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Overburden Management for Formation of Internal Dumps in Coal Mines

C. Drebenstedt *Technical University Bergakademie Freiberg, Germany*

M. Struzina *Technical University Bergakademie Freiberg, Germany*

Abstract

The removal of overburden is an essential activity in surface mining. In the large German coal mines, the overburden to coal ratio can reach 6 m³/t and the depth of the mines can be up to 300 m. The total amount of overburden removal is approximately 1 billion m³/a. To minimise the costs and the impact to the environment, the formation of inside dumps with high productive continuous mining technique is required. The formation of the dumps is influenced by several factors, like slope stability, stability of working benches, dumping of cultivation substrates on the surface, design of the landscape, surface water flows/erosion prevention and acid mine drainage (AMD) (Drebenstedt 2001, 2006). The paper introduces the specific conditions of overburden management and shows strategies for AMD control. It is presented as a mine planning and operational management system for optimal overburden dumping.

1 Problem statement

The extraction of mineral raw materials from the earth's crust and the resulting exposure to the environment can change the chemical and physical properties of both the mined (extracted) rock and the in situ rock adjacent to the place of extraction. Where the potential consequences of these changes are often the greatest is when the rock contains iron sulfide minerals (e.g. pyrite and marcasite). Upon exposure to oxygen in the atmosphere and in the presence of water, the oxidation of the rock induces the release of protons and sets off a sequence of other chemical conversion processes that results in the release of cations and the formation of sulfate, sulfuric acid, and a low pH environment. The chemical reactions can be summarised as follows:

$$2\ FeS_2 + 7\ O_2 + 2\ H_2O \rightarrow 2\ Fe^{2+} + 4\ SO_4^{2-} + 4\ H^+ \quad (1)$$

$$2\ Fe^{2+} + 0.5\ O_2 + 2\ H^+ \rightarrow 2\ Fe^{3+} + 2\ H_2O \quad (2)$$

$$2\ Fe^{3+} + 6\ H_2O \rightarrow 2\ Fe(OH)_3 + 6\ H^+ \quad (3)$$

$$14\ Fe3+\ FeS_2 + 8\ H_2O \rightarrow 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+ \quad (4)$$

The presence of micro-organisms (e.g. *Thiobacillus ferrooxidans*) can further speed up the conversion process. In general, this process is referred to as the formation of acidic water and, internationally, as acid mine drainage (AMD) or acid rock drainage (ARD).

Of the mining processes that are typically undertaken during the course of operations, the following activities are the major ones likely to be responsible for allowing the access of oxygen and water to the iron sulfides:

- The lowering of the groundwater level.
- The exposure of the rock surface to the air by loosening the structure of the rock mass and by processing the rock thus mined.
- The dumping/depositing of rock and the processing of residues.

The resultant lowering of the pH, the formation of sulfates and the release of cations may all have negative effects on soil and water quality. Most plants and aquatic biota have limited survival and growth in substrates and waters at a pH value of less than 3.5. At low pH, carbonates and heavy metals can dissolve and become bioavailable and more readily transferred to other locations through rainfall and runoff. The consequences of this process become especially critical when heavy metal concentrations in solution assume dimensions that potentially endanger not only the environmental values of an area but also the health of fauna and humans.

The process of acidic water formation is a phenomenon occurring all over the world in the mining sector, both in surface and underground mining, as soon as there are iron sulfide minerals and the reaction conditions are satisfied. In Germany, this applies to tertiary, sulfide-containing sediments that are exposed in the course of lignite mining and then deposited in overburden dumps. The same conversion processes also continue in old unfilled underground workings and on dumps of disused ore and spar mines, where these undesired chemical release processes, especially the release of heavy metals, are still occurring after hundreds of years.

While the oxidation of iron sulfides and the generation of acidic conditions can also occur as a result of natural causes, many of the instances where environmental problems are caused by these processes are of anthropogenic origin.

