Neutralized Mine Water for Irrigation – Cost and Feasibility Study

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Abstract The gold mines in South Africa produce about 345 ML of acid mine water. The purpose of this study was to identify cost effective solutions. The short term solution requires neutralization and metal removal to avoid negative environmental and health effects. The long term solution requires that surface water would not become salty from the discharge of saline mine water. For the short term solution, limestone/lime treatment was proposed.As a long term solution it was proposed to use neutralized mine water for irrigation. The irrigation option offers the benefit that the small volume of saline mine water will be kept away from the large volume of surface water destined for domestic use and normal irrigation. Through irrigation, 80 % of the mine water will be evaporated, resulting in the precipitation of gypsum as needle crystals in the soil.

Keywords neutralised mine water, irrigation, AMD treatment, Sequence Batch Process

Introduction

South Africa is well endowed with vast mineral resources and the wealth created through mining. In some areas these impacts have resulted in severe degradation of the quality of water. Water use in South Africa is dominated by irrigation, which accounts for around 62 % of all water used in the country, with domestic and urban use (including water for industrial use supplied by water boards) accounting for 27 % and mining, large industries and power generation accounting for 8 %. Commercial forestry plantations account for a little less than 3 % of water used by reducing runoff into rivers and streams. Agricultural activities also intercept rainfall and are not included in this breakdown.

Acid mine drainage (AMD) has for many years been a major environmental challenge associated with the mining industry, especially in the Western, Central and Eastern mining basins of Gauteng Province. The Western Basin AMD decants uncontrolled at a flow rate of 10–60 ML/d. Similar situations exist in the Central Basin and in the Eastern Basin. In the Central Basin the water was at a depth of 540 m below the decant level at the time of writing, and rising at an average daily rate of 0.7 m. It is anticipated that decanting or overflow of acid mine water, at an expected rate of 60 ML/d, may start in 2013/14. The quality of this water is also acidic and saline, similar to the AMD decanting from the Western Basin. The immediate construction of a neutralisation plant is required for removal of free acid, metals and uranium, and for partial sulphate removal.

Many activities have been carried out by research organizations and industry to find a solution to the acid mine water problem. Full-scale limestone neutralization for free acid has been implemented on the West Rand with considerable cost savings when compared to other acid neutralisation processes. Pilot studies have also been completed on desalination using chemical processes. Freeze desalination could be a cost-effective solution for brine streams. A pilot plant has been assembled and can be inspected in operation at the Soshanguve Campus of the Tshwane University of Technology (TUT).

The Expert Team of the Inter-Ministerial Committee on Acid Mine Drainage investigated the matter in 2010 and recommended specific actions to further manage and control the AMD associated with the Witwatersrand mining boom (Expert Team of the Inter-Ministerial Committee under the Coordination of the Council for Geoscience 2011), recommended that acid mine water needs to be neutralized in the short term and for the long term that options be identified to prevent salinization of surface water.

The Department of Water Affairs (DWA) has appointed the Trans-Caledon Tunnel Authority (TCTA) to be responsible for the short term solution as required by the recommendations of the Inter-Ministerial Committee on Acid Mine Water (Creamer 2012). In June 2011, after a tender process, BKS and Golder Associates were appointed to develop a short-term plan to address the immediate concerns of the AMD problem. An urgent task was to neutralise the water decanting in the Western, Central and Eastern Basins (Creamer 2012). Owing to the huge threat posed by AMD, it was decided by TCTA to employ proven technology that uses limestone treatment for neutralisation of free acid, followed by additional lime treatment for removal of iron(II) and other (semi)-metals (Van Niekerk 2011). This approach has been applied widely for treatment of AMD (Aubé 2004). This treatment process (referred to as the 'High Density Sludge (HDS)' process) consists of a pH correction/sludge conditioning stage, a neutralisation/aeration stage, and a solid/liquid separation stage (Osuchowski 1992). A due diligence study of the Witwatersrand mining basins estimated the capital cost of AMD neutralisation plants for the three basins at a total of R924 m (million). As only R255 m. was approved for this project by Cabinet (Creamer 2012), ways of making up the shortfall of R669 m. should be identified, or, alternatively, options for reducing this high capital cost need to be investigated and applied.

