Review paper

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Possibilities of recycling of metallurgical slags and coal mining wastes and reclamation of dumping grounds in Upper Silesian Coal Basin (southern Poland)

Možnost recikliranja metalurške žlindre in premogovniške jalovine ter rekultivacije odvalov v Zgornješlezijski premogovni kadunji (južna Poljska)

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Abstract
The problem of disposing of post metallurgic and coal mining wastes in Upper Silesian Coal Basin (USCB) is discussed. Characteristics of petrographic and mineralogical composition of wastes as well as description of geochemical processes occurring in the waste material are presented. Environmental impacts of waste dumps and threats for the inhabitants living in the neighbourhood of these objects are shown. The possibilities of the secondary use of material collected on the dumps and further reclamation of described areas are indicated.

Key words: post metallurgic wastes, coal mining wastes, dumps

Izvleček
V članku obravnavajo probleme odstranjevanja metalurških in premogovniških odpadkov v Zgornješlezijski premogovni kadunji (ZŠPK). Prikazane so značilnosti mineraloške in petrografske sestave odpadnih snovi in opisani geokemični procesi, ki v njih potekajo, in tudi okoljski učinki teh odvalov in ogroženost prebivalstva, živečega v okolici. Opisane so možnosti sekundarne uporabe materiala z odvalov in rekultivacije prizadetih območij.

Ključne besede: metalurški odpadki, premogovniški odpadki, odvali

Introduction

Waste dumps resulting from coal mining, steel production and ore exploitation constitute a significant problem for the environmental protection in the Upper Silesia region, which is one of the most industrialized regions of Poland (Figure 1).

The waste dumps, both post-metallurgic and coal mining wastes, are a proof of the mining and processing of hard coal, bog iron ores, zinc and lead ores and accompanying silver ores, conducted since the early middle-ages. It is extremely unsettling that in many Silesian cities dumps as old as 100 years are still present [2].

The waste material accumulated for years is made up of a mixture of mining and smelting wastes, disposed in a non-selective manner without any protection of the subsoil. It often happens that at a single dump, wastes resulting from the processing of various ores are present. This is related to the conversions of the former smelters depending on ore availability. Documents have been preserved which provide evidence on the conversion of smelters to enable the processing of ores that were available at the time.

Examined objects considering significant amount of metals or coal in wastes may comprise perspective anthropogenic secondary resources. That is why the question of recovery of secondary materials from dumps with regard to technological possibilities and economical profitability is very important.

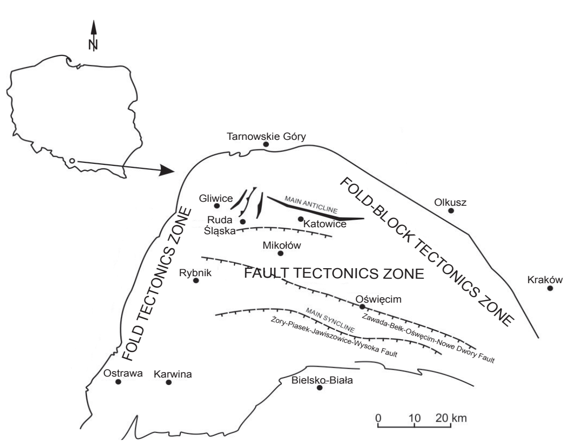


Figure 1: *Sketch of Upper Silesian Coal Basin (Probierz, Borówka, 2009, modified)* [1].

Field works

The record of the old dumps constitutes a significant problem. Current contours of many of the dumps are blurred and it is not possible to determine their precise boundaries (Figure 2). Some of the dumps have suffered denudation due to weathering processes occurring throughout the years. It should, however, be noted that smelting wastes may still be present in the subsoil.

In the past, when the ore deposit was depleted and no new accumulations have been found nearby, it was more profitable to move the entire industrial infrastructure into another place, which – among other things – was caused by the lack of transport routes. Processing of ores was also directly connected to the mining of hard coal, which was used as a furnace fuel – this is why the smelting and mining dumps are often located in close vicinity.

For the needs of inventarization of post-mining and post-metallurgic dumping grounds it was done a literature study, the information was also obtained from administrative units and companies which are the owners of dumps (e.g. coal companies, companies of restructurization of the mines); these data have been verified during field investigations.

According to self study and literature data in the area of Upper Silesia there were recorded:

— 38 waste dumps after metallurgy of Zn-Pb ores as well as steel and iron (Figure 2),
— 41 waste dumps after mining and preparation of Fe ores (Figure 3),
— 231 coal mining waste dumps (Figure 4).

Altogether in the area of Upper Silesia occur though over 300 waste dumps of different genesis and various composition of wastes.