2 The impact mine planning has on the process of acidic water formation

2.1 Possible measures

The process of acidic water formation can basically be influenced by mine planning (Drebenstedt et al., 2006). A prerequisite would be sufficient knowledge of the geogenic acidic water potential, i.e. a geochemical characterisation of the rock subjected to mining. The climatic conditions, as well as the existence and sensitivity of the surrounding environs that may be affected, must also be given due regard. Hence, a clear distinction must be made between the effects and the appropriateness of the measures against acidic water in arid, deserted areas on the one hand and in densely populated, humid climates, on the other.

Mine planning can ensure, through the ensuing proper mining operations, that the formation of acidic water is prevented from occurring (primary measures) or that the unavoidable formation of acidic water is minimised and neutralised (secondary measures). Tertiary measures will have to be planned when it is impossible to control the acidic water within the required limits (quantity and quality) during the mining operations.

2.1.1 Primary measures

According to the above chemical processes, the protons should be able to be prevented from being released by preventing the sulfide minerals from coming into contact with oxygen and water. As an example, it is possible to exclude the oxygen from the air by employing wet mining techniques.

In order to implement the primary measures, the position of the working levels in open-cast lignite mines, where the rock has settled in layers, can be arranged in such a way that they are placed above the sulfide-containing strata, so that they will be prevented from getting into contact with the oxygen in the air (Eyll-Vetter, 2007).

2.1.2 Secondary measures

The formation of acidic water can usually not be completely avoided in a mine, so that the following secondary measures aimed at reducing the formation of acidic water can be taken:

- Reducing the reaction time.
- Buffering the unavoidable proton surplus by alkaline components.

The reaction time can be reduced by planning faster mining and dumping processes. If sulfide-containing rock remains on the surface of, say, slopes or interfaces for a longer period, it can be covered with neutral, cohesive materials, in order to reduce the acidic water formation. In the case of dumping sulfide-containing overburden internally, the future groundwater level will have to be taken into consideration. Since the air will be excluded once the groundwater level rises again in the lower area of the dumpsite, rock with a higher acidic water potential should be dumped here, so as to stop the acidification process as early as possible (at the international level, this was given as the reason in the past for dumping sulfide-containing rock below the water level). In addition, chemically neutral rock or rock with a low acidification potential can be dumped in the unsaturated zone above the groundwater level (Paul, 2007). This is especially important when the quality of the upper aquifers has to be maintained because of its value to, and use by, adjacent or nearby users, including protected environmental areas such as nature reserves.

If acidic water is generated in hollow sub-surface spaces that are created by mining activities and then permanently filled with air, i.e. above the groundwater level, the backfilling of preferably alkaline material may stop, or at least delay, the further sulfide conversion.

Another technological task of mine planning and the ensuing mining operations is the selective dumping of alkaline rock with rock that is potentially generating acidic water with the aim of achieving neutralisation. If protons are released by the vertical and horizontal flow of the groundwater, this can be neutralised by generating buffer zones that are laterally, vertically or diffusely introduced. The required alkaline potential must be established by taking into account the pH value of the inflowing water and the water quality of the outflowing water. If no natural material is available for buffering the acid potential during the ongoing mining operations, external alkaline materials will have to be used. In general, reactive limestone is suitable for this purpose, although the lignite mining industry can also take advantage of the alkaline potential of ash that is generated in the combustion process. This ash material has different inherent and process-dependent reactive lime contents.

2.1.3 Tertiary measures

Tertiary measures will be required when it has not been, or when it will not be, possible to keep the acid potential within the limits stipulated. Admittedly, mining companies have often existed for several centuries, while the requirements concerning the fight against acidic water have been introduced much later, or the primary and secondary measures have proved to be technically impossible or unreasonable. Tertiary measures can thus be taken during operations as scheduled or in the process of remediation.

Among the tertiary measures that can be undertaken to protect the environment against detrimental effects are the following:

- Subsequent addition of reactive alkaline potential (Scholz et al., 2007).
- Collecting and 'cleaning' the acidic water.

