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Technical Communication

Optimizing the Effluent Treatment at a Coal Mine by Process Modelling

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Abstract: The water network of a coal mine was audited and simulated by an interactive steady state model and the results were used to optimise the mine's water management strategy. Simulation of the interactions showed that calcium carbonate powder could be used as an alternative to lime for neutralization of acid water at a reagent cost saving of 56%. Gypsum crystallization would reduce sulphate concentrations in the neutralization plant by 30% and in the coal processing plant by 60%. The capital cost for a neutralization/gypsum crystallization plant for separate treatment of coal discard leachate and less polluted streams would cost 3.0 million Rand (R), compared to R10.3 million for combined treatment. Only slightly less (8.9 t/d vs. 9.5 t/d) sulphate removal would be achieved during separate treatment. The over-saturation index (OSI) value can be controlled effectively by removing sulphate from the feed water for coal processing. Sulphate has to be lowered to 350 mg/L in a flow of 222 m^3/h to obtain an OSI value less than 1. The capital cost of a 222 m^3/h biological sulphate removal plant was estimated at R21.8 million (R4.1 million/(ML/d)); the running cost was estimated at R13.7 million/a (R4.10/m^3). Pre-washing of the coal would reduce capital and running costs.

Key words: stream segregation; sulphate removal; water-network simulation

Background

Acid mine water has to be treated to make it suitable for industrial use or for discharge into public streams. Lime treatment is normally used for neutralization and metal removal. If required, desalination processes such as biological sulphate removal or membrane techniques may be used. The limestone neutralization and iron oxidation process (Maree et al. 2004a) was developed as an alternative to conventional lime treatment. This process reduces alkali cost by more than 50%. The first full-scale plant, with a capacity of 80 m^3/h, was constructed at BCL, Botswana (Maree 2004b). A second limestone neutralization plant was constructed at the Navigation Section of the Landau Colliery, Witbank, South Africa, by Anglo Coal. The latter mine was in the process of implementing a water management strategy. The objectives of the strategy included: providing water fit for coal beneficiation plant use with limited corrosion and scaling potential; mitigation of the environmental impacts associated with mine water discharges; closure of mine water circuits; and maximum re-use and utilisation of effluent streams.

Modelling is useful in selecting the most suitable water management strategy (van Tonder et al. 2000). The Toe Seep (coal discard leachate) neutralization project had been identified as the next component of the overall water management strategy to be constructed. A model was used to determine if the limestone neutralization process was appropriate for the Navigation site and to determine the:

- Degree of gypsum crystallization associated with the existing system in the primary neutralization and coal processing plants;
- The effect of gypsum crystallization on the gypsum saturation index after separate and joint treatment of Toe Seep water and less polluted streams;
- The effect of gypsum crystallization on the effluent from the coal processing plant when a side-stream of the flow from the thickener to the coal processing plant is treated;
- Additional sulphate removal required to ensure that the water in the coal processing plant is not over-saturated with respect to gypsum;
- Amount of sulphate that could be removed through pre-washing of the acid coal; and
- Capital and running costs associated with the various treatment options.

Model Description

A water flow and chemical mass balance model was developed that made provision for the following stages: the existing neutralization plant, a new gypsum crystallization plant located after the existing neutralization plant, a new Toe Seep plant, with or without gypsum crystallization, a biological sulphate removal plant, a coal processing plant, a sludge disposal pond, and a waste disposal area for fine coal and the coal discard. The various input parameters were the:

- Flow rates at the neutralization plant, discard leachate neutralization plant, sulphate removal plant, thickener underflow to discard dump, and penstock return water;
- Chemical composition of the feed waters to the neutralization plant, discard leachate, and penstock.
- Chemical composition of treated water from the sulphate removal plant;
- Percentage sulphate removal through gypsum crystallization in the stages where gypsum forms (the discard dump, the coal processing plant, and the crystallization treatment plants); and
- Alkali consumption (in the neutralization plant and in the coal processing plant).

The output parameters were: flow rate, chemical composition, gypsum saturation level of all other streams, and capital and running costs.

The model was based on the following principles:

- Electron neutrality: the molar equivalents of the cations (acidity, Fe (II), Fe (III), calcium, and magnesium) had to equal that of the anions (sulphate);
- Steady state equilibrium at each point; and
- OSI = $[SO_4]_{solution}/[SO_4]_{equilibrium}$

where: [ ] = concentration in mole equivalent/L, OSI represents the over-saturation index, and $[SO_4]_{equilibrium} = 1500/48 + [Mg^{2+}]$ (determined empirically).