Non-developed dumps are usually uncovered and their slopes are not protected against crumbling of the accumulated material (Figure 2). In certain locations which are especially prone to weathering, silty forms occur, which are easily blown out and carried by wind. This fosters the distribution of pollution to further areas.

On the surface of dumps` slopes there were observed phenomena similar to gravitational mass movements (landslides). The erosion processes on the slopes were additionally

Figure 2: *Zn-Pb wastes on the dump in Ruda Śląska.*

Figure 3: *Wastes after iron and steel production on the dump in Chorzów.*

Figure 4: *Burned waste material on coal mining waste dump in Mysłowice.*

Figure 5: *Coal mining wastes and their contact with surface water. Waste dump in Kaniów.*

strengthened by anthropopression (e.g. illegal using of waste dumps for cycling). The erosion troughs situated on one of the dumps had a depth of more than 40 cm.

The water flowing on and infiltrating the wastes causes the washing out of the elements and their migration – especially to the soil environment.

One of the most dangerous environmental impacts of mining wastes is surface water and groundwater pollution (Figure 5). There is a well-known problem of AMD processes (acid mine drainage).

The effect of AMD processes is a contact of sulphur compound, particularly pyrite FeS_2 with water. Major chemical effects are pH reduction (connected with increased acidity), increase of sulphate, iron, manganese and aluminium contents, oxygen reduction and destruction of the bicarbonate buffering system [3–6].

The problem of the dumps in the Upper Silesian Coal Basin is a lack of systematic groundwater monitoring on and around the waste dumps as well as legal regulations, concerning particular requirements according to the mentioned above monitoring systems [7].

Recovery of coal may result in changes to the hydrogeochemical profile of the anthropogenic vadose zone, arising from the re-mining and re-disposal of coal extractive waste [4].

Laboratory tests

Despite the passing of years, smelter slag still contains certain amounts of metals [8, 9]. Table 1 presents examples of analyses of the chemical composition of Zn-Pb slag (Figure 2) and iron slag (Figure 3).

A significant amount of heavy metals also draws attention. These include Zn, Pb and Cd – especially in the Zn-Pb slag. As a result of the weathering processes, these metals are released from slag components and are carried to the environment along with the solutions. This process is intensified by the presence of sulphur compounds in Zn-Pb slag, the oxidation of which leads to the formation of easily washed-out sulphates (Figure 6).

Table 1: *Chemical composition of metallurgical slags – examples of analysis*

Oxide [mass fractions,%]	Slag after Zn-Pb production (Figure 2)	Slag after steel production (Figure 3)
SiO_2	19.67	21.75
Al_2O_3	3.58	6.85
Fe_2O_3	23.13	14.28
FeO	6.89	1.51
MnO	0.05	0.90
CaO	5.63	32.14
MgO	5.06	6.76
Na_2O	0.85	1.36
K_2O	0.16	0.17
SO_3	10.21	0.58
LOI	22.45	11.70

Element [μg/g]	Slag after Zn-Pb production (Figure 2)	Slag after steel production (Figure 3)
Cd	79.80	3.10
Co	10.00	8.00
Cr	42.00	2 810.00
Cu	71.00	107.00
Ni	80.00	34.00
Pb	7 731.00	1 010.00
Zn	41 500.00	901.00

Self study

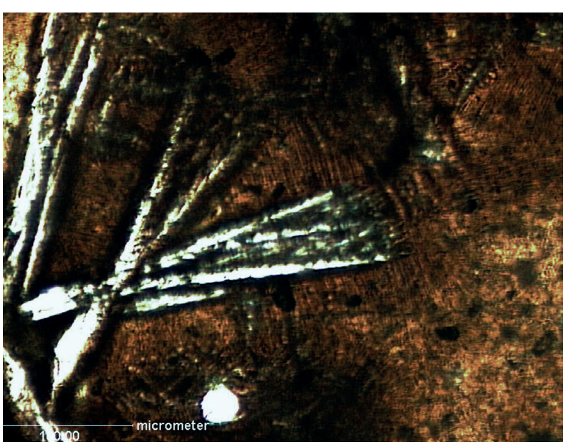


Figure 6: *Microphotograph of crystals of gypsum in glaze (Zn-Pb slag); transmitted light, magnification 200, one nicol* [2].

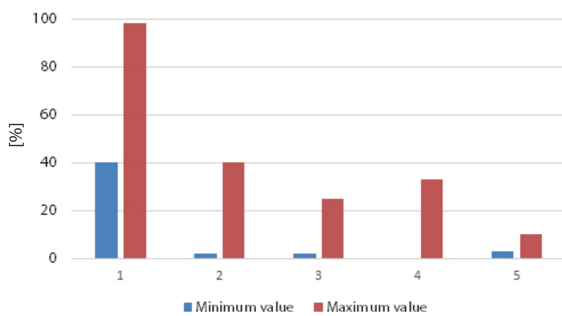
In acidic reaction of the environment, the metals are mostly transferred to the soil in the direct vicinity of the dump. The research conducted in this region indicated that the soil around the dumps is characterized by a high level of contamination, especially due to the content of cadmium, which is a particularly toxic element.