Reactive alkaline material can be subsequently added to the acidic groundwater or to the acidic surface water in several ways, including:

- The injection technique.
- Banking-up/back-filling (reactive walls).
- In-lake or in-pit treatment.

An effective measure to prevent the detrimental effects of water contaminated by mining are water treatment plants that are operated during or after the mining activities and that are geared to the chemistry of the water in the mine. The water will first have to be collected by suitable measures in wells, drains, drifts etc. and cleaned. Apart from the technical structures for the chemical treatment of water, naturally operating systems, such as wetlands, have also been tested over time. When designing such systems, the cleaning objectives and the quantities of water to be treated need to be duly taken into account.

Alternatively, or in addition to the cleaning, the water may also be evaporated in mining regions with a negative water balance, e.g. in deserts, in order to prevent the water from being discharged into the surroundings, which may have a detrimental impact on the environment.

2.2 Integrated mine planning and operations as regards the acidic water management

In order to plan and monitor the above measures, integrated planning and operating management tools can be used, for which the following modules will be required:

- A geochemical/hydrological deposit model.
- The mining, dumping and back-filling planning.
- A material tracing system.

- A geochemical dumpsite model.

Geochemical rock analyses, as part of the deposit model, are necessary in order to be able to determine and plan the measures that are required for the management of the potential acidic water formation. Analogous models are known and widely used for orebody definition (ie determining the quality of the raw material) or for the evaluation of the suiteability of overburden for reclamation to name just two examples. Hydrological models can be used to document the flow of the groundwater and of the surface water. Both sets of information, i.e. the geochemical and the hydrological data and analyses, are fundamental prerequisites for all further planning processes.

The mine layout plans are suitable tools for the mining and dumping operations that are aimed at implementing the primary and secondary measures, while avoiding or at least reducing the formation of acidic water at the same time. Possible ways of using opportunities arising in this respect are, among other things:

- The position of the working levels and the dividing surfaces (interfaces).
- Soil mixing while being excavated.
- Soil mixing while being conveyed (in the case of widely branched extraction systems).
- The dumping technology.

Not only can the material tracing system control how the planned specifications are implemented, but it can also be used to intervene when failures occur and control or corrective measures needs to be implemented. The tracing system makes it possible to generate a geochemical dumpsite model that can provide information on the spatial arrangements of how rock with different properties has actually been dumped. This, in turn, may trigger subsequent improvement or scheduled tertiary measures, or it may prove the effectiveness of the measures taken.

Sampling at the extraction site and at the dumpsite can support the models most effectively. Giving due regard to the acidic water potential during mine planning and ensuring the quality of the raw materials mined as well as the geotechnical safety should be both a matter of course.

3 Experience gained with the amelioration of bare dumpsite soil

The generation of arable dumpsite surfaces after tertiary, non-arable substrates have been deposited there began some 50 years ago and was based on the result from scientific studies conducted during operations. This standard or case study may serve as an example of how the acidic water management has been planned and organised and will be described in more detail below. Spreading arable substrates over the dumpsite surface or the amelioration of non-arable substrates can also be included among the secondary measures of acidic water management.

The soil is an important site factor when it comes to planning and implementing land reclamation projects (Klapperich et al., 2007). The physical and chemical properties of the bare dumpsite soil have a crucial impact on the possible use of the post-mining areas. The careful selection of suitable soil substrates during the ongoing mining and dumping activities, their spreading over the dumpsite surface, and an understanding of the types of soil making up the overburden will therefore be major prerequisites for avoiding labor and cost-intensive improvement measures later on (Drebenstedt, 1998b).

The land reclamation methods and techniques in the major German lignite mining regions differ considerably from each other due to the varying properties of the soil substrates found in the overburden. The substrates in the Lusatian and Central German mining regions, especially the ones in the top layer of the remediation areas, are of an inferior quality and non-arable and will have to be improved under soil-chemical and physical aspects through amelioration measures. In the mining industry, the term amelioration generally refers to the entire complex of soil-improving measures that will ensure the recultivation and land reclamation of the dumpsite surface. The term "basic amelioration" has been coined in the Lusatian mining region (Drebenstedt, 1998a).

