

Joanna Urbańska*, Krzysztof Urbański*

Selected Aspects of Reclamation of Soda Waste Landfill Sites**

1. Introduction

The nineteenth and twentieth centuries witnessed a rapid growth of industry, which resulted in changes in the natural environment. The development of the soda industry was a good example of that. Factories producing soda in the past century left their traces in the form of industrial waste landfill sites, which are difficult to handle to this day.

In the case of soda waste, there are at least a few adverse effects which hinder conducting the reclamation process, such as the content of readily soluble compounds [17, 26] which, when penetrating into the environment, may be included in various interactions with it, or the fact that they are produced in large quantities and are stored in large sedimentation tanks, which are significantly noticeable in the landscape.

For these reasons, their reclamation becomes an important, socially desirable and sometimes very costly objective.

2. Trends in Land Management

Following the literature on the issue of soda waste sedimentation tanks, three basic ways of managing the area of tailing ponds can be distinguished:

- 1) leaving the sedimentation tanks to the spontaneous succession,
- 2) conducting selected technical and biological reclamation treatments,
- 3) management of sediments.

* AGH University of Science and Technology, Faculty of Mining Surveying and Environmental Engineering, Department of Development and Environmental Protection, Krakow, Poland

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3. Spontaneous Succession

Spontaneous succession exists on a variety of industrial waste landfill sites. Spontaneous overgrowth of such wasteland, as numerous researchers have proved [16, 21, 42] is still very slow, mainly due to: lack of appropriate plant species on-site or in the surrounding, water shortages or excesses, high concentrations of salts or heavy metals, nutrient deficiencies, too alkaline or too acidic reaction, or strong erosion.

The process of natural succession can be divided into several stages. The first one is the colonization of the surface by plants which are the most resistant to extremely adverse conditions of a habitat. The second one refers to the creation of the turf, or the total coverage of the area with herbaceous vegetation. The third one is the possibility of introducing shrubs and trees. The individual steps depend in particular on the origin of the wasteland, and therefore on the nature of the formations which are deposited in dumps or sedimentation tanks.

According to Hewlett, in the case of soda waste landfill sites, the stages of spontaneous succession could be as follows [14]:

Stage I – associated with highly alkaline and saline sedimentary material, introducing pioneering alkaliphilic and halophilic vegetation.

Stage II – associated with transformed sedimentary material, with a marginal salinity and alkaline pH; emergence of herbaceous vegetation and tree seedlings.

Stage III – associated with sedimentary material subject to far-reaching transformation as a result of the constant interaction of atmospheric variables, and noticeably marked processes resembling in its characteristics the phenomenon of rock weathering; areas with well-developed woody vegetation are mainly dominating.

Stage IV – the entire area is dominated by a well-developed ecosystem.

The tailing ponds of soda plants are classified, according to Krzaklewski [21], as the objects with a difficult level of biological reclamation, where the lack of spontaneous overgrowth of the wasteland is maintained for a minimum of 10 years. However, leaving the sedimentation tanks to the spontaneous succession as “the direction of reclamation” has some reasons in the case of soda waste tanks. One of the arguments may be the time of creating and filling the tank, during which climatic factors may systematically lead to the reduction of harmful substances in the surface layers of the sediment. It may be accompanied by the first attempts to colonize the surface by the plants and the emergence of the first stage of plant succession, which could later be destroyed or inhibited by reclamation treatments.

Examples of spontaneous plant succession on soda waste sedimentation tanks can be observed in Germany near Bernburg [10, 11] and in the Czech Republic – near Petrovice [13, 32]. There are sedimentation tanks where the development of vegetation derived from spontaneous succession, which has lasted for over 70 years, can be seen. The research conducted in Germany allows us to observe and compare the individual stages of plants conglomerations formed in this way, and the

transformation of the stored material and the formation of the substrate under their influence. They visualized the impact of natural succession on the accumulation of organic carbon (i.e. the phenomenon confirming soil-forming processes [9]) and the stabilization of organic matter. And the presence of organic matter was associated with the age of the sedimentation tank and the fact how long it was covered with the vegetation layer. The soil formed in these specific conditions has been classified as lime regosols mixed with a great amount of industrial waste (Calcareous spolic regosols) [41].

The research carried out in the Czech Republic focused mainly on observations of growing vegetation within the sedimentation tanks, emerging by spontaneous succession and its influence on the abundance and diversity of microfauna, including mainly representatives of the Nematoda type (nematodes). The observations have shown that the greening of landfill sites continues to tens of years, and with the growth of vegetation and the emergence of new species of plants, the number of micro-organisms increases as well, but even after almost 80 years of plant succession, their specific composition shows numerous differences, compared with the semi-natural forest nearby [13].

4. Assisted Reclamation

Vast areas of wasteland are often subjected to a standard three-stage technical and biological reclamation [8, 15, 28] or only selected treatments aimed at supporting the spontaneous processes of environment restoration.