DWA has appointed Aurecon to investigate a long term solution. Treatment targets that are targets for treated water quality will be site-specific and depend on a number of factors, including issues relating to protection of plant and equipment from corrosion, as well as protection of environmental values of receiving waters. In contrast with water-rich mining regions, South Africa not only faces high acidity and dissolved metal problems associated with AMD. The limited dilution potential associated with low rainfall exacerbates the contribution of salinity associated with AMD to the salinization of water resources. For example, effluents from gold mines contribute about 35 % of the salt load but only 6 % of the water flow at the Barrage in the Vaal River (the major water source of the industrial heartland of South Africa).

The aims of this investigation were to demonstrate the following: (i) Alkali cost for neutralization can be reduced by 50 % by using limestone for removal of free acid, iron(II), iron(III), aluminium(III), and lime for removal of the other metals present in low concentrations. Maree *et al.* (2013) demonstrated that the Sequencing Batch Reactor (SBR) is an improvement on the existing limestone neutralisation technology currently employed at several mines, especially when the focus is on Fe(II)-oxidation. (ii) Irrigation of crops with neutralized mine water where mine decant water offers a sustainable and cost-effective alternative to desalination as a long term solution.

The irrigation option is attractive as the relatively small volume of neutralized mine water (200ML/d), is kept away from the far larger volume of surface water which is used for domestic purposes (Rand Water produces 4 000 ML/d) and current irrigation in this region is roughly estimated at 10 000 ML/d).

Through irrigation, depending on prevailing weather conditions, cropping system selection and irrigation management, around 80 % of the mine water can be beneficially evaporated, resulting in precipitation in the soil, of 80 % of the gypsum in solution in the neutralised water. At an estimated average irrigation rate of 750 mm/year, an area of around 3.9 × 3.9 km will be needed for irrigation of 30 ML/d, and 10 × 10 km for 200 ML/d (areas will depend on cropping system selection). The potential for use of gypsiferous water for crop irrigation was first evaluated in South Africa by Du Plessis (1983). Jovanovic *et al.* (2002) investigated crop response to irrigation with gypsiferous mine water, as well as the impact on soil and groundwater resources over more than 10 years in commercial scale field trials set up at several collieries on the South African Highveld. Sugar-beans, maize, wheat, potatoes and pastures were irrigated on virgin and rehabilitated land. Good crop yields were obtained, and, based on borehole measurements, groundwater impact was limited. It was concluded that irrigation with gypsiferous mine water is feasible and worth considering as part of the solution to South Africa's AMD problems (Annandale *et al.* 2011). Irrigation provides some flexibility, and cropping systems and irrigation practices can be designed to optimise water use, area needed for irrigation, gypsum precipitation, profit, or job creation.

The concern that leachate will affect groundwater can be addressed by careful site selection for irrigated fields, and if necessary, the installation of a drainage system. The collected leachate is to be treated, where necessary, with RO/Freeze desalination to recover clean water and salt. Possible scaling of the pivot system will be avoided using methods such as $BaCO_3$ treatment, diluting the neutralized water with desalinated water from the freeze desalination stage, or with fresh water. The volume needed for dilution will not exceed 10 % as it is only to ensure that the water is below the saturation level of gypsum.

This process configuration offers the following benefits: (i) Low initial treatment cost of acid water, as neutralization will only cost 46 % of that of the current operation. (ii) Irrigation of mine water will result in job creation and the generation of agricultural products. The big benefit of irrigation is that it can handle large volumes of water, and if carefully designed and well managed, should be able to pay for itself. Even if irrigation is subsidized to a degree through the supply of irrigation and storage infrastructure, the supply of some farming equipment, and the pumping of water, this is likely to be a relatively small cost compared to other treatment options. (iii) No need to contaminate large volumes of clean water with neutralized, saline mine water. (iv) No waste sludge due to sludge processing into raw materials and valuable by-products. (v) Limited pollution of groundwater. In most applications the proposed irrigation will be applied in areas where groundwater is already polluted. The hydro-geological setting will determine the approach to be followed to intercept and manage the leachate from the irrigated fields (*e.g.* minimizing the leachate to treat through interception and evaportranspiration with trees, freeze desalination or controlled release).

