Initiatives to enhance water quality in residual pits in the remediation of eastern German lignite mines

Ralph Matthes, Dr. Friedrich v. Bismarck

1. Introduction

Due to the drastic decrease of production in eastern German lignite mines since 1990 many pits, power- and processing plants had to close. Most of these pits and plants are today in the remediation programme. Only very few profitable mines could be privatised and are still active (VATTENFALL, MIBRAG, ROMONTA). In order to carry out the large and complex remediation tasks, the LMBV (Lausitzer und Mitteldeutsche Bergbauverwaltungs-gesellschaft) was founded in 1994. This enterprise is owned by the federal government. In line with the subsequent remediation activities three main tasks appeared:

1) Balance out the ground water deficit from mine dewatering
2) Flooding the residual pits
3) Recreation of natural relationships between the bordering rivers and water bodies.

The whole deficit of static groundwater-resources amount to nearly 13 billion m³. After completing all flooding activities, new lakes covering a total area of about 26.000 hectares will be created.

The former mining activities have an ongoing disadvantageous impact on water quality in the concerned regions. Even the intense utilisation of all surface- and underground water resources are insufficient to compensate for the negative impact. In the process of mine dewatering (groundwater lowering) and also large scale removal of the overburden, the subsurface was ventilated. Associated with these processes an extensive oxidation and solution from geogen minerals like pyrite and marcasite takes place. These chemical reactions are responsible for the high degree of iron and sulphate as well as particularly extreme low pH-values in ground- and surface water. The planned connection of the flooded pits with natural rivers is a possible way to achieve a good water quality. The water quality requirements depend on the regional situation and vary from pit to pit. The minimal aim is to guarantee that the water quality in the existing natural water system does not deteriorate by the new connection with these mining areas. After the European Water-Framework-Directive comes fully into effect, for some residual pits it might be possible that the standards for the respective drain parameters would rise.

Best practise and also a low-price method of flooding is to bring enough alkaline river water into the new lakes. Unfortunately in Lusatia water is a rare resource and the acidification processes in the tertiary waste material are very high.

In the following an overview of different initiatives and some project examples of how to protect and to improve the water quality in former eastern German mining districts will be given.

2. Treatment methods

In principle there are four approaches for treatment methods.
These are:

1) The surface water flow
2) The ground water flow
3) The water bodies
4) The groundwater bodies.

For each of these approaches there are special kinds of treatment methods. In addition there are of course other typical elements for flooding of pits like

- using river water for flooding processes
- flooding speed
- flooding control
- natural water rising process.

The last four methods are the most important methods for flooding pits and for generating a good water quality. In general, the natural rising process of the groundwater will take a lot of time and has a disadvantageous impact on water quality. The mode of action varies between the two mining areas in eastern Germany. In the mining district south and north of Leipzig there are big rivers with enough daily water quantity. In addition there is a long-term contract with MIBRAG for the supply of good mining water from dewatering. Unfortunately the Lusatian area is characterised by low precipitation and a lack of water. Thus, the flooding processes have to be interrupted for several months each year causing a negative impact on the quality of the water in the flooded pits. In the following an overview is given of current treatment methods used and corresponding research aims.

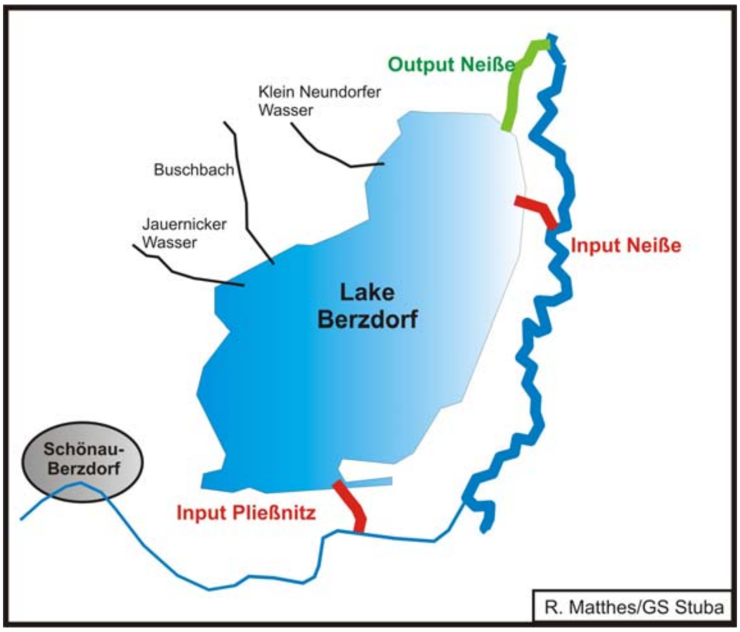
2.1 Flooding water from rivers and flooding speed

Best practise and also a low-price method of flooding is to bring enough alkaline river water into the new lakes within a short period of time. Existing acidity will be reduced and the high sulphate concentration will be attenuated. But also the ordinary remediation process is benefiting form a quick rise of the water level. As a result, it is possible to create a steeper slope of the dumps because the water body gives the necessary pressure for the dump stability. Fig. 1 shows an example of an optimal flooding process.

With the maximal run-off from the river Pließnitz (2.5 m^3/s) and river Neiße (10 m^3/s) it would be possible to complete the flooding process after only four years. This flooding time is unique considering the dimension. A large lake is created covering an area of about 960 hectares with a depth of up to 70 m and a water volume of 330 million m^3.

Normally, the flooding processes in such dimensions takes 10 to 15 years. And after that period it will be necessary to stabilise the water level and to guarantee a good water quality. This part is called the *aftercare phase* and can take several years more. Only after sustainable conditions are achieved, the lake can be released from the mining law and a safe new use can start. In Berzdorf this will be possiblly significant earlier.

Fig. 1 Flooding system for the ‘Berzdorf’ pit



2.2 Flooding control

If water resources are rare, controlling of the flooding process, which means the complex combination of all flooding parameters, is determined as the beginning for necessary technical water treatment measures. On the one hand, if possible, the pits must be connected among themselves to generate concentration points for the reconnection into the rivers. On the other hand, every future lake should have a connection to a river to take in alkaline water. The decisions on such investments are, of course, always based on a cost-benefit analysis. Figure 2 shows the technical links for the new reservoir Lohsa II.

The figure demonstrates that only one reconnection point exists where three lakes discharge. The entire flooding processes in all of Lusatia are controlled from one office location.

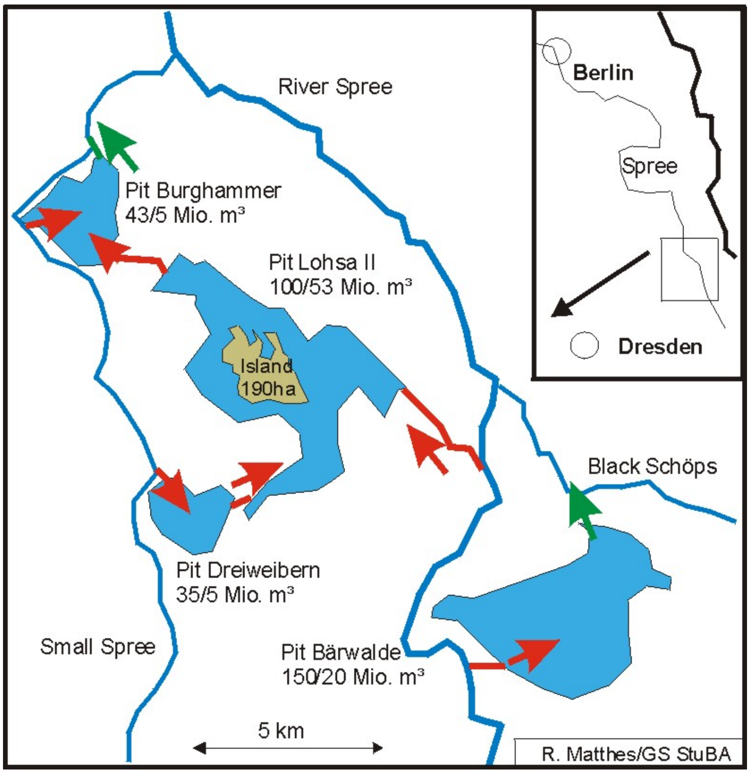


Fig. 2 Retaining System “Lohsa II” – topographical overview

2.3 Surface water flow

- mine water treatment plant

The treatment of the surface water flow in the mines is done in common mine water treatment plants. However, the two mining districts in eastern Germany differ from each other. While in central Germany usually a special cleaning of the mine water is not required, in Lusatia those plants are necessary. Generally, their principle of action is always the same: with the addition of limestone or lime products in mine waters the iron will precipitate. The iron is one of the sources of acidity and the di-sulphide oxidation is responsible for the extreme low pH-value. As a result of the reaction, iron hydroxide sludge is produced which will be cleaned up and dumped in the pits. The neutral water has to be discharged in the river or will be used for flooding the pits. A reduction of sulphate with these chemical reactions is not possible. The LMBV is operating the following treatment plants:

Location (pit name)	Status (now and later)	Cleaning capacity (old and new) m^3/s
Pößnitz (Lauchhammer)	In use; improved efficiency	0.5
Lichterfeld (Klettwitz-Nord)	In use; improved efficiency	1.5
Kortitzmühle (Laubusch)	In use; new construction	0.25 / 2.2
Rainitza (Meuro-Süd)	In use; extension planned	1.4 / 2.0
Lohsa (Lohsa II)	new construction	5.0
Flowing off Ilsesee (Meuro-Süd)	new construction	4.0

In addition there are six treatments plants operated by active mining companies (VATTENFALL). The cost for the treatment plants are considerable and can easily add up to more than one million Euro per year.

In central Germany there is no need for big cleaning capacities due to a lower degree of iron and sulphate. For example, in the active ‘Profen’ pit the mine water is only air conditioned. This method is sufficient to reduce the degree of iron. Afterwards the water is used by LMBV for flooding their pits. Unfortunately, newest scientific and limnological research indicates that the influence of the waste material in the pits is sometimes so high that additional treatment activities will be needed.

As this kind of mine water treatment plants can not reduce or minimise the degree of sulphate for the remediation programme, further research is carried out with the aim to solve the sulphate problem. Potential beneficial methods are in the fields of electrochemical measures and also in microbiologic reductive sulphide precipitation for example.

- electrochemical water treatment

The advantage of this method is to use running chemical processes for resource extraction. For that purpose, sulphate water has to be brought in the cathode space of an electrolysis cell. As one of the side products, hydrogen is formed. The generated hydrogen could be used as an energy source for fuel cells. As a result of the removal of protons, the pH-value increases and, simultaneously, heavy metals, which are present in the water, precipitate. For a continuous chemical process it is essential that the sulphate-ions migrate to the anode. Due to this reaction the degree of sulphate can be reduced by nearly 30 %. Depending on the addition of different reagents at the anode ammonium persulphate but also sulphuric acid are produced. Ammonium persulphate can be used as oxidant, as catalyst, and also for surface treatment of metals. The next aim is to increase the flow rate. It is planned to build a pilot facility.

- microbiologically reductive sulphide precipitation

In a long-term test (over 16 months) it could be demonstrated that the addition of methanol is a real efficient organic source (food) for microbiological populations. These microbiological populations, working under anaerobic conditions, are responsible for the formation of sulphide from sulphate. In heavy-metal sludge sulphides precipitate as metal-sulphide, which have to be cleaned up. Therefore, the aim of the actual planning is to clean up that sludge in anaerobic parts of old pits. If the precipitation of sulphides is performed with iron, the result of this reaction is pyrite, the source of acidity and quality problem. However, often there is not enough free iron in the underground material. Therefore, it also has been tried to use iron hydroxide sludge obtained from mine water treatment plants. These experiments are very new and still under investigation.

The long time stability of the pilot facility could be verified. However, the required water flow-rate could not be achieved. Currently, the water flow rate is 0.3 m^3/s at maximum.

2.4 Groundwater flow

In principle, treatment of groundwater is possible ex-situ as well as in-situ. In Germany, ex-situ treatment requires a permission of water rights to carry groundwater. Additionally, it is not allowed to discharge this water back into the groundwater without prior treatment. Therefore, many scientists have to clean the water in-situ using so called active and/or passive fixed bed or fluid bed reactors.

- active fixed bed reactor

By using this type of reactor the most important advantage is the possibility to control the running process by a systematic addition of agents. One typical example is the ‘Senftenberg Lake’ in Lusatia. The ‘Senftenberg Lake’, a flooded pit which is now 20 years old, has got a neutral pH-value today. But many waste dumps and remediation pits around the lake have become a risk for that lake because they cause an increasing acidity by rising of groundwater. Therefore, in a research project it was tried to find out alkaline compounds which are able to stop this trend. Large tests have been performed using substances like whey, brewery sullage, vegetable sullage, black liquor, and methanol. After all, methanol was found to give the best results. This was checked in a field test. Methanol was added to groundwater by infiltration. As a result, sulphide precipitation took place in the underground and pyrite was generated. As previously mentioned the reaction cannot proceed completely because there is a lack of free iron. One advantage of this reaction is the disposition of precipitates in the underground. Nevertheless, it is necessary to verify possible effects which can happen in the underground. This could be any slack flows of precipitates which cause dump stability problems or negative effects for the planned post mining landscape by changing the final groundwater level.

- passive fixed bed reactor

Passive fixed bed reactors are maintenance-free but cannot be changed after construction. They are inactive after they are used up. Any reapplication of alkaline materials is not possible. Sometimes this handicap could be advantageous. This can be shown exemplarily for the waste dam between two pit-lakes Skado and Sedlitz. The water in both of the lakes is characterised by a pH value of about 3 but at a different level. Into the dam a reactive wall was built in a depth from 12 to 27 metres. This wall consists of sand and ashes. These ashes were obtained from lignite power plants. They still contain a high amount of lime used for gas desulphurisation. The necessary reactor stability was of high importance. This particular field test can be used to supply information on the rate of consumption, reaction times, flow behaviour, and colmation. After finishing flooding both lakes will have the same water level and the reaction stops. Even in case of failure there is no negative influence of long-term dam stability. This clearly demonstrates the importance of the location designated for this special treatment. In figure 3 the principle is shown.

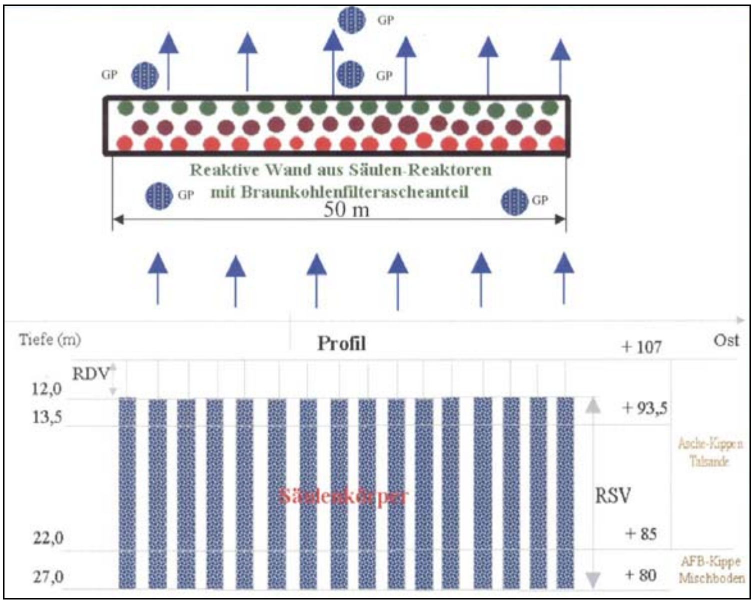


Fig. 3 Passive fixed bed reactor – active principle

Classical in-situ fixed bed reactors are constructed oxic or anoxic wetlands. By the addition of organic carbon sources and alkaline materials, and also by applying appropriate rules for the construction of wetlands, a rising of the pH-value is possible. For the remediation of eastern German lignite mines these elements are only sporadically used. The reasons for this can be seen in a necessary flow rate of 1 to 7 m^3/s, as well as the huge space, which is required.

However, in the opinion of the authors there are some possibilities for using this method if it will be linked to other treatment methods. The flow from the pits into the rivers is not constant during a year, thus, constructed wetlands sometimes are able to assume the treatment function.

2.5 Water bodies

Right from the beginning of the remediation programme in 1991 the LMBV became the owner of already flooded lakes or pits and was confronted with the conditions of rising levels of groundwater. In most cases standard treatment methods could not be used. In order to treat the water body in-situ other methods have been tested. On the one hand available alkaline materials (like ashes, lime stone deposits, iron hydroxide sludge) have been intensively investigated, on the other hand external sources (soda, ash or dolomite) have been tested.

Two examples will be given here:

- ashes reactivation

After finishing mining activities, the ‘Burghammer’ pit was used for discharging fluid ashes of the power plants in Schwarze Pumpe. Finally over 26 million tons of ashes were discharged. Due to the flue gas desulphurisation these ashes still have a high amount of lime. This high alkaline potential created a neutral water body (water volume 36 million m^3 with a water area of 445 ha). After the discharge of the ashes came to an end in 1996 and in combination with an increasing groundwater level, the influence of the oxidation processes in the waste materials in the dump increased enormously. As no sufficient buffer capacity was available the pH-value dropped from 7 to 3.

By the ‘eta AG’ company a simple but effective treatment was developed for these special conditions. A part of these ashes was extracted by a swimming dredger. Then, ashes and the sea water together reacted in a centrifuge. As a result, the pH-value of the acid water increased again up to 7 although the buffer capacity was not specifically high (K_S = max. 1.5 mmol/m³). During the time of the experiment (nearly one year) an amount of only 14 tons of ashes was needed. However, a short time later the pH-value dropped again. So the following conclusion can be drawn:

1) Using this method, very quickly an increasing pH-value can be obtained. However, it is not possible to form a hydrogen carbonate buffer (lack of carbon dioxide).
2) The consumption of alkaline material is very small, the extraction rate and reactivation is very efficient.
3) The influence of acids from the waste material in this pit is so high that only a continual treatment of the water body will be successful. This requires a constant flow of funds.
4) There are risks and open questions with regard to an increasing concentration of sulphate and chloride in the water body during reactivation of ashes.

This method can be useful in combination with other treatments. These methods could be:

- the use of alkaline mats or lime stone filter on the slopes,
- microbiological methods, or
- constructed wetlands.

Unfortunately, in the present time there are neither results and only few new ideas for projects to combine these methods.

- soda application

In central Germany in the residual lake of the former ‘Bockwitz/Dammwasserhaltung’ pit, a single attempt was performed to use soda solely for neutralisation. The general advantage of using soda is:

1) Soda can be very well and completely dissolved in water. Its reaction rate is very fast.
2) The dissolving of soda in acid water generates HCO_3^- which acts as a hydrogen carbonate buffer. Simultaneously, carbon

dioxide is created. This carbon dioxide fumigates without any significant increase of its concentration on the lakes surface.

Compared to other alkaline compounds its higher price is disadvantageous. But for a technical application only small requirements are necessary. Soda can be directly supplied into the water body via air pressure from the transportation truck. This method will be applied in an adjacent lake this year. Because the influx of ground and surface water is supposed to be pH-neutral, a re-acidification of these two lakes is unlikely. Therefore, this method seems to be adequate for this location.

2.6 Groundwater bodies

Any treatment of a groundwater body is inseparable connected to an underground body treatment. Generally, there are two possibilities:

a) The underground body (waste material) has to be treated with alkaline materials already during the active mining process. This method is applied in the mining district Rheinische Revier in the ‘Garzweiler’ pit. There are 40,000 tons of lime stone added to the waste material annually with rising tendency.
b) Alkaline material also can be added to an existing waste dump. There are some project ideas for using lime milk instead of water with the stabilisation of the dump slopes applying a so called method of vibro-compaction. The main advantage of this treatment is low costs because no additional bore-holes are needed.

3. Outlook

According to the previous comments there are many options to reduce the iron concentration and to increase the pH-value of the acid mine water as well. The problems concerning the high degree of sulphate are still not solved. Therefore, there are much more research projects in the field of remediation which for instance analyse the natural attenuation in 100 years old waste dumps and try to simulate the processes during this time. At the same time, there are pilot projects using selected methods to test their praxis suitability. Now it is the challenging task for the authors to connect the results obtained from different methods as well as to seek for interdisciplinary approaches to solve the problems. This is essential since these problems are complex and differ from case to case. One treatment method mostly does not cover all requirements.

The financial allocation for the current program of remediation of eastern German lignite mines ends at the end of 2007. It is well known, that after this time the remediation will have to be continued. Until then, the typical remediation operations will loose their importance and questions as how to secure the flooding of a pit with sufficient water, and also how to get a good water quality within the pits have to be answered. Without solving these problems a successful use of the post-mining landscape will not be possible. In some cases the flooding will take until the year 2020 and even later. For that reason it is necessary to have a system to safeguard and control the lakes with rising water level. The organisational frame has still to be created and essential operations and costs have to be planned for the future. Actually, this subject is becoming the main focus in the field of remediation. Finally, these are task which will require a lot of money. They all have one single aim – to guaranty a safe use afterwards. However, not every use of the post-mining lakes must be and can be guarantied by the mining company LMBV, because some water quality problems to be solved are extremely difficult as well as expensive. In conformity with the European Water Framework Directive it is also possible to refuse measurements if the cost are inappropriate. In the future the triad of remediation, the desired new use, and the costs must be even more harmonised.

References

Governmental Steering and Budgeting Committee for the Rehabilitation of East-German Lignite Mines (StuBA), Protocol Remediation Lignite Mines 1992/2003 [Protokoll Braunkohlesanierung 1992/2002], Berlin.

LMBV (2003) Flooding Post-Mining Lakes – Measures to Control Water Quality in Lusatia [Restlochflutung – Maßnahmen zur Steuerung der Wasserbeschaffenheit in den Bergbaufolgeseen der Lausitz], Berlin.