Basic melioration aims at:

- Regulating the acid balance of the soil, especially that of sulfur-containing tertiary dumpsite substrates.
- Supplying the bare dumpsite soil with nutrients, especially potash, phosphorus and nitrogen (K, P, N).
- Improving the sorption properties of sandy soil or the structure of cohesive soil (regulating the air and water balance in the soil).
- Enriching the soil with humus and activating the soil biota.

The amelioration homogenises the soil substrates in the amelioration horizon and reduces the wetting resistance at the same time, thus reducing the propensity of the soil, especially of the sulfur-containing tertiary soil, to erosion. The basic amelioration will therefore create the starting conditions for plant growth and for the development of soil biological activity. Basic amelioration includes the following working steps:

- Establishing the work input required after the site investigation; supply and storage of any required alkaline materials and nutrients.
- Processing and spreading the components, which are to be partly incorporated into the dump surface.
- Loosening heavy soil before the actual amelioration.
- Working the components into the amelioration horizon.
- Trial sowings.

The type and scope of the basic amelioration will be derived from the results of the site investigation and materials characterisation and from the intended use of the land. The types of soil mapped during the site investigation may range from “suitable for cultivation”/post tertiary, requiring little amelioration, to “unsuitable for cultivation”/tertiary, requiring a high amelioration input, and can also include mixed soil.

In order to improve the acid balance with a long-lasting effect, the precise dosing of the lime additions is of the essence. It should be remembered that acid will always be re-generated and re-supplied by the weathering process. The lime doses and selection will therefore not be based on the bare soil’s current, but on its potential, acidity, with the latter being established through an acid-base balance.

Given a working depth of 1.0 m and a target pH value of 5.5-6, the quantity of base carriers required, e.g. limestone, will amount to a maximum of 200 t Ca0/ha in the case of extremely acidic soil (pH value < 2). The demand for macro-nutrients may come up to 200-300 kg N/ha, P/ha and K/ha each. Not surprisingly, in view of these input quantities, cost-effective amelioration techniques have been searched for from a very early point in time. The Domsdorf technique (lime-containing ash used for soil improvement measures) and the Böhlen technique, just to name two examples, were patented and applied as early as the beginning of the 1960s (Drebenstedt, 1994). This is a development that will be pursued further under the new statutory conditions.

The success of the amelioration will largely depend on the dosability of the amelioration agent on the dumpsite surface, especially where heterogeneously distributed substrates are involved. The spreading equipment used for dosing the input quantities will therefore depend on the type of surface it has to cope with. If limestone and fertiliser are to be spread and worked in by just one work step, care shall be taken that the components do not react to each other. The most important element of the basic amelioration is working in the components into the soil. If the land is to be given over to forestry use, the tertiary bare dumpsite soil will be ameliorated up to a depth of 1 m, depending on the actual site conditions and the type of trees to be planted, in order to create a sufficient soil depth for the roots to grow. The soil will have to be thoroughly mixed throughout the entire amelioration horizon. The right amelioration equipment and techniques can only be selected effectively once the agreed post-mining land use is known (Drebenstedt, 1997).

The success of the amelioration will be checked through the result of the initial sowings, which allows non-compliant areas to be identified, and where the soil will have to be re-treated. The basic amelioration is an important step in the process of land reclamation and of remediating the bare dumpsite soil. In order to hand over the land to a follow-up user, all information about the original substrates, the amelioration agents and techniques used, the working depth, the subsequent land use etc. will be recorded in a cadastral survey.