Methods

The following approach was followed to determine the capital and running costs associated with neutralization, needed to protect the environment from acid mine water in the short term, and irrigation, which can avoid salinization of surface water in the long term: (i) Prepare a process configuration for each option, (ii) Determine the capital cost for each option, (iii) Determine the running costs associated with each option and (iv) Identify whether there are any shortcomings that need to be addressed prior to full-scale implementation.

Discussion

In this study a cost effective solution was proposed for the AMD problem in Gauteng, South

Africa. The solution is based on neutralization with limestone and lime for cost effective removal of acid and metals, followed by irrigation to prevent salinization of surface water with neutralized mine water.

Neutralization

The plant design for neutralization includes the following stages: SBR, Clarifier, Limestone Handling and dosing system and chemical storage facility. The SBR is equipped with a compressor and fine bubble diffuser for aeration and a draught tube to mix the slurry contained in the reactor. Mine water, sludge and limestone slurry is first pumped into the SBR to allow acid neutralization, iron(II)-oxidation and some gypsum crystallization. Upon completion of iron(II)-oxidation, lime is dosed to precipitate metals and to allow further gypsum crystallization. This approach affords a lower alkali cost as limestone ($CaCO_3$) is used for neutralization of free acid (H_2SO_4).With the aid of aeration, removal of iron(II) as iron(III), and aluminium(III), which form the main dissolved cations of Witwatersrand AMD. Lime is used only for removal of metals such as manganese and magnesium. Reaction rates are related to the concentrations of the various reactants; the higher the concentrations, the faster the reaction rates. Benefits of the SBR system are, direct control of effluent quality and partial desalination down to sulphate levels lower than 2000 mg/L, through gypsum crystallization.

Upon completion of the neutralization, and oxidation reactions and gypsum crystallization, the bath content of the SBR is drained into a clarifier. Limestone (precipitated calcium carbonate, or milled limestone, both with a moisture content of 25 %) is stored in a V-shaped storage and dosing facility. A water jet is used to slurry the limestone to a solids content of 20 %, and dosed into the reactor. Limestone is available from the paper industry (SAPPI) or an alternative source will be mined limestone that is milled on-site or at the mine in a wet mill. Wet milling offers the benefit that the raw material can be transported in tipper trucks and will not need to be stored in silos. The estimated capital cost of this SBR treatment system amounts to R3.5 million per ML/d treatment capacity.

Quality of treated water

Table 1 shows the chemical composition of the feed and treated water after the various stages. The TDS of the feed water decreases from 4232 to 3779 mg/L after neutralization. The gypsiferous water is thus suitable for irrigation. Irrigation in combination with freeze desalination offers the benefit that no saline rich, neutralized mine water is discharged into rivers In fact, there is a good chance that any seepage will be limited to already polluted areas to a limited extent, which may negate the need for the final desalination step. The TDS of the leachate from the irrigation is calculated to be 8 295 mg/L, based on the assumption that 80 % of the water is evaporated during utilization through irrigation. This and even higher concentrations can be treated effectively through freeze desalination, if required.

Chemical, energy and labour requirements

Table 1 shows that a dosage of 1570 mg/L $CaCO_3$ will be needed for removal of free acid, iron(II), iron(III) and aluminium, followed by a low dosage of 97 mg/L lime for removal of manganese and other metals. Manganese removal may not be required which will allow further savings. The neutralized water that is saturated with gypsum will not be discharged into rivers or streams. It will mostly be evaporated and beneficially utilized through irrigation. Leachate could be intercepted and treated with freeze desalination as a further option if deemed necessary. Table 1 also compares the alkali cost of the current treatment process with the proposed treatment. The current alkali cost, where limestone is used for neutralization of only the free acid, amounts to R2.42/m^3 (R26.4 million/year for 30 ML/d), compared to R1.27/m^3 (R13.9 million/year)

