Advanced Mobile Inlake Technology (AMIT) – An efficient Process for Neutralisation of Acid Open Pit Lakes

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Abstract As effects of acid rain have been recognized in Sweden first, technologies to treat acidified Lakes have been developed in the late 1970ies and further optimised, leading to a mature boat technology. This publication demonstrates a further optimisation of this enhanced spreading technology, based on trials in lab and pilot scale as well as chemical and economical simulations, to adapt process and used substances to the treatment of acid mine lakes with more complex water chemistry.

Key Words lake liming, spreading boat, Burghammer, open pit mining, water acidification, acid mine water

Introduction

Germany is the biggest lignite producer and user worldwide. In 2008 175.3 million tons were mined (Rempel et al., 2009) and combusted in nearby power plants. Enormous open pit mining activities create new landscapes, characterised by a huge number of open pit lakes, for more than 40 years. These lakes are filled with groundwater and become acidic in most cases due to the leaching of the overburden. To face the atmospheric immissions of acids in Swedish lakes, spreading techniques by boats have been developed in the 1970ies. 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). Current boat technology is able to distribute up to 250 tonnes per day (see Figure 1).

The Swedish technology worked reasonable 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.

Figure 1 *Spreading boat in action: A slurry of $CaCO_3$ and lake water is prepared on the boat and distributed up to 25 meters to each side of the boat. The boat distributes up to 250 tons $CaCO_3$ per day*

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.

Due to public awareness of the problem of acidified lakes in the German lignite mining areas the spreading boat technology has gathered political interest on a federal state level (Zschiedrisch, 2009). Following, development and optimisation steps will be discussed. The example of the lake "Burghammer" demonstrates the successful implementation of the developed strategy.

Methods

Scientific Background

Oxidation of the mineral Pyrite under wet conditions is the reason for acidification of open pit lakes. End products of the reaction between FeS_2 and O_2 are sulphuric acid and Fe^{2+} (Singer & Stumm 1970). The low pH-value of the resulting water causes a leaching of other pedogenic elements as Aluminum. This process results in extremely acid water that has high loads of salts penetrating into the open pit lakes. Table 1 shows extreme values measured in Eastern German open pit lakes.

With a variety of batch and pilot experiments with original water from open pit lakes it turned out that a two-stage neutralisation, with $CaCO_3$ and then $Ca(OH)_2$, having an optimised grain size distribution, offers neutralisation efficiencies close to the theoretical maximum (Schüppel, 2009). To achieve full dissolution of the applied substances, the coarsest $Ca(OH)_2$ particles should be smaller than ≈ 140 µm (see Figure 2) and the product should be changed at pH=4.5—5. This strategy marks not only a scientific optimum but also an economic.

Schüppel focused mainly on the modelling of the dissolution of $Ca(OH)_2$ particles. Modelling the dissolution of $CaCO_3$ is more challenging due to the dependency of the reaction rate constant and the chemical reaction order on the pH-value. Nevertheless, Arakaki & Mucci (1995) demon-

Table 1 *Extreme values measured in Eastern German open pit lakes*

	Extremes	Measure in	Date
Iron	821 mg/l	Lugteich	February 2002
Aluminium	53 mg/l	Sabrodter See	August 2004
Calcium	572 mg/l	Sabrodter See	April 2001
Magnesium	125 mg/l	Blunoer See	September 2001
Sulphate	3770 mg/l	SB Lohsa II	March 2001
$pKB_{8,2}$	39.8 mmol/l	Lugteich	February 2002
Conductivity	3870 µS/cm	Sabrodter See	August 2003
pH-value	2.15	Bergener See	March 2004

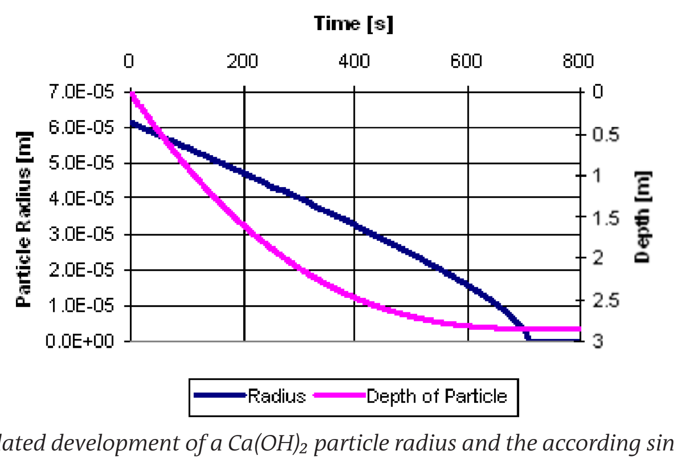

Figure 2 *Simulated development of a $Ca(OH)_2$ particle radius and the according sink depth in an open pit lake. The lake would have to be at least 3 m depth to achieve a complete dissolution of the product (Schüppel, 2009)*

