

# Neutralisation of acid leachate in a coal processing plant with calcium carbonate

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## ABSTRACT

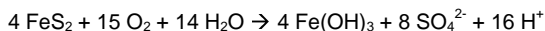
*A technology has been developed using calcium carbonate (limestone) instead of lime for neutralisation of acid mine water. A novel robust limestone handling and dosing system has been developed and implemented where waste CaCO<sub>3</sub> from the paper industry is slurried to a constant density. In this process, powdered CaCO<sub>3</sub> is used for pH adjustment to facilitate iron oxidation, metal precipitation (e.g. Fe<sup>3+</sup> and Al<sup>3+</sup>), and gypsum crystallisation in the same reactor. The novelty of this development lies in the fact that conditions were identified where ferrous iron can be oxidised at pH 5.5 by the addition of CaCO<sub>3</sub>. Previously, lime was used to raise the pH to 7.2, where the rate of iron oxidation is rapid. In addition, the limestone slurry can be used to neutralise acid leached from the unwashed coal in the coal processing plant. Lime was completely replaced by powdered calcium carbonate, reducing the alkali cost by 55% (R 4.5 million/annum). Mass balance modelling has optimised the treatment process.*

**KEY WORDS:** calcium carbonate, calcium hydroxide, calcium oxide, lime, unslaked, slaked, limestone, acid mine drainage, AMD, acid mine water, neutralisation, coal processing plant, model, iron oxidation, sulphate, treatment.

## BACKGROUND

Mining has been the single most important sector of the South African economy for many years. Acid mine drainage (AMD) is synonymous with pollution from coal mines. AMD may result from coal discard dumps, flooded underground workings and exposure of the coal in an opencast pit. AMD forms as a result of pyrite oxidation. The primary pollutants of AMD are acidity (H<sup>+</sup>), iron, sulphate, manganese, and sometimes aluminium. Of these, the most important pollutant is probably iron. The iron oxidizes and hydrolyses, producing ferric hydroxide and additional acidity, which in turn reduces the pH to levels sometimes below 3.

The following equation describes the overall formation of AMD:



One of the best forms of AMD mitigation is effective water management. Effective water management involves pollution prevention, effective clean and dirty water separation, maximum reuse and recycling of polluted water, and waste minimisation. If these options are maximised, there may not be a need for treatment or if treatment is still required, the volume required to be treated will be greatly reduced. Various methods of AMD treatment are employed in South Africa and around the world, including: calcium oxide (unslaked lime), calcium hydroxide (slaked lime), calcium carbonate (limestone), sodium hydroxide (caustic soda), sodium carbonate (soda ash), barium sulphide, barium hydroxide and barium carbonate neutralisation. Additional treatment can be provided using membrane technology, biological sulphate reduction, hydrothermal, electrochemical and ion exchange processes.

The most common of these is lime neutralisation, which can be accomplished conventionally, by using the recycled sludge process, or by using the high density sludge (HDS) process, which is generally regarded as superior (Pretorius, 1998). The HDS process was developed by the Bethlehem Steel Corporation (USA) at the end of the 1960's (Kostenbader & Haines, 1970) and has been employed in two neutralisation plants at the Navigation Plant and at the Kromdraai Opencast Mine of Landau Colliery.

#### **CONVENTIONAL LIME NEUTRALIZATION**

This process involves contacting AMD and lime while ensuring good mixing, good aeration, and removal of solids by separation. The main disadvantage of the process is that the solid precipitates settle slowly and generate a bulky sludge that is difficult to dispose of (Pretorius, 1998).

#### **RECYCLED SLUDGE PROCESS**

In this variation, part of the settled sludge is mixed with the fresh AMD prior to lime addition. It produces a much denser sludge due to the "seeding" effect of the precipitates in the recycled sludge. Bethlehem Steel Corporation (USA) developed this modification to the conventional process (Kostenbader and Haines, 1970).

#### **HIGH DENSITY SLUDGE (HDS) PROCESS**

The HDS process is very similar to the recycled sludge process but differs in that the lime is added to the recycled sludge before it is mixed with the AMD. This process was also developed by Bethlehem Steel. The HDS process can produce a more dense sludge than the recycled sludge process. Figure 1 depicts the configuration of the HDS process (Kertell et al., 1988).