Parameter	Future						Current		
Chemical feed:	Western & Central	CaCO3	Lime	Irrigation leachate	Freeze de-salination	Freeze de-salination brine	Western & Central	CaCO3	Lime
Flow (ML/d)	30.0	30.00	30.00	6.00	5.70	0.30	30		
Flow (m³/h)	1 250	1 250.00	1 250.00	250		13	1 250	1 250.00	1 250.00
Dosage (100%) (mg/L)		1 570.00	96.20					853.80	626.19
Stock solution (%)		15.00	10.00					20.00	10.00
Chemical dosage (m³/h)		16.33	1.57					6.66	10.23
Purity (%)		89.00	85.00					89.00	85.00
Utilization (%)		90.00	90.00					90.00	90.00
Actual dosage (mg/L)		1 960	126					1 066	819
Usage (t/d)		58.8	3.8						
Price (R/t)		500	2 300					500	2 300
Cost (R/m³)		0.98	0.29			25.00		0.53	1.88
Cost (R/m³)			1.27			25.00			2.42
Cost (R/month)		894 273	263 921			228 125		486 323	1 717 933
Cost (R/month)			1 158 194			228 125			2 204 255
Cost (R/year)		10 731 273	3 167 055			2 737 500		5 835 871	20 615 192
Cost (R/year)			13 898 328			2 737 500			26 451 062
Evapration (%)				80.00					
Capital cost (R/(ML/d))			3 000 000		20 000 000				
Capital cost (R/ha)				55 000.00					
Capital cost (R)			90 000 000	80 300 000	120 000 000				
Total Capital Cost (R)					290 300 000				
Total Capital Cost (R/(ML/d))					9 676 667				
Irrigation (mm/year)				750.00					
Recovery (%)						95.00			
Area (km²)				14.60					
Area (ha)				1 460.00					
Cost ratio			0.53						1.00
Cost (R/year)									
Chemical usage (t/d)		58.80	3.77					31.98	24.56
Inventory (days)		20.00	7.95					20.00	1.22
Storage (t)		1 176.03	30.00					639.55	30.00
Sludge (mg/L)		1 593.84	260.00	9 900.00		114 815.0		144.44	1 709.40
Sludge (mg/L)			1 853.84	9 900.00		114 815.01			1 853.84
Sludge (t/day)			55.62	59.40		34.44			
CaSO4.2H2O in leachate (as Ca)				874.51					
Na2SO4 in leachate (as Na)				452.82					
MgSO4 in leachate (as Mg)				750.00					
NaCl in leachate (as Cl)				150.00					
Soluble salt (t/day):									
CaSO4 in leachate				17.84					
Na2SO4 in leachate				8.39					
MgSO4 in leachate				22.28					
NaCl in leachate				1.48					
Total				49.99					
pH	3	6.50	8.50	8.50			3	6.50	11.20
Total Acidity	1500	0.00	0.00	0.00	0.00		1500	716.20	0.00
Iron(II)	400	0.00	0.00	0.00	0.00		400	400.00	0.00
Iron(III)	0	0.00	0.00	0.00	0.00		0	0.00	0.00
Aluminium	50	0.00	0.00	0.00	0.00		50	0.00	0.00
Manganese	56	56.00	0.00	0.00	0.00		56	56.00	0.00
Magnesium	150	150.00	150.00	750.00	75.00	13 575.00	150	150.00	150.00
Sodium	110	110.00	110.00	550.00	55.00	9 955.00	110	110.00	110.00
Sulphate	3100	2 718.16	2 622.16	5 910.79	591.08	76 205.28	3100	3 100.00	2 622.16
Chloride	30	30.00	30.00	150.00	15.00	2 715.00	30	30.00	30.00
Alkalinity	0	70.00	100.00	100.00	10.00	100.00	0	70.00	100.00
Calcium	326	794.90	806.90	874.51	87.45	2 319.58	326	667.52	806.90
Free acid	506	0.00	0.00	0.00	0.00		506	0.00	0.00
TDS (mg/L)	4 232	3 901	3 779	8 295	830	104 830	4 232	4 556	3 779
TDS (t/day)			113	49.8	4.7				
TDS precipitated (t/day)				63.6					
Cations (+) (meq/L)	65.43	58.87	57.47	129.37	12.94	1 666.09	65.43	66.83	57.47
Anions (-) (meq/L)	65.43	58.87	57.47	129.37	12.94	1 666.09	65.43	66.83	57.47
Cations - Ca (+) (meq/L)	49.13	19.13	17.13	85.64	8.56	1 550.11	49.13	33.45	17.13
Gypsum ppt (mg/L SO4)				7 200.00					
Gypsum (t/d $CaSO_4$)				59.40					
Gypsum (t/a/ha SO_4)				10.80					
Gypsum (t/a/ha $CaSO_4$)				14.85					

