Advanced Treatment of Waters Affected by AMD

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Abstract The fast and effective treatment of large surface and groundwaters that are effected by acid mine drainage (AMD) might be the most certain issues humanity has to face within the coming decades. Three different and economical proven approaches will be discussed within this paper: Overburden buffering, effluent neutralisation in combination with further production of desired metals and lake liming with an enhanced spreading boat technology. Overburden buffering is a unique technology done in the western part of Germany during the excavation of lignite. Results show that the acidification of the water, penetrating the overburden, can be prohibited effectively. In-situ leach mining of metals is gaining more and more importance throughout the mining industry. This process requieres special, cost effective neutralisation strategies in order to receive the desired metals. Uranium mining will be discussed as an example for this approach. Lake liming is one of the last possibilities to treat large acidic surface waters. Sucessfull examples of treatments in Sweden and Germany will be presented. All approaches together will enable the long term solution for mining water related problems.

Key Words AMD, Overburden Buffering, Lake Liming, Neutralisation, Spreading Boat

Introduction

Germany has a long ranging history of underground and open pit mining. Mining in the Ore Mountains ("Erzgebirge"), for example, dates back to the 12th century. As well, Germany is the biggest lignite producer and user worldwide. In 2008, 175.3 million tons were mined (Rempel *et al.*, 2009), while 91% (Kaltenbach *et al.* 2009, p. 2) was combusted in nearby power plants. Enormous open pit mining activities for more than 40 years created new landscapes, characterised by a huge number of open pit lakes.

Based on this history, environmental issues like water management and treatment have always been an issue.

Lhoist, a world wide operating lime producer provided reagents, associated services and the technology for three different applications over the past years which will be discussed in this paper.

Overburden Buffering

The biggest lignite mining area in Germany is located between Aachen, Cologne and Möchengladbach (see circle in Figure 1), which is focused on the three opencast mines Garzweiler, Hambach and Inden with an annual output of around 100 Mt in 2007 (Kaltenbach *et al.* 2009, p. 3).

The Garzweiler mine is going to deliver 1,500 million tons of lignite by 2045 (RWE Power 2011). About 7,000 million m³ of overburden, of which 5,200 million are endangered by acidification (RWE Power 2011), have to be moved during the mining. Between 14% and 17% of the Pyrite in the overburden is oxidised to sulphuric acid and Fe(II)/Fe(III) during the mining. In order to prevent the formation of high saline and acidified groundwater after the mining, overburden buffering is applied since 1998 (Wisotzky 2003, p. 51).

Figure 1 Distribution of Lignite and hard coal in Germany. The circle marks the open pit mining activity in which overburden buffering is applied. Figure taken from EURACOAL 2011.

According to Wisotzky 2003 (p. 56), the average mass share of $CaCO_3$ that is put into the overburden is 0.08%. RWE Power, the operator of the open pit mine owns four dosing silos that are installed directly above the belt conveyer. There, the limestone is dosed on the passing by overburden, while the dosing rate is controlled by the additional basicity demand of the soil and its mass flow. The mixing between the alkaline substance and the overburden is done at the exchange between two belt conveyers and at the spreaders indirectly (see Figure 2).

About 9,150 tons of limestone with an average particle size of 125 µm (d_{50}) (see Figure 3) can be stored on site within four different silos (see Figure 2).

The $CaCO_3$ used is a very pure Devonian limestone. The use of fly ashes has also been discussed, but has some disadvantages like the additional introduction of sulphur in the overburden via gypsum, the danger of overdosing and therefore the creation of pH values in the soil >12 and the absence of CO_3^{2-} that is able to form $FeCO_3$ (Wisotzky 2003, p. 56). Therefore, this option has been rejected.

Lenk *et al.* was assigned for a continuous and scientific monitoring of the effect of overburden buffering by RWE Power. He concluded after a multitude of measurements and a follow up time of 9 years that the overburden was neutralised completely causing a neutral pH value in the runoff water. By this, Fe and heavy metals are withholded in the overburden leading to a significant improvement of the situation of AMD and environmental impacts.

Effluent Treatment

AMD can occur from the oxidation of sulphur containing minerals (e.g. Pyrite) that got in contact with oxygen or due to intentionally introduced acid (e.g. sulphuric acid) that was used during the in-situ leach mining of heavy metals like uranium. Both origins of the acid harm the environment equally because low pH values facilitate the dissolution of minerals that contain (heavy) metals. The resulting highly saline waters endanger either the groundwater or surface waters and have to be treated for this very reason.

DIAMO, a Czech federal organisation responsible for the remediation of former mining sites, developed together with Lhoist an innovative, cost effective and efficient water treatment strategy at the former uranium mining site Stráž pod Ralskem that is close to the eastern border of Germany.