4 Tertiary measures

4.1 Integration into the planning system

As explained above, an integrated planning and management system can, if applied to the dumpsite structure and design, determine and control the mass deposition relatively precisely as far as the dumping location and the quantities and qualities involved are concerned (buffer capacity, acid-base balance, acidification potential). In terms of the acidic water management, the planning system will also facilitate a suitable dumpsite configuration and management, since the structure and the design of the dumpsite are almost completely known.

A dumpsite system generated against this planning background will require comparatively little maintenance and the discharge of acidic water from the dumpsite body into the connected aquifers or water bodies should be considerably reduced.

If non-compliant areas were to be identified in the dumpsite system in regards to the acid-base balances that may have been caused by, for example, technological errors or deviations from the planned technology as a result of the prevailing operating conditions, the integrated planning and management system will still be able to identify such non-compliant areas as far as their quantity, position and quality are concerned. This, in turn, will make it possible to carry out tertiary remediation measures selectively and with a comparatively low input, so as to avoid any subsequent maintenance measures and to achieve a good acid-base balance all over the dumpsite despite those non-compliant areas.

It is conceivable in this context, to give just one example, that some buffer materials are added directly to the location where the non-compliant area has been identified. In order to be able to do so, the location of this non-compliant area would still have to be directly accessible, at least temporarily, during on-going operations. If the non-compliant area were to be located at the surface of the dumpsite, buffer materials could be ploughed in like it is done during agricultural or forestry recultivation measures. Similarly, buffer materials (e.g. limestone slurry) could also be infiltrated selectively, on demand and parallel to operations to the extent permitted by the peripheral geotechnical conditions. In this case, a recently described technique, the so-called pressure infiltration (Wils, 2005), could be applied.

Similar measures can used while the dumpsite is being set up, the subsequent buffering can also be accomplished through conventional deep wells (dry wells) or by way of pressure infiltrations after the dumpsite has been completed, although the necessary quantity of the buffer material and the extent of the action are rather restricted.

4.2 Pressure infiltration

As compared with deep wells, which require a high construction input and have a comparatively low infiltration capacity, this technique requires relatively little input and therefore justifies the limited service life of such an infiltration source. This type of infiltration uses pipes without filter and with openings at the bottom through which pressurised water is channeled into the water bearing strata of loose rock. The infiltration tests with untreated water carried out in MIBRAG's open-cast mine at Profen, with the help of this technique, have been successful (Struzina, 2006).

4.3 Flow channels/water treatment

If coarse material (sand-gravel mixtures) is selectively dumped in a certain place, preferential flow paths can be created, the position of which is known and that can be used for further works in the sense of the acidic water management.

If the dumpsite body is penetrated by groundwater at a later point in time, water with a buffer capability will flow into the non-compliant place and can counteract the acidification there.

Should it become necessary to pump off water during maintenance measures, so as to prevent qualitatively unacceptable water from being discharged into ambient aquifers (as an example), the planning and management system, in accordance with the premises described above, may also contribute to minimising the quantity of the water to be pumped out or the input required for pumping the water. As mentioned earlier, preferential flow paths may be generated that make it possible to carry out pumping measures selectively, in a locally restricted place and thus at a considerably reduced cost.

The creation of preferential flow paths, as well as the knowledge of their location and the extent of non-compliant areas with regard to the quality of the dumpsite water, will not only make it possible to minimise and concentrate the pumping of water, but will also reduce the input for processing the pumped water. The neutralisation plant in the Peres residual hole of MIBRAG's "Vereinigtes Schleenhain" open-cast mine may serve as an example.

Here, although under different planning premises, strongly acidic and iron-containing water discharged from one section of the dumpsite is treated to get a neutral pH value by adding limestone slurry, so as to allow bivalent iron to oxidise to trivalent iron by adding oxygen, which will precipitate. The water thus treated will then flow into the main drainage, where it is mixed with the water from all filter wells and with the surface water of the Peres mining field. The separate treatment of this locally discharged water will ensure that the entire water from the main drainage satisfies the discharge conditions imposed on the draining ditch (Jolas, 2004).

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