

## Results of Studies Performed for Reduced Impact of Materials Conversion Processes in Mixed Soil Dumps

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**Abstract** In the course of lignite mining, overlying Quaternary and Tertiary sediments come into contact with atmospheric oxygen when the groundwater table is lowered and sediments are removed and placed in overburden dumps. The iron sulphide minerals contained in these surface layers oxidize and release iron, sulphate and protons into the developing open-pit dumps. As a consequence, acid is released causing buffer reactions of carbonate and silicate materials (Wisotzky 1994, Hoth 2004). Reaction products of this primary mineral dissolution are reversibly stored in the pore water and in secondary materials and may cause the generation of acid mine waters. With the rising groundwater level in the dumps, the flow of generated problematic materials can cause degradation of groundwater quality in the groundwater runoff of the overburden dumps.

**Key Words** acid mine drainage, buffer, mixed soil dump, lignite open-pit mining, iron hydroxide, dump model

### Introduction

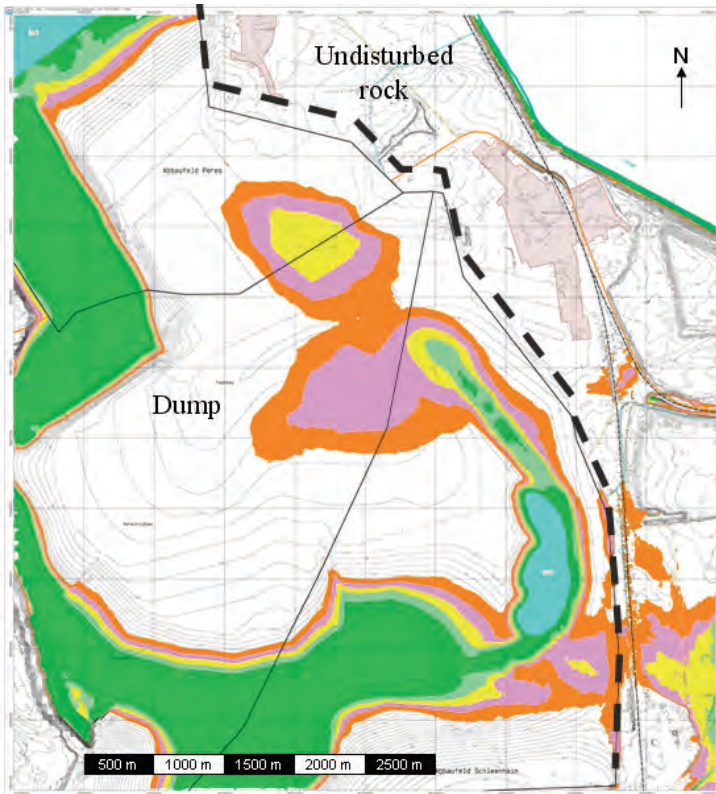
Acid Mine Drainage has been a known issue of lignite mining for many years. Therefore, MIBRAG commissioned a mine water treatment facility in 2010 that treats the produced mine water before discharged into receiving water. Another issue is the generation of acid mine water during the rise of groundwater in the dumps and its interaction with surface water. To be able to counteract the formation processes of acid mine water early, i.e. during mining and dumping operations respectively, MIBRAG, the Institut of the Drilling Technology and Fluid Mining of the TU Bergakademie Freiberg and GEOmontan GmbH have jointly conducted extensive studies during the past years. In the course of these studies, unconsolidated rocks in the areas intended for future mining were examined and characterized with regard to their potential for material conversion. The active Schleenhain mining field as well as the Peres and Groitzscher Dreieck mining fields are part of the United Schleenhain mine which is located south of Leipzig. The production of 11 million tonnes of lignite per year requires the removal of 25 – 30 million cubic meters of overburden by conveyor operations. While seven levels are operated in the pit, two dumping benches with one spreader each are operated at the dump. Overburden masses from the Schleenhain mining field are expected to be dumped until 2013, afterwards the Schleenhain mining field will be exhausted and the excavation will move into the Peres mining field. The final form of the Schleenhain inner dump under examination is planned as a plateau with a depression

in the central area and a hollow lake at the dump surface (fig. 1). The resulting valley structure is directed towards the Peres lake that will be created after completion of mining activities in the Peres mining field. Thus, the surface water and the pending dump groundwater can flow freely towards the Peres lake.

Parallel to the studies of material conversion processes in the Schleenhain dump area, a planning tool was developed to track the overburden on its way from the pit via conveyors to the place where it is dumped by spreaders and to predict the spatial distribution of unconsolidated rock inside the dump. The findings can be used in connection with material-specific and geochemical parameters of the overburden to influence the distribution of materials sensitive for acidification and materials with acid buffering capacities in the dump and, thus, reduce the negative impact of material conversion processes. Attention had also to be paid to the fact that the trace metal and iron loads as well as acidification are basically limited to the dump as the new groundwater body and to the immediate outward flow. Sulphate, however, as a conservative substance can also lead to increased sulphate loads in further dump groundwater runoff and, consequently, affect groundwater and surface water qualities.

### Material and methods

Within the scope of the joint study conducted by the TU Bergakademie Freiberg and the GEOmontan GmbH in order to determine the geogenic potential for groundwater acidification (Hoth *et al.*



*Figure 1 Planning of the final form – Schleenhain inner dump (MIBRAG mbH).*

2010), five wells from dry drillings in the prospective mining field and face samplings were used to collect field eluates on-site. Based on the location of the main coal deposits between Middle Eocene and Oligocene, the overburden masses to be sampled are sediments of Tertiary and Quaternary origin. While the Tertiary substrates can be classified as terrestrial in their sequence in the deep Eocene layers, fluvial-estuarine sediments predominante in the transition zone to the Upper Eocene. In the Oligocene, marine sands of the Böhlen formation prevail due to the flooding by the Palaeo Northsea (Standke 2008). Nearly full glacial cycles were identified in the Quaternary deposits. Mainly, terrace gravel, glacial-fluvial sands and varved were accumulated. According to Eissmann and Litt (1994), the lower Elster basal moraine forms a huge boulder clay complex. In the following Weichsel glacial stage, extensive loess drifts indicate the end of the glacial sequence of strata (Stoll *et al.* 2009). These loess drifts are covered by wetland sediments and peat formations of the Holocene.

Due to the various genesis types, different acidity generation potentials can be expected (Hoth *et al.* 2010). Grain size analyses were conducted for the determination of weathering rates in order to be able to physically and geochemically classify the extracted core samples. Overburden solids

analyses for TIC, TOC and sulphur content represented further key issues of the study in addition to the determination of hydrolytic acidity as a measure for the overall acidity, and weathering tests. On the basis of the results gained by the weathering tests, combinations of buffer tests were defined – taking into consideration the future mining technology – and subsequently performed at the laboratory. After blending the quantity units, weathering tests were conducted again and parameters such as hydrolytic acidity, pH value, conductivity and release of iron and sulphur were measured. Quality monitoring of dump groundwater was performed in supplementary tests. The objective was to determine dump water capacities for buffering and sulphate reduction (NA – Natural Attenuation). In total, samples were taken and hydro geochemically evaluated from 19 dump groundwater measuring points. Another possibility to improve dump water quality is explained by Nitsche and Bethge (2009). Iron hydroxide residues from the mine water treatment facility of the United Schleenhain mine are placed in the high dumping section of the lower dump (spreader 1119, 1st inner dump). The buffer capacity of iron hydroxide residues shall be used to reduce the amount of necessary redevelopment efforts in adjacent surface water and

groundwater bodies. In preparation of the iron hydroxide residue disposal in selected locations, the Quaternary and Tertiary sediments were analyzed for their acidity, alkalinity, metal content and hydraulic properties. For this purpose, substrate samples were taken from directly cast overburden, the low, high dumping sections and the top soil and eluate samples were generated on-site. Based on the pH value and the electric conductivity, conclusions were immediately derived on whether the material was of Quaternary or Tertiary origin. The samples were cooled and prepared for analysis on the same day. To determine the metal content, aqua regia dissolutions were performed. As the mobilization of the metal contents is to be ascribed to the effective pH values of the pore water, and the pH values are determined by effective substrate acidity during the first phase of rising groundwater levels (elution), the acidity constitutes a key criterion for the capability to counteract the long-acting process of post-acidification within the course of further rising groundwater levels (Nitsche and Bethge 2009).

The geochemical parameters of the overburden layers that were analyzed earlier must now be used with the respective geological and technological models in order to draw conclusions about dump properties subject to mine planning.

After completion of the drill core analysis, the drill point coordinates, stratigraphy and results of the geochemical analyses are entered into the geological 3D model. The reconciliation of the actual production machines' location and position of the respective digging unit (actual state) with the generated geological model offers information about when the materials were actually extracted. The excavation of materials can be tracked in real time by a specifically developed transport model.

The length of the belt conveyors, the transfer points between conveyors and the large machines and the operating conditions of the conveyors are entered in the system for a simulation of conveyor operations in the transport model. The parameters of the extracted materials determined within the scope of actual and model data reconciliation are transferred from the geological model to the transport model at the delivery points. Extracted material classified as "overburden" is transferred to the dump model. The purpose of the dump model is to generate information about the composition of the dump. On the basis of the assumption that no additives shall be used for quality improvement, the composition of the future dump must be controlled prior to extraction, i.e. prior to reconciliation of actual and geological model data. Thus, the mine planning department is responsible for balancing qualities and quantities taking into account the geological model and technical equipment of the mine. They calculate quality-related target quantities for the individual units of equipment. Consequently, a systematic operation of excavators, conveyors in the pit and mass distribution facility enables a variable composition of dumping materials and their distribution at both dumps. The transport and the dump models are used for documenting and controlling purposes.

## Results

According to Hoth *et al.* (2010), the evaluation of eluate taken from drill holes in the area to be mined shows a predominance of slightly acidic and neutral pH values of substrates at Schleenhain. While boulder clay was found to be slightly alkaline and thus suitable as acidity buffer, areas sensitive for acidification were locally identified

**Table 1** Results of weathering tests after 50 and 250 days, Schleenhain mining field (Hoth *et al.* 2010, p 82).

	Hydrol. Acidity		pH value		Fe release		SO <sub>4</sub> release	
	mmol/kg *TS		[/]		mg Fe/100g TS		mg SO <sub>4</sub> /100g TS	
	50d	250d	50d	250d	50d	250d	50d	250d
Boulder clay	0	0	6 - 9	6 - 9	<10	<10	<50	<50
Aquifer	5	10 - 25	4 - 6	3 - 5.5	<10	20	<50	<50 - 250
Aquifer 2								
Upper Böhlen Formation	0	0	6	6	20	<10	50	<50
GWL 2								
Lower Böhlen Formation	10	100	3.5	2.5	20	250	350	800
Aquifer 3	10	40	3 - 4	2.5 - 3.5	20	<10 - 100	50	100 - 400
Aquifer 4/5	5	10	5.5	3 - 5	<10	15	<50	50
Haselb. Clay	5	10	7	6.5	<10	<10	<50	50

\*TS - dry substance

in Early Pleistocene layers. Stronger mineralized sections were identified in aquifers 2 and 3 at the Peres mining field. The overall pH value is above five. As for buffering properties, the boulder clay qualifies as a high TIC carbonate buffer at Schleenhain and Peres. Sulfur contents are higher at the Peres mining field. This is attributable to the Genesis. Aquifer 2 is the main acidity carrier at the Peres mining field. Positive buffering capacities of boulder clay were also determined in weathering tests (tab. 1). No release of iron and acidity was observed in either mining field. Only minor quantities of sulphate were released. Aquifer 2 was classified as main acidity carrier in both mining fields, whereas values of up to 800 mg Fe per 100g dry substance and up to 4000 mg SO<sub>4</sub> per 100g dry substance have been recorded at the footwall of aquifer 2 at the Peres mining field with the brown sands, i.e. releases at Peres are much higher than at Schleenhain. The estuarine sediments of aquifer 3 are also acidic. No relevant contents were identified in all remaining layers. On the basis of the weathering tests, future pH values of below 3 can be, in general, predicted for the substrates of aquifers 2 and 3. Consequently, an exposure of dump sections must be avoided. A release of sulphate must certainly be avoided in aquifer 2, since sulphate is acting as a conservative substance. An addition of 40 % of boulder clay to the buffering test helped to fully limit the release of acidity and Fe for neutralization purposes in aquifer 2 after one year. A share of only 20 % of boulder clay was enough to generate the same result for aquifer 3. Furthermore, a boulder clay portion of 20% and more accounts for reduced sulphate release. Release of iron depends directly on the pH value and, consequently, the buffering result. Iron release is completely prevented under neutral conditions. In an analysis, dump groundwater was found to range between slightly acidic and neutral pH values of more than 5.5. Basically, there were three dif-

ferent groups of groundwater identified at the dumps. Group 1, representing main parts of the dumps, had Fe contents of less than 50 mg/L and SO<sub>4</sub> contents between less than 1300 and 1900 mg/L. Group 2 featured significantly higher Fe- (350–500 mg/L) and SO<sub>4</sub>- contents (2000–3000 mg/L). The last group was found in extremely weathered water with SO<sub>4</sub> contents above 4000 mg/L and Fe contents around 1000 mg/L. The highest trace element contents were measured in the latter of the three groups, too. Furthermore, the effectiveness of the carbonate buffers determined on the basis of the DIC content of Peres substrates should also be mentioned at this point in comparison to the Schleenhain deposits.

The following conclusions can be drawn from the substrates analyzed within the scope of iron hydroxide residue disposal. On the basis of the layered silicate structure of clay minerals and the resultant charging properties, the Haselbach clays were found to be more resistant to weathering than the acidic Pödelwitz sands (aquifer 2). The acidity of sands ranged between 14 and 18 mmol per kg of dry substance regardless of dumping conditions. The acidity of clay was found to depend on the time factor. While the acidity of recently dumped clay samples was 5 mmol per kg, clay samples of the high dumping section that had been exposed for a longer period reached values of up to 41 mmol per kg of dry substance. In a pilot test, a buffer capacity of 3.5 mol per kg of dry substance was determined for iron hydroxide residues from the Schleenhain groundwater treatment facility. In titration tests, the iron hydroxide residues were classified as high carbonate.

Analyzed metal concentrations of Al, As, Cd, Cr, Cu, Hg, Ni, Pb and Zn in iron hydroxide residues are within the same range as analyzed substrates (tab. 2) and can, therefore, be used for neutralization of acidic dump sections. Due to low pore water velocities, the development of an anaerobic

Parameter	Unit	Sand	Clay	*EHR
Alkalinity	mmol/kg TS	n.b. - 14	n.b. - 49	3500
Acidity	mmol/kg TS	4 - 18	3.5 - 41	
Al	mg/kg TS	2700-21900	1260 - 64780	2970
As	mg/kg TS	<3	<3 - 13	10.4
Cd	mg/kg TS	<3	<0.3 - 1	<0.3
Cr, total	mg/kg TS	4.3 - 10.5	4.8 - 64.4	11.7
Cu	mg/kg TS	0.6 - 2	0.8 - 28.6	14.4
Hg	mg/kg TS	0.03 - 0.14	0.09 - 0.4	0.06
Ni	mg/kg TS	1.9 - 2.6	1 - 38	81.5
Pb	mg/kg TS	3 - 11.8	1.6 - 49.5	11.2
Zn	mg/kg TS	3.8 - 48.6	1.2 - 985	349

\*EHR - iron hydroxide residue

Table 2 Metal contents of analyzed substrates in aqua regia dissolution (Nitsche and Bethge 2009, p. 32).

milieu can be assumed if topsoil is dumped on the top of the dump. On the basis of the assumption that pH values will finally reach a value of around 5, a mobilization of the metals will become possible only in the first phase of rising groundwater levels. This process can be avoided by the inserted iron hydroxide residues. A further advantage of iron hydroxide residues is that they help to reduce oxidizing processes in partly covered, exposed dump sections (pyrite weathering) by airtight (Nitsche und Bethge 2009). In the future, the above-mentioned results of geochemical investigations shall be used in the dump model planning tool also described above in order to enable quality-driven dumping operations for the management of acid mine drainage in the future.

**Conclusion**

In conclusion, a dumping sequence as shown in figure 2 can be derived from the presented results. Unconsolidated rock (aquifer 3) sensitive for acidification and varved are dumped in the lower dump area. Iron hydroxide residues whose alkalinity is considered to be sufficiently effective to neutralize the acidity potential of aquifer 3 shall be placed at the dump base of the low dumping section. Furthermore, iron hydroxide residues shall also be dumped at the surface of the high dumping section of the lower dump. The transportation of the residues which have a solid content of 5 % through a PE pipe line guarantees flexible distribution in the individual dumping sections. The dumping sections themselves appear as rib structures, all of them dumped separately. High dump-

ing operations of the upper dump must be set up in a way to guarantee a composition of unconsolidated rock sensitive for acidification (aquifer 2, 40 %) and unconsolidated rock buffering acid (boulder clay, 60 %). The high carbonate solid content of boulder clay starts having an effect at this point, since it is the carbonate buffer which is used up as the first buffer stage. Further buffers are used in lower pH ranges and the mobilization of heavy metals is initiated (Hoth *et al.* 2010). Finally, a mixture of cohesive and non-cohesive topsoil shall be applied to reduce the recharge of new groundwater and seepage water accordingly. Also the subsequent use for agricultural purposes shall help to counteract post-acidification.

**Summary**

Even though the success of the new dumping technology has not yet been proven on a real example, the investigations described above have illustrated which parameters become effective. Long-term success can be predicted taking into account geochemical compositions, mobilization of substances on the basis of groundwater dynamics and using available planning tools.

Consequently, the presented measures can help to optimize the water quality in dump aquifers. Neutralizing efforts primarily based on in-lake methods (pontoons or ships), i.e. the addition of carbonate substances, can either be reduced or will not be necessary at all. In return, redevelopment measures become more sustainable which will also help to save resources (additives) in the long term.

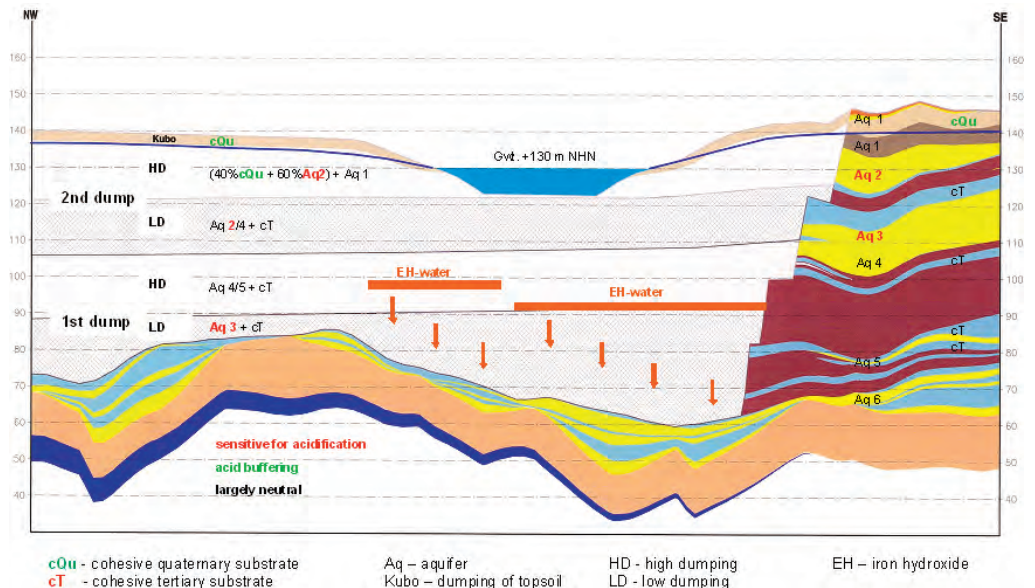


Figure 2 Dumping sequence and distribution of iron hydroxide residues (MIBRAG mbH).

### Acknowledgements

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