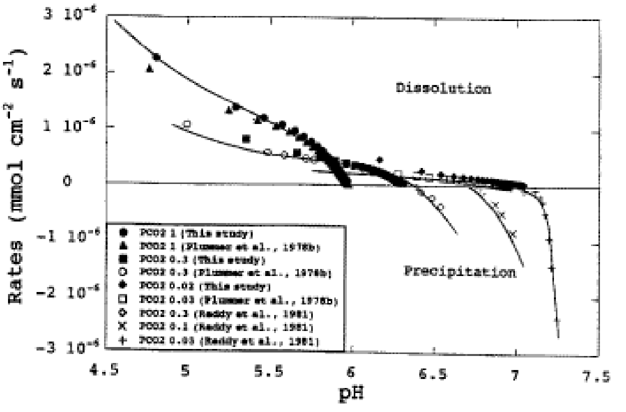

Figure 3 *Dissolution rates of $CaCO_3$ at different pH-Values (Arakaki et al. 1995)*

strated that the dissolution rate of $CaCO_3$ at a pH-value below 4.5 is more than three times higher than at 5.5 (see Figure 3). This finding is in good agreement with the empirical observation that high neutralisation efficiencies can be reached with limestone for as long as the pH-value is below 5 (Schüppel, 2009). At this pH-value, about 90% of the total base buffering capacity of the water of the open pit lake "Burghammer" is neutralised (Al- and Fe- buffer). Concluding, 90% of the neutralisation can be done with $CaCO_3$.

Open Pit Lake "Burghammer"

Table 2 shows the water chemistry of the lake "Burghammer" before the neutralisation.

The neutralisation potential (NP) calculated by Koch et al. (2008) underestimates the total need for OH^- ions, which are necessary to neutralise the water of an open pit lake and to set up a certain buffer capacity. The expected demand of base is 3.6 mmol/L (0.5 mmol/l of maximum buffer + 0.2 mmol/L dismissed base capacity).

A total theoretical demand of neutralisation agent was calculated: The lake "Burghammer" comprises approximately 36 million m³ water (LMBV GmbH, 2009). Additional acid inputs result

Table 2 *Water values of the lake "Burghammer" (Koch et al., 2008; [1]NP = neutralisation potential of the water, defined as $NP = KS4.3 - 3cAl^{3+} - 2cFe^{3+} - 2cMn^{2+}$)*

Conductivity	2290 µS/cm
pH-value	2.90 (15.8°C)
$K_{B4,3}$	2.34 mmol/l
NP[1]	-2.88 mmol/l
Fe	16.1 mg/l
Mn	4.74 mg/l
Al	3.3 mg/l
Ca	283.7 mg/l
Mg	52.2 mg/l
Na	43.5 mg/l
K	12.1 mg/l
SO_4^{2-}	1222 mg/l
Cl^-	79.2 mg/l
TOC	2.6 mg/l
TIC	0.8 mg/l

as follows: 20% acid from the sediment (Neumann et al., 2007) and 10—15% acid from the groundwater during the neutralisation (Neumann et al., 2007). A total neutralisation demand results in the range of 169 to 175 million $mol_{eq.}$ OH^-. 90% of this demand were covered by $CaCO_3$, the rest by $Ca(OH)_2$. Technically available limestone has a purity of 98.8%, hydrate of 96.6%. A combination of these numbers delivers a theoretical limestone demand of 7700—7970 tons of limestone and 650—670 tons of hydrate.

The initial neutralisation of the lake "Burghammer" was carried out between 20th of March and 26th of June 2009. About 10,000 tons of limestone and 1.000 tons of hydrate were equally distributed on the lake (Kuyumcu et al., 2010). The pH-value was increased up to 8 and metals like Iron and Aluminium (Kuyumcu et al., 2010) were precipitated. The reached buffer capacity was 0.33 mmol/L.

Taking into account these numbers, the neutralisation efficiencies were 77—80% for $CaCO_3$ and 65—67% for $Ca(OH)_2$. These high efficiencies in combination with the little time requirement for the whole process were only possible due to the intensive basic research and optimisation carried out. Moreover, there is no other technology available to achieve the same results in a comparable time frame. Due to the still remaining acidic groundwater flow into the lake a first re-treatment was performed between 28th of August and 10th of September 2009 using 680 tons of $Ca(OH)_2$ (Kuyumcu et al., 2010). The pH-value was increase from 6.2 to 8. The monthly net flow of acid into the lake is roughly 3 million mol_{eq} H^+. For as long as the acid groundwater flow remains a re-treatment has to be performed every 2—6 months to maintain the adjusted water quality.

Conclusion

Open pit lakes can be neutralised by the optimised Swedish boat technology. Based on the outcomes from the lab and pilot experiments it can be conducted that the majority of surface waters with high concentrations of Iron, Aluminium, Sulphate, Calcium, Magnesium etc. and low pH-values can be treated with the presented technology. Time, investment costs and product demand are very little in comparison with other techniques, such as water treatment plants.

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2 NP: Neutralisation Potential of the water.