Results

In addition to the existing situation, we investigated: separate and combined neutralization and gypsum crystallization of Toe Seep water and less polluted streams; gypsum crystallization of water from the coal processing plant; tertiary sulphate removal; and pre-washing.

Discussion

Limestone ($CaCO_3$) powder offers the following benefits over lime for neutralization of acid water:

- Reduced alkali cost: powdered $CaCO_3$ costs 150 South African Rand (R)/t (1 U.S.$ = R6.5, June, 2004) vs. R610/t for unslaked lime. This represents an alkali saving of 56% (Table 1).
- No silo is required for storage. Only a sloped concrete slab or hard surface is needed.
- Reduced use of lime slaker.
- $CaCO_3$ is safe to handle. It reacts only under acidic conditions.
- No dust, as the product contains 20% moisture.

The water is over-saturated with respect to gypsum after neutralization with lime, resulting in scaling of pipelines, screens, and other equipment (e.g. cyclones and spirals). The model indicated that 30% of the gypsum crystallization occurs in the primary neutralization plant and that 60% occurs in the coal processing plant (Table 2).

Table 3 shows the benefit of neutralizing discard leachate with an acidity of 11.5 g/l separately from the less polluted streams (acidity = 600 mg/L). The flow rate of the discard leachate is 40 m^3/h while that of the less polluted streams totals 120 m^3/h. During separate treatment, the capacity of the capital construction is much lower than during combined treatment (R3.0 million vs. R10.3 million). Only slightly less gypsum removal is achieved during separate treatment (8.9 t/d vs. 9.5 t/d).

The OSI value in the coal processing plant needs to be 1 or less to prevent gypsum scaling. This can be achieved in the following ways:

- The make-up water of the coal processing plant needs to be sufficiently undersaturated with respect to gypsum so that the OSI value is 1 or less after acid from the coal has leached into the water and is neutralized with lime or $CaCO_3$. This option will be discussed in the next section, using the biological sulphate removal process.
- Acid that leaches out in the coal processing plant can be neutralized with $Mg(OH)_2$ instead of lime.

Table 1. Cost comparison between $CaCO_3$ and lime for the Toe Seep Neutralization plant

Parameter	Alkali	
	$CaCO_3$	Unslaked lime
Flow rate (m^3/h)	40	40
Acidity (g/l)	10	10
Acid load (t/d $CaCO_3$)	9.6	9.6
Molecular mass	100	56
Utilization efficiency	80	70
Purity (%)	75	85
Consumption (t/d)	16.00	9.04
Delivered price (R/t)	150.00	610.00
Cost (R/year)	880,000	2,010,000
Saving (R/year)	1,130	0
Cost ratio	44	100

Table 2. Gypsum crystallization in the primary neutralization plant and in the coal processing plant

Parameter	Primary neutralization plant	Coal processing plant
Feed water (ML/d)	4.08	4.08
Feed SO_4 (mg/L)	2,400	2,224
Acid leachate from coal (t/d $CaCO_3$)		6
SO_4 from coal (mg/L)		1,471
SO_4 from feed water and coal		3,695
Equilibrium SO_4 (mg/L	1,812	1,935
Effluent SO_4 (mg/L)	2,224	2,640
SO_4 removal (%)	29.9	59.9

Table 3. Effect of separate and combined neutralization and gypsum crystallization on sulphate removal

Parameter		Separate Option	Combined Option
Flow (m^3/h)	Leachate discard	40	
	Make-up	120	
	Combined		160
SO_4 feed (mg/L)	Leachate discard	11,500	
	Make-up	2,531	
	Combined		4773
SO_4 treated (mg/L)		2,289	2086
OSI after neutralization and crystallization		1.16	1.05
Gypsum (t/d)		8.9	10
Capital cost (R)		3,000,000	9,800,000
Running cost (R/m^3)		1.08	1.08

Table 4. Effect of the capacity of a gypsum crystallization plant on the OSI value of the coal processing plant

Feed rate (m^3/h)	OSI
0	1.37
100	1.30
200	1.25

requires a separate stage where Mg^{2+} is precipitated with lime at pH 12, followed by gypsum crystallization. The $Mg(OH)_2$ could be recycled.

- The water in the coal processing plant can be treated for gypsum crystallization to a level near its saturation level. Table 4, however, shows that a large volume needs to be treated to make an impact. At a high flow rate of 200 m^3/h, the OSI is still 1.25, compared to 1.37 without treatment. The total flow of 1,250 m^3/h needs to be treated to prevent gypsum scaling, which would not be an affordable option.