Table 1 *Comparison of alkali cost and salt load to surface water between current and proposed treatment options*

Item	Value
Flow (ML/d)	30
Profit (R/ha)	5 000
Area (km^2)	14.6
Area (ha)	1 460
Profit (R/year)	7 300 000
Profit (R/(ML/d))	243 000

Table 2 *Estimated profit from irrigation*

when limestone is also used for removal of iron(II), the main dissolved component in acid mine water.

Profits to be generated from the farming activities will depend on the cropping system selected, market forces, and overheads allocated to the farming operation. Conservatively, depending on cropping system selected and market forces, a profit of around R5000/ha is quite feasible. Table 2 shows that a profit of R5000/ha amounts to an income of R7.3 million per year or R243000 per ML/d for a 30 ML/d treatment facility. The main benefit associated with irrigation, however, is that of job creation and the relative savings when compared to existing alternative desalination technologies. This makes this a viable option even if no direct farming profit is generated.

Waste products and re-use potential

The following waste products/re-usable products will be produced from 30 ML/d: (i) 55.6 t/d gypsum, $Fe(OH)_3$, $Al(OH)_3$, MnO_2 and other metal hydroxides will be produced in the neutralization stage. Initially this sludge will be stockpiled in an open pit, but later will be processed to recover metals, sulphur and $CaCO_3$. Pilot studies are at an advanced stage where gypsum is reduced to CaS at 1050 °C. The CaS is converted to sulphur and $CaCO_3$. South Africa imports 3 million t/year of sulphur at a price of R2000/t. $CaCO_3$ is used for neutralization of acid water and as filler in the paper and pharmaceutical industries. (ii) 59.4 t/d gypsum (14.85 t/ha per year $CaSO_4$) will be precipitated in the soil during irrigation. Much research has been carried out where it has been demonstrated that many crops can be produced successfully using gypsiferous water. (iii) 49.9 t/d salts will leach through the soil to already polluted groundwater, or be collected by means of a drainage system. The 49.9 t/d salts will be made up of 17.8 t/d $CaSO_4$, 8.4 t/d Na_2SO_4, 22.3 t/d $MgSO_4$ and 1.5 t/d NaCl. If the leachate is collected and processed during freeze desalination, separate recovery of the various compounds will be possible at a later stage.

Capital cost of a 30 ML/d treatment facility

The capital cost for neutralization and irrigation is estimated at R148 million (R4.9 million per ML/d) for a 30 ML/d plant (Table 3), calculated as follows: (i) R90 million for limestone/lime treatment (R3 million per ML/d) (ii) R36.5million for the centre pivots. The Fig. was calculated from: R25 000/ha; a flow of 30 ML/d; irrigation or 750 mm/year; requiring an area of 14.6 km^2 or about 1500 ha. (iii) R6.8 million (R0.23 million per ML/d) for storage of water for an estimated 10 day requirement, as it is not possible to irrigate responsibly at a constant rate (Table 4). (iv) R13.5 million for farming equipment and soil conservation works on newly developed irrigation fields. (v) R0.65 million for optimization studies – this will involve soil surveys to identify irrigable soil profiles, a geo-hydrological study to determine the fate of water and any solutes leaching from irrigated fields and to propose cost effective means of intercepting this water, dam design and placement, and the determination, through agricultural modelling, of ideal cropping systems and areas required to develop under irrigation to utilize the water available. (vi) If leachate is collected via a drainage system it can be treated with freeze desalination. The capital cost of such a system is estimated at R20 million per ML/d and the running cost at R30/m^3. Such a system will only be considered if it appears to be needed. (vii) R43.8 million for a leachate system (R1.5 million per ML/d). Depending on the outcome of a soil and geo-hydrological survey, a

