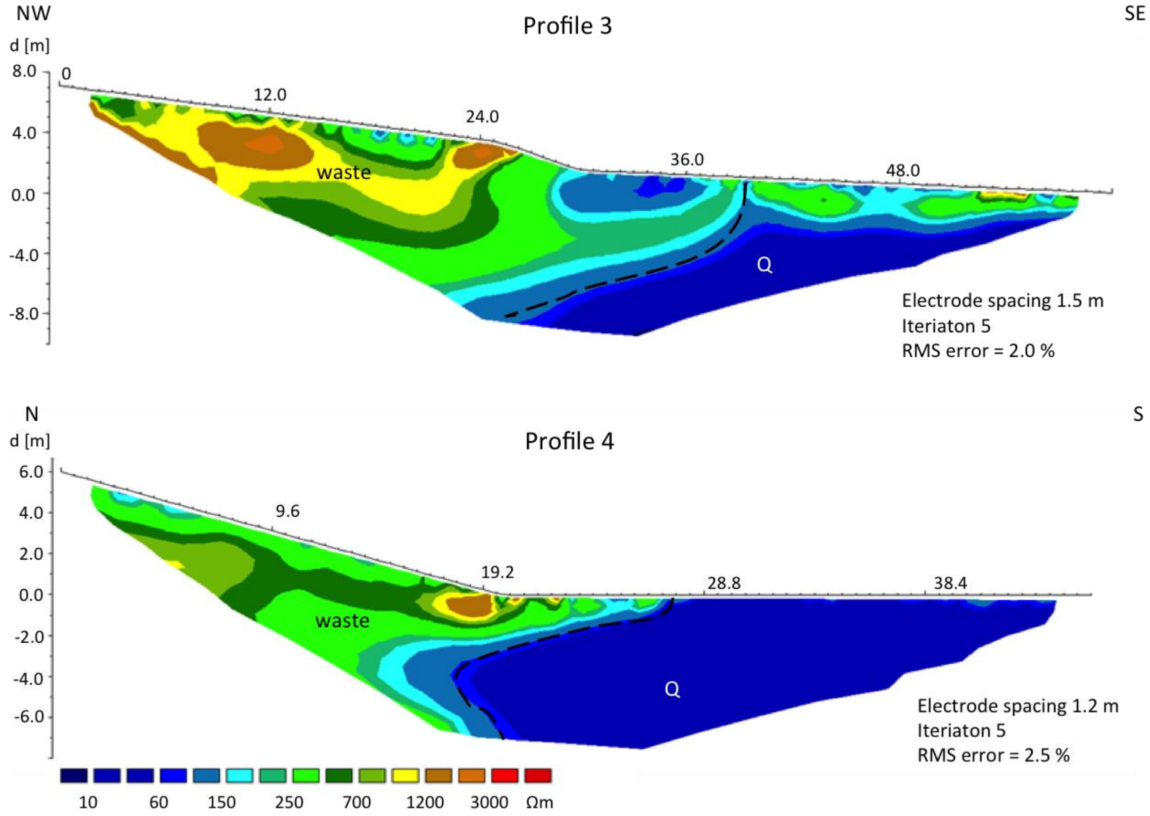

***Fig. 4** The electrical resistivity variations of waste dump on the boundary between the waste dump and surrounding soils of the embankment and the Quaternary deposits represented by clayey sediments (Q). Black dashed line represents the base of the waste dump.*

washery waste (3 – 80 Ωm) (Kondracka, 2013). The measured electrical resistivity is probably mainly dependent on grain size (the larger the particle size, the higher the electrical resistivity), the degree of saturation in pores and electrical conductivity of pore solution. Similar conclusions were presented by Furche et al. (2007) and Graupner, et al. (2007).

6 Conclusions

ERT profiling is a useful technique for obtaining information about the distribution of electrical variation and waste thickness. Electrical resistivity of waste depends on the state of compaction and varied from 250 Ωm to 8000 Ωm for waste stored on the bottom of embankment (very compacted) to 150 Ωm to 1 200 Ωm for waste from the slope of embankment (fined grained loose material). Depth of waste deposition in the area of investigation, based on ERT profile interpretation, varied from 6 m to 8 m what allowed to establish the thickness of waste for 19 m.

The interfaces between higher electrical resistivity of waste and low electrical resistivity of ground (clayey soils) gave the opportunity to identify the boundary of waste occurrence what is problematic for similar areas with waste characterized by low electrical resistivity occurring in Upper Silesian Region.

Gradation in electrical resistivity can be inferred to relate to differences in the progressive change in moisture contents, heavy metal concentration and state of waste compaction in the embankment.

Performed studies proved that resistivity measurements is essentially non-destructive, quick and cheap methods which can provide particularly important information about changing chemical composition of waste and mechanical properties of embankment. The ERT measurements were able to detect the impacts of smelting waste on the clayey soils and determine the boundary between the waste and underlying soils.