Biological Treatment

From the previous section, it can be concluded that the most effective way to prevent gypsum scaling in the coal processing plant is to treat the feed water to below the saturation level of gypsum. We then had to determine what volume would have to be treated and what level of sulphate would need to be removed. Table 5 shows the effect of biological treatment on the OSI value in the coal processing plant. Lowering the sulphate concentration to 350 mg/L for a flow of 210 m^3/h would produce an OSI value of 0.98 (less than 1). A 222 m^3/h biological sulphate removal plant was estimated to cost R21.8 million (R4.1 million/(ML/d)); it was estimated that the operating cost would be R4.10/m^3.

Pre-Wash of ROM in Coal Processing Plant

Leachate studies showed that when run-of-mine coal is submerged in water, acid is washed off from the coal within 5 min. This option would require the following modifications to the Navigation operation:

- Install a pre-wash system for the coal. Neutralized water could be used as wash water. A counter flow wash system will have the benefit that minimum acid remains on the coal that enters the coal washing plant.
- Neutralize the acid water from the washing operation in the proposed Toe Seep Neutralization plant. Although the acid load from the coal would remain the same, this change would mean that less acid would have to be neutralized in the coal processing plant and hence, scaling in the coal processing plant can be reduced. The reduction in scale will be directly related to how much acid is redirected to the Toe Seep Neutralization plant. The aim should be to transfer 80% of the acid load currently neutralized in the coal processing plant to the Toe Seep Plant. The rest of the acid could be neutralized by dosing powdered $CaCO_3$ as a slurry at one or more places in the coal processing plant (similar to the current situation where lime is dosed).The effect of such a change in the operation of the coal washing plant can be determined from the current model. Table 6 shows the effect when the alkali consumption in the coal processing plant is reduced from the current 6 t/d (as $CaCO_3$) to 3 and 1 t/d, respectively. Implementing such

Table 5. Effect of separate neutralization and biological treatment on the OSI value in the coal processing plant

Parameter	Option 1	Option 2	Option 3
OSI in CPP feed	1.21	0.86	0.12
OSI in CPP	1.41	1.28	0.98
Sulphate removal (t/d SO_4)	22.4	24.4	28.8
Toe Seep neutralization/crystallization plant capacity (m^3/h)	40	40	40
Sulphate removal plant capacity (m^3/h)	50	105	222
Capital cost for biological plant (R)	4,920,000	10,332,000	21,844,800
Capital cost for biological plant (R/(Ml/d))	4,100,000	4,100,000	4,100,000
Running cost for biological plant (R/m^3)	3.53	3.79	4.10

Table 6. Effect of pre-coal washing on the OSI value in the coal processing plant

Parameter	Option 1	Option 2	Option 3
Alkali dosage to CPP (t/d $CaCO_3$)	6	3	1
OSI for the feed to the coal processing plant	0.16	0.58	0.86
OSI in the coal processing plant	1.00	1.00	1.00
Capacity of the sulphate removal plant (m^3/h)	215	150	105
Capital cost (R)	25,295,529	18,899,529	14,471,529
Running cost (R/a)	13,429,951	10,515,088	8,505,088

an operation would reduce the required capacity of a sulphate removal plant from 222 m^3/h when 6 t/d acid is neutralized in the coal processing plant to 150 m^3/h and 105 m^3/h for 3 and 1 t/d alkali respectively.

These capacities are based on a discharge of 40 m^3/h. If the alkali dosage is reduced from 6 to 1 t/d (as $CaCO_3$), the capital cost of the sulphate removal plant would be reduced from R25.3 million to R14.5 million and the running cost from R13.4 million/a to R8.5 million/a.

Conclusions

1. Calcium carbonate powder can be used instead of lime for neutralization of acid water, saving 56%.

2. Gypsum crystallization in the primary neutralization and coal processing plants can reduce sulfate concentrations 30% and 60%, respectively.

3. During separate treatment of coal discard leachate and the less polluted streams, the capital cost for a neutralization/gypsum crystallization plant amounts to R3.0 million, compared to R10.3 million during combined treatment. Only slightly less gypsum removal would be achieved during separate treatment, namely 8.9 vs. 9.5 t/d.

4. Gypsum crystallization from the water in the coal processing plant is an inefficient method for controlling the OSI value.

5. The OSI value can be controlled effectively at 1 by treating the feed water to the coal processing for sulphate removal. A flow of 222 m^3/h would need to be treated for removal of sulphate to 350 mg/L to obtain an OSI value of 0.98 (less than 1). The capital cost of a 222 m^3/h biological sulphate removal plant is estimated at R21.8 million (R4.1 million/(Ml/d)); the running cost is estimated at R4.10/m^3.

6. Pre-washing of the coal would reduce capital and running costs.

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