Item	Cost
Flow (ML/d)	30
Neutralization (R)	90 000 000
Centre pivot (R)	36 500 000
Storage (R)	6 851 000
Tractors and equipment (R)	13 500 000
Security	150 000
Studies (R)	650 000
Total cost (R)	147 651 000
Total cost (R/(ML/d))	4 922 000

Table 3 *Capital cost for neutralization, irrigation and storage for 30 ML/d*

Parameter	Value
Flow (ML/d)	30
Storage period (days)	10
Free volume (%)	10
Volume (m3)	330 000
Excavation cost (R/m^3)	180
Soil to remove (m3)	15 000
Excavation cost (R)	2 777 000
Engineering cost (R)	2 777 000
Plastic area required (m^2)	10 000
Plastic liner price (R/m^2)	65
Plastic line cost (R)	648 000
Construction cost (R)	648 000
Storage pond cost (R)	6 851 000
Storage pond cost (R/(ML/d))	228 000

Table 4 *Cost of storage (design included) of 30ML/d for a period of 10 days*

drainage system can be installed at a cost of R30 000 to R60 000/ha, but initial indications are that this will not be necessary.

The R4.9 million per ML/d (Table 3) compares very favourably with alternative treatment options. The capital cost of neutralization combined with reverse osmosis at the eMalahleni Treatment Works amounts to R25 million per ML/d.

Due to the low concentrations of sodium and chloride in the water from the Western and Central Basins, it may not be justifiable to attempt to prevent soluble sodium and chloride from leaching back into the already polluted aquifers. This will only be a feasible option if irrigation fields are carefully sited so that leachate returns to the polluted source water. However, if leachate has to be intercepted and treated, this can and will be done with a RO/freeze desalination plant that will be designed and optimised for the volume of water that needs to be treated. This is likely to add R1.5 million per ML/d, assuming a fourfold concentration of the neutralized water through irrigation. This is still significantly more cost effective than the RO option on the whole volume of neutralised water.

Conclusions

Two conclusions can be drawn from this work: (i) Limestone (calcium carbonate) can be used for complete removal of iron(II) in an SBR system within 90 min reaction time. Subsequently, lime can be used for complete removal of metals. The alkali cost for treatment of AMD from the Western Basin would amount to R2.80/m^3 treated in the case of limestone/lime treatment, compared to R5.83/m^3 treated if lime is used for both stages. (ii) The estimated capital cost for the SBR process amounts to R3.5 million per ML/d.

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References

Annandale JG, Beletse YG, Stirzaker RJ, Bristow KL (2011) Managing poor quality coal-mine water: Is irrigation part of the solution? In: Observations on Environmental Change in South Africa, Larry Zietsman, (ed.) Sun Press, 174–177.

Aubé B (2004) The science of treating acid mine drainage and smelter effluents. www.infomine.com/publications/does/Aube.pdf. [Accessed: 16.03.2007].

Creamer T (2012) TCTA again warns of funding shortfall for acid water projects, Mining Weekly, 19 January 2012.

Du Plessis HM (1983) Using lime treated acid mine water for irrigation. Water Science & Techology 15, 145-154.

Expert Team, of the Inter-Ministerial Committee, under the Coordination of the Council for Geoscience (2010). Mine water management in the Witwatersrand Goldfields, with special emphasis on acid mine drainage. Report to the Inter-Ministerial Committee on Acid Mine Drainage, 21 October.

Jovanovic NZ, Annandale JG, Claassens AS, Lorentz SA, Tanner PD, Aken ME, Godgson FDI (2002) Commercial production of crops irrigated gypsiferous mine water, Water SA, 28(4), 413–421.

Maree JP, Louw WJ, Carlsson, FHH (2013) Neutralisation treatment of AMD at affordable cost, Water SA, 39(2), (in press).

Osuchowski R (1992) Advanced treatment of acid mine water, Technology SA, April, 9 – 11.

Van Niekerk A (2011) Personal communication, 5 July 2011, Dr André van Niekerk, Divisional Director – Water Engineering, Golder Associates Africa (Pty) Ltd, PO Box 13776, Hatfield, 0028, South Africa.

Note

As irrigation will take place over already polluted groundwater the cost of the liner could be avoided.

US$1 = R9.19 (18 April 2013)