In the future geoelectrical research will be extended with other geophysical methods and geochemical analysis what will lead to correlation the electrical properties of waste and soils with the presence of heavy metals concentration.

Acknowledgements

The measurements were financed from the Grants for Young Scientists at University of Silesia: 1M 0413-001-1-01 “The electrical conductivity measurements as an indicator of contamination with heavy metals”

References

BÉRUBÉ A.P. *Investigating the streaming potential phenomenon using electric measurements numerical modelling with special reference to seepage monitoring in embankment dams,* Ph.D. Thesis. Luleå University of Technology, pp. 59, 2004.

BOGOSLOVSKY V.A, OGILVY A.A. *Application of geophysical methods for studying the technical status of earth dams,* Geophysical Prospecting, Vol. 18, pp.758-773, 1970.

CABAŁA J., ŻOGAŁA B., DUBIEL R. *Geochemical geophysical study of historical Zn-Pb ore processing waste dump areas (Southern Poland)*, Polish Journal of Environmental Study 17, No. 5, pp. 693-700, 2008.

CABAŁA J. *Metale ciężkie w środowisku glebowym olkuskiego rejonu eksploatacji rud Zn-Pb*. Wydawnictwo Uniwersytetu Śląskiego, Katowice, pp. 77-78, 2009.

CABAŁA J., IDZIAK A., KONDRACKA M., KLECZKA M. *Fizyko-chemiczne własności odpadów występujących w obszarach historycznej przeróbki rud Zn-Pb*. Prace Naukowe GiG, Kwartalnik, Wydanie Specjalne Nr III, Katowice, pp. 141-152, 2007.

CHODYNIECKA L., HABER T. *Procesy hipergeniczne w zwałowiskach odpadów poflotacyjnych po produkcji cynku i ołowiu, Rudy i Metale Nieżelazne* R. 40, Vol. 6, pp. 184-189, 1995.

FURCHE M., MEIMA J.A., GRAUPNER T., GRISSEMANN CH., RAMMLMAIR D. *Transport in mine tailings: Geophysical monitoring reactive transport modelling*, In: Proceedings of SGA Meeting, Dublin, Ireland, 2007.

GRAUPNER T., KASSAHUN A., RAMMLMAIR D., MEIMA J. A., KOCK D., FURCHE M., FIEGE A., SCHIPPERS A., MELCHER F. *Formation of sequences of cemented layers hardpans within sulfide-bearing mine tailings (mine district Freiberg, Germany)*, Applied Geochemistry, Vol. 22, pp. 2486–2508, 2007.

JARCZEWSKI W., ZIORBOWSKI Z. (red.) *Rewitalizacja miast polskich-diagnoza*; praca zbiorowa, Kraków, 2010.

JONCZY, I. *Charakterystyka mineralogiczno-chemiczna zwałowiska odpadów poprodukcyjnych huty cynku i ołowiu w Rudzie Śląskiej – Wirku oraz jego wpływ na środowisko*. Monografia, Gliwice, Wydawnictwo Politechniki Śląskiej, 2006.

KONDRACKA M. *Wpływ składowisk odpadów górniczo - hutniczych rud Zn – Pb na zanieczyszczenie gruntów w świetle badań geofizycznych*, praca doktorska, Uniwersytet Śląski, pp. 1- 206, 2013.

KONDRACKA M., WIŚNIEWSKA K. *Geoelectrical measurements on waste Zn-Pb disposal in Bytom area*, Young researchers 2011, 12th International scientific conference of PhD. students, young scientists pedagogues, pp. 380-386, 2011.

LOKE M., BARKER R. *Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method*, Geophysical Prospecting, Vol. 44, pp. 131-152, 1996.

MAINALI G. *Monitoring of tailings dams with geophysical methods*, doctoral thesis, Sweden, pp 93, 2006.

MZYK I. *Charakterystyka geochemiczna odpadów po hutnictwie rud cynkowo-ołowiowych ze zwałowiska w Rudzie Śląskiej*-Wirku, Zeszyty Naukowe Wydz. Budownictwa, nr 21, Koszalin, pp. 715-722, 2003.

UMWS Raport końcowy Urzędu Marszałkowskiego Województwa Śląskiego: *Rewitalizacja obszarów zdegradowanych – ocena procesu i identyfikacja pożądanych kierunków działania podmiotów publicznych i prywatnych w województwie śląskim czerwiec*, FUNDEKO Korbel, Krok-Baściuk Sp. J., Katowice, pp. 172, 2011.

WARCHULSKI R. *Prognoza emisji pierwiastków potencjalnie toksycznych ze składowanego materiału hutniczego Zn-Pb w świetle badań petrograficznych i geochemicznych*. Ogólnopolski konkurs dla studentów i młodych pracowników nauki na prace naukowo-badawcze dotyczące rewitalizacji terenów zdegradowanych 2014.

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