In-situ leach mining was carried out in Stráž pod Ralskem between 1967 and 1996. Within this period 4,100 kt H_2SO_4, 312 kt HNO_3, 112 kt NH_3 26 kt HF and 1.5 kt HCl were used to extract 15,562 tons of uranium (Diamo, 2011). Today, it is assumed that 800 kt of H_2SO_4 are still loose in the underground of the former leaching fields that cover an area of 24.1 km^2. 266 Mm^3 of groundwater are contamained and have to be treated succe-

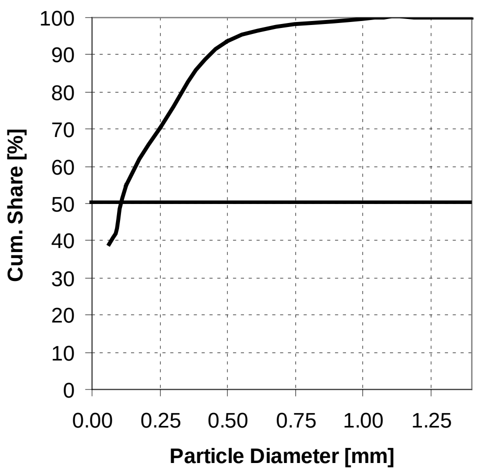

Figure 3 *Particle size distribution of limestone that is used for the overburden buffering at Garzweiler.*

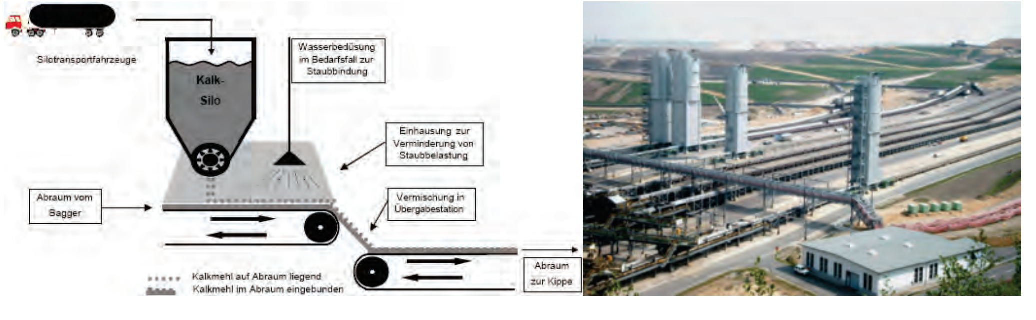

Figure 2 *Principle of limestone mixing with the overburden (left, Wisotzky 2003, P.51) and the four dosing stations in Garzweiler (right).*

Figure 4 *Geographic location (left) and processing situation on site (right, Diamo 2011) of Stráž pod Ralskem uranium mining site.*

sively. Within the water treatment complexes of DIAMO, groundwater firstly enters a desalinisation complex in which aluminium-ammonium sulphates and a water containing around 150 g/L of dissolved compounds are produced. This high saline water is neutralised with milk of lime (MOL). Lhoist inverstigated and optimised the slaking conditions of quicklime with the available water. Based on these investigations two dosing stations, dosing 3.2 tons per hour, each of CaO (Neutralac® Q) were installed and are working since 2009 with a constant Neutralac® Q quality provided by Lhoist. The CaO content is higher than 93.5 % while the reactivity is in the range between one to four minutes. The milk of lime has a final concentration before it is used of 20% and a viskosity of 300—400 mPa·s. After the neutralisation amonia stripping is done.

Lake Liming

Unfortunately, overburden buffering is a relative new development that was not used when Lignite seams were mined and exploited over the past decades in the eastern part of Germany (Lusatia). Nowadays, most of the former open pit mines are filled with or are steadily filling up with groundwater that is extremely acidified and enriched with metals like iron and aluminium.

To face the atmospheric immissions of acids in Swedish lakes, spreading techniques by boats have been developed in the 1970's. Boat technologies are able to distribute powdered limestone very equally over the surface of the lake in order to achieve a complete neutralisation of the water and to set up a buffer to prevent fast re-acidification (Sverdrup, 1985). The current boat technology is able to distribute up to 250 tons per day (see Figure 5).

The Swedish technology worked reasonably fine for the past 30 years to treat acidified lakes with a pH value above 4. An important advantage of the boat technology is the comfortable transportability on a normal trailer and the possibility of a direct launching without an artificial slipway.

However, water chemistry in German open pit lakes is different from those in Sweden. Therefore, it was essential to develop a special neutralisation strategy for open pit lakes and to prove its applicability. The presentation of the process development was done at the last IMWA in Sydney, Canada 2010 (Pust *et al.*, 2010).

Since 2009, Lhoist is in charge of the remediation of the former open pit lake Burghammer which comprises approximately 36 Mm^3 water (LMBV GmbH, 2009). Between 20th of March and 26th of June 2009 about 10,000 tons of limestone and 1.000 tons of hydrated lime were equally distributed over the lake (Kuyumcu *et al.*, 2010). The pH value was increased up to 8 and metals like

Figure 5 *Spreading boat in action: A slurry of $CaCO_3$ and lake water is prepared on the boat and distributed up to 25 m to each side of the boat. The boat distributes up to 250 tons $CaCO_3$ per day.*

iron and aluminium (Kuyumcu *et al.*, 2010) were precipitated. The reached buffer capacity was 0.33 mmol/l. The neutralisation efficiencies were in the range between 77 and 80% for $CaCO_3$ and 65 and 67% for $Ca(OH)_2$.

Due to the still remaining acidic groundwater flow into the lake, six re-treatments had to be performed in 2009 and 2010, using each time around 500 tons of $Ca(OH)_2$. The pH value was stabilised between 6 and 8.

Conclusion

AMD can be treated efficiently with calcium carbonates or lime-based products, enabling the prevention of acidification, the treatment of acid drainages and the remediation of large acidified surface waters.

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