Iron slag is characterized by a lower concentration of heavy metals such as Cd, Co, Ni, Pb and Zn. However, it shows greater concentration of Cr, which is an element introduced to the furnace charge to improve the properties of the produced steel. It must be noted that iron slag is characterized by a higher value of CaO – 32.14 %, while in the Zn-Pb slag, the CaO content is 5.63 %. The presence of calcium oxide is very favourable, as it has an effect on the preservation of alkaline properties of slag and limits the migration of heavy metals.

Due to the above, it is the iron slag that is considered as a material providing perspectives of application in the production of various kinds of aggregates. Iron slag dumps are thus successively liquidated and the obtained material is used for economic purposes, especially because it is characterized with favourable technical properties. The Zn-Pb dumps still pose a problem and it seems that the most rational solution is the biological restoration of these sites.

Petrographic composition of coal mining wastes

Coal mining wastes represent in majority adjacent rocks, which belong mostly to sedimentary rocks (siltstones, mudstones and sandstones). In the waste material occur also coal shales and significant percentage of coal substance. Detailed values of petrographic composition of coal wastes are presented in the Figure 7.



Explanations: 1 – Siltstones 40–98 % | 2 – Mudstones 2–40 % | 3 – Coal shales 2–25 % | 4 – Sandstones 0–33 %; | 5 – Coal 3–10 %.

Figure 7: *Petrographic composition of coal wastes in Upper Silesian Coal Basin.* [10]

Possibilities of the secondary use of material collected on the dumps

There are technical possibilities of recovering of coal from the coal mining waste dumps. The coal recovery reduces also hazards of self-ignition and dump fires. The process of coal recovery is economically justified. From over 230 coal mining dumps in the USCB still remain more than 100 dumps which may be considered as anthropogenic secondary deposits (considering objects which are not thermally active). In the past, there were several examples of successful recovery of coal from the dumps (e.g. Central Mining Waste Dump in Smolnica, waste dumps in Buków – SW of the USCB), some of the dumps are still being exploitated – e.g. a waste dump in Panewniki, a waste dump in Knurów, a waste dump in Czerwionka (a central part of the USCB). The most valuable waste dumps in terms of their recovery are the largest ones. However, it must be taken into consideration other features, e.g. the ownership title, localization, regarding the neighbourhood of protected areas, accessibility and local community interests [11]. Due to the fact that the amount of coal in the waste material may be up to 10 % (between 3–10 %, with the assumption that an average amount of coal to be recovered accounts for 5–7 %), it can be estimated that total potential amount of recovered coal from the dumps in the USCB shall account for more than 45 million Mg [12].

The dumps of wastes after metallurgy processes represent important potential recovery objects, due to the significant amount of metals (several – dozens percent, regarding mainly lead, zinc as well as other elements, also REE). However, the technology of recovery has not been developed yet. The problem is chemical composition of metals, which are in majority included in the glaze. This problem requires further scientific studies.

Conclusions

In the Upper Silesian Coal Basin, for many years, waste dumps were an integral part of the landscape. But now, due to the environmental activities, the attention has been paid to the environmental hazards, associated with the presence of dumps. These hazards involve mainly water pollution, dust emissions and self-ignition as well as fires of the waste material. On the other hand waste dumps are a potential source of secondary materials which could be use in different sectors of economy. The recovery of coal from wastes disposed on dumping grounds is technically possible and economically justified. The recovery of metals from post-metallurgic dumps has a great potential, but the technology must be developed and requires further studies. It should be remembered that before taking any actions, it is important to know mineralogical and chemical composition of wastes. Basis on such studies, it can be drawn conclusion involving safe utilization of wastes. A very important question is proper reclamation and using of the dumps after successful recovery. These sites may play a new role in the cultural landscape, in a way of creation of new functions – as artistic, cultural, recreation and tourist areas. It should be noted that the most danger for the environment are old dumps after zinc and lead production. Wastes gathered on them contain a lot of heavy metals, which usually are dispersed in glaze so at present the only rational action to undertake seems to be the creation of a protective layer on the surface of such dumps. The layer should be from soil material of appropriately selected physicochemical parameters, which would ensure favorable conditions for the vegetation of plants. The waste dump should be also isolated by insulation facilities to hinder the migration of the elements to soil.

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