The HDS process can neutralise AMD and facilitate oxidation reactions, such as ferrous to ferric hydroxide, manganese to manganese dioxide (pH > 9) or to manganese hydroxide (pH > 11), aluminium to aluminium hydroxide (pH 6.5) (van Tonder and Günther, 1998). The HDS process generates very little excess alkalinity (50 – 100 mg/l as CaCO<sub>3</sub>), even at high lime dosages (high pH).

When the pH exceeds 9, the characteristics of the sludge changes; a very gelatinous type of sludge forms that is difficult to settle, even with polymers. Part of the settled sludge is recycled and the sludge particles grow in size with age (Kostenbader and Haines, 1970). Generally, the larger the sludge particles, the better the settling but when the sludge particles become too large, they can hinder settling (Bosman, 1974).

It is critical that sufficient sludge recycle is maintained at all times, since it is vital for “seeding” in the sludge reaction or conditioning tank. Not only is the sludge a “seeding” agent but the sludge also contains a certain amount of unreacted lime (20 – 40%), which reduces the lime consumption (Maree, (1997).

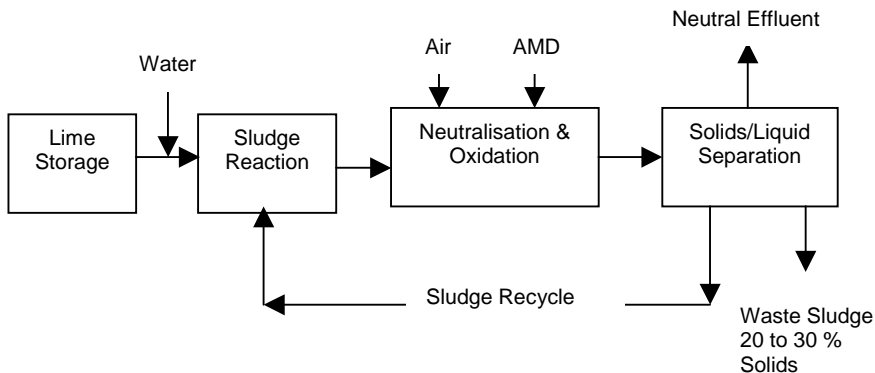


Figure 1. Process configuration of the High Density Sludge process

Control of a HDS process is only possible with full automation. This is done by controlling the lime dosage accurately as a function of the pH in the neutralisation / oxidation tank or aeration tank. Accurate control of the HDS process in this manner ensures effective neutralisation (> 95%) and iron oxidation (> 95%), and low turbidity.

### LIMESTONE PROCESS DEVELOPED BY THE CSIR / ANGLO COAL

A process has been developed by the CSIR and implemented by Anglo Coal that avoids the high cost of lime by using limestone in the HDS process. Limestone was previously deemed to be an ineffective alkali source in such processes due to the limited solubility of the calcite and the iron oxy-hydroxide coatings that eventually encapsulate the rock limestone particles, therefore rendering the limestone inert (Renton and Brown III, 1995). This was mainly for coarse limestone particles, i.e. grain size 2 - 6 mm. The CSIR process uses powdered limestone (a by-product of the paper industry), which is highly reactive and can be used effectively in the HDS process.

### LIMESTONE HANDLING AND DOSING SYSTEM

Two full-scale limestone make-up and dosing plants have been installed at Landau Colliery. The original was installed at the Navigation Plant (supplies up to 50 tons/day) and the second at the Kromdraai Opencast mine (supplies up to 30 tons/day). Modifications / upgrades were made based on operational experience to improve the efficiency of the system and to ensure that additional lime is not required.

The Navigation Plant limestone system consists of the following:

- inclined concrete slab
- slurry tank
- recycle pump
- spray nozzles
- load cell density control system
- transfer pumps

## CONTROL PHILOSOPHY

The control philosophy was based on the original Navigation Plant limestone make-up and dosing system. Limestone is dumped onto the inclined concrete slab and slurried (5 – 15% solids) with a water jet. The direction of the water is controlled by the density of the slurry, which is monitored continuously with an on-line density meter. When the slurry density is below a set value, the water jet sprays directly onto the CaCO<sub>3</sub>-dump. When the slurry density is at the set value, the water jet sprays on lower end of the slab where the slurry gravitates into the CaCO<sub>3</sub>-slurry make-up tank.

The level in the CaCO<sub>3</sub>-slurry make-up tank is controlled by an automatic valve linked via a level control. The recycle stream between the slurry make-up tank and the slab is passed through a stone trap for removal of stones and grit in the powdered CaCO<sub>3</sub>.

Transfer pumps transfer the limestone slurry from the make-up tank to the various points of application.

The original density control system consisted of load cells that were positioned beneath the slurry tank and control valves in the recycle line. When the density of the slurry was too low, slurry was passed via the CaCO<sub>3</sub> slab to the slurry tank, thereby slurrying more limestone into the make-up tank. When the density was correct, recycled slurry was returned directly to the make-up tank. Two pneumatic control valves allowed the slurry to flow either to the CaCO<sub>3</sub> dump, via a series of fixed nozzles in the slurry line on the walls of the slab, to the slurry tank (when the slurry density was too low), or directly to the slurry tank (when the density was at the required density).

In addition to the load cells, an ultrasonic level controller on the make-up tank regulated the neutralised water input by maintaining a constant level in the make-up tank. This system was found not to be effective for maintaining a constant limestone slurry density due to changes in the water level in the tank and the high turbulence of the slurry as a result of the agitator. Based on the initial full-scale performance trials, modifications / upgrades were made to enable the plant to support a CaCO<sub>3</sub> through-put of 20 t/d and higher:

## DENSITY METER

The original density meter was replaced with a new density meter, which uses a smaller load cell and a pipe and only takes a side stream off the recycle line to measure and control the density (i.e. an in-line density meter). Linked to the density meter is a pneumatic-controlled spray system, which allows the nozzles to spray onto the limestone dump when required.

The load cell system has the following features:

- Digital output that gives the mass of the density cell. The mass can be zeroed e.g. when the density cell is filled with neutralised liming plant water.
- It is programmed to activate/stop a control unit at set high and low values.

## GRIT / STONE REMOVAL

Foreign material is sometimes mixed in the fine limestone, which results in blockages of the suction line to pumps and the spray nozzles. To alleviate this, the slurry was directed from the slab into the feed sump of the recycle pump, which is inside the slurry tank, via basket sieves that trap large stones. The mesh size of the basket sieves has been selected so that it needs to be cleaned only once a shift. A cyclone stone trap was also installed to remove smaller particles.

## SPRAY SYSTEM

Initially, fixed nozzles connected to slurry lines positioned on the side walls of the slab were used but this required the movement of the limestone on the slab via a front end loader or the opening and closing of the desired valves on the spray system.

Instead, swivel nozzles were positioned on the side walls of the slab. The swivel nozzles are connected via a manual controlled valve and a flexible pipe to the outlets on the slurry line on the walls of the slab. A pneumatic cylinder controls the direction of the water jets. When the density meters signals that the density is high enough, the cylinder directs the water jet onto the clean section of the slab to wash all remaining limestone from the slab into the slurry tank. When the density meter signals that the density of the  $\text{CaCO}_3$  is too low, the cylinder moves continuously to spray a water jet over a 1 to 2 m section of the dump.

## KROMDRAAI LIMESTONE PLANT

Based on the success of the limestone handling and dosing plant installed at Navigation, which resulted in the complete replacement of lime with limestone, it was decided to replace the lime at the Kromdraai Liming plant with limestone. The design of the Kromdraai plant took into account the design flaws at Navigation. The main differences were:

- A larger and wider slab
- High pressure jets instead of small spray nozzles
- Separate tanks for slurry make-up and storage / dosing

The basic make-up of slurry is the same as the modified Navigation Limestone Plant. However, three high pressure jets are used to slurry the limestone into the make-up tank instead of the fine spray nozzles. This prevents the fine mist that occurs at the Navigation Limestone Plant and no blockages occur. The larger slab allows for a bigger inventory of limestone on the slab than at the Navigation Limestone Plant.

$\text{CaCO}_3$ -slurry is transferred directly from the recycle line between the slab and the  $\text{CaCO}_3$ -slurry make-up tank to the  $\text{CaCO}_3$ -slurry storage tank. The level in the storage tank is controlled at a constant level with a float valve. The high pressure of 3 bar in the recycle line is sufficient to lift the slurry to the higher level of the storage tank. By having two tanks, one for make-up and one for storage / dosing allows for a more consistent limestone slurry density.

Limestone is removed completely from the slab using only a water jet. No front-end loader is required to remove waste from the slab.

## ANALYTICAL MATERIALS AND METHODS

The feed water, conditioning tank, aeration tank, and turbocirculator are sampled every shift (8 hours) to ensure that optimum iron oxidation and neutralisation is occurring. Each sample is monitored for pH (electrode), electrical conductivity (electrode), acidity as mg/l  $\text{CaCO}_3$  (titration), ferrous iron as mg/l Fe(II) (titration), and alkalinity as mg/l  $\text{CaCO}_3$  (titration) at each sampling point to ensure that a consistent limestone slurry density is achieved. The slurry density is checked manually each shift and compared with the density meter to determine whether calibration is required.

## DISCUSSION

Limestone was initially dosed to the liming plant at the Navigation Plant to replace lime in June 2001. Based on this success, lime was gradually replaced in the coal processing plant from June 2002. Finally, limestone was dosed at the Kromdraai Liming plant to replace lime completely from January 2003. In the following sections, a comparison between lime and limestone will be made in terms of tons/day alkali consumed, tons/day of alkali wasted, and

the costs thereof. The performance of the various plant applications will be evaluated based on the use of limestone versus lime.

### NAVIGATION LIMING PLANT

The main purpose of the Navigation Liming Plant is to provide the coal processing plant with neutralised make-up water. The acid water fed to the liming plant, at a flowrate of ~ 5 Ml/day, had a pH of ~ 3.0, a ferrous iron concentration of ~ 50 mg/L as  $Fe^{2+}$  and an acidity of ~ 380 mg/L as  $CaCO_3$ . This equates to an average acid load of ~ 1.9 tons / day as  $CaCO_3$ . Over the 12 month trial period, an average of 2.2 tons/day of limestone was dosed, resulting in an over-dosage of 0.3 tons/day. Figure 2 shows the acid load in the feed water versus the amount of limestone and lime added.

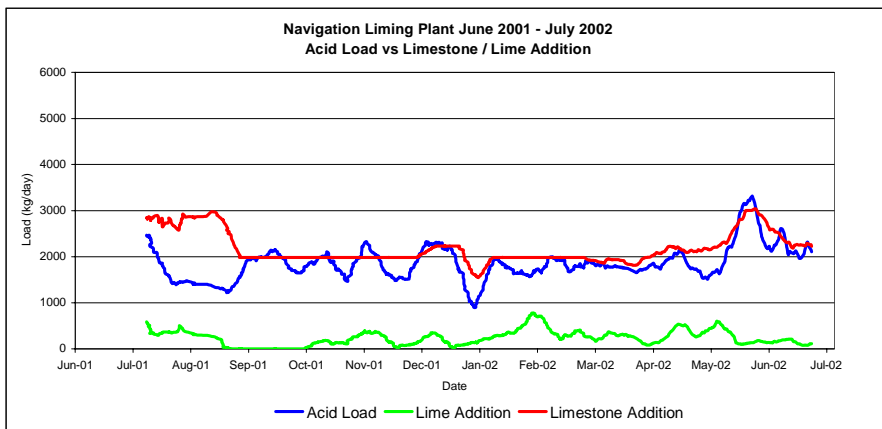


Figure 2. Navigation Liming Plant - Acid Load vs Limestone Addition

Figure 2 indicates that at the Navigation Plant, lime was still used for final polishing and for any upsets in the limestone make-up and dosing system. However, from this work it was realised that lime could be replaced completely since the lime addition merely neutralised the unliberated carbon dioxide in the water from the reaction between the limestone and acid water. Figure 3 shows the neutralisation efficiency of limestone versus lime over the same period in the Navigation Liming Plant. It should be noted that when dosing lime, the dosing rate is controlled by pH and acid load. However, when dosing limestone, the pH can only be theoretically raised to maximum of 8.3. In practice, when using powdered limestone, the maximum pH is ~ 7 – 8, due to dissolved carbon dioxide given off by the dissolution of the  $CaCO_3$ . Therefore, the amount of limestone used is controlled by the acid load.