The examples of a standard (three-stage) reclamation are, among others, the processes on the selected complexes of the sedimentation tanks of the former Soda Plant "Solvay" in Krakow, where the reclamation works were carried out in 1989–1995. Preliminary design works (stage I) preceded the implementation of the technical assumptions of the reclamation project (stage II). The treatments included: leveling of the dikes separating the individual sedimentation tanks, shaping and securing the slopes, application of topsoil layer as well as execution of water drainage system [20, 31]. Soil material used to secure the crown of the sedimentation tanks was mostly coming from the building site excavations, which meant that it was characterized by a great diversity of mechanical composition [1, 22]. A total of about 185,000 m³ of soil material was applied on the tailing ponds, of which about 35,000 m³ was the material for reinforcing the slopes, while 150,000 m³ was the material used to construct the topsoil [1]. Upon the completion of the technical works, the biological stage of the reclamation followed (stage III), which consisted mainly of seeding the topsoil with a mix of grasses and legumes [1].

Due to the high labour and cost consumption of such a reclamation method, various modifications are often applied, mainly consisting of the replacement of soil material building topsoil layer with an alternative material. This function is often

taken over by all kinds of sewage sludge [33]. In such cases, the sediments play a dual role, and thus function as an insulating layer, and due to the high nutrient content are also able to intensify the growth of grass and herbaceous vegetation. In addition, the sediments in the form of sludge can be placed on the landfills with grass seeds through the so-called hydro-seeding, which dramatically reduces the workload. It should be remembered, though, that the sediments in contrast to the natural organic fertilizers in their composition may have significant amounts of heavy metals, especially when derived from the highly urbanized and industrialized areas [2, 33]. These metals can penetrate and accumulate in the plants and become included in the cycle of matter and energy [12, 27]. An example of such a sediment reclamation concept are landfill sites in Soda Plant in Janikowo. Technical reclamation was brought here to the liquidation of the dikes separating individual sedimentation tanks, and to leveling of their surface. Biological reclamation was carried out based on sewage sludge and sowing seeds of meadow grass mixtures. In addition, until intensive growth of grasses, plants protecting and increasing the process of vegetation were planted [33, 34].

These reclamation treatments are often supplemented with additional qualities aimed at protecting the environment from the harmful effects of soda waste landfills. One such quality is the use of fast-growing vegetation having the ability to bioaccumulate, which is used to filter the leachate from the landfills. This becomes a particularly important issue when the stored waste contains a lot of easily soluble salts, which, together with the infiltrating rainwater, can penetrate the groundwater or watercourses, highly polluting them [38, 40]. The test solution based on the exploitation of osier willow as a filter medium was introduced in the United States in Syracuse [5, 39], where huge deposits of sediments collected in the close vicinity of the lake are contributing to the changes in its physical and chemical parameters [7, 29].

5. Management of Sediments

The management of the sediments would be the best solution to the problem of soda waste, but due to their physical and chemical properties, at least for now, this type of waste treatment is very limited. The high content of calcium chloride (CaCl_2) and sodium chloride (NaCl) significantly reduces the possibility of soda waste management. The methods of removing these compounds or of significantly reducing their amount in waste were already worked on since 1938 [35]. Poorly developed waste disposal techniques were due to the fact that the issue of waste management in those days was marginalized [18, 36]. As the interest in the problem of accumulated sediments and negative impacts that may occur on the environment was increased, works on potential soda waste management methods were being developed. As a result, it turned out that this waste can be used in various manufacturing industries, to a limited extent.

One of the proposed solutions to the problem of soda waste was using it in agriculture as a substitute for agricultural lime [3, 6], however, as a detailed study revealed [30], raw waste did not qualify as a fertilizer. This was mainly due to the high chloride content and excessive humidity which was resulted from high hygroscopicity [30]. Only after partial processing, yielding fertilizer chalk or fertilizer calcium carbonate [23], the waste could be used in agriculture. The "Solvay" Soda Plant launched this type of production line in 1960 [4, 19].

The usability of soda waste was also examined in terms of its use as raw material for the preparation of mortar or cement mixtures [3, 6, 35]. Partial management of soda waste, especially that in the solid form, is also carried out in the process of using it to produce various kinds of earth structures (construction of tank and road embankments) [24, 25], while the semi-liquid waste is trying to be used as the filling material for excavation voids and depressions caused by mining damage, or in the liquid form – directly injected into the deep layers of soil [23]

6. Summary

The provided examples of various manners of soda waste management prove that the development of an effective method for reclamation which would give tangible results poses numerous problems. They should be seen mainly in the specific nature of the waste, among others, in their semi-liquid form, heterogeneity within a sedimentation tank, a large content of easily soluble salts or strongly alkaline reaction.

Taking into account the standard methods of reclamation for large area sedimentation tanks, very high costs should be expected, associated with transporting the soil masses needed to protect the tanks against the effects of weathering. Additionally, there are hydraulic engineering works to capture any rainwater leachate and infiltrating from the tanks, as well as the works associated with seeding or planting of plants shaping the biological architecture of the reclaimed facility. However, such works are carried out, but their intensity is usually adapted to the local requirements and current needs.

As a result, despite the continued development of various technologies for soda waste management, still a very large mass remains within sedimentation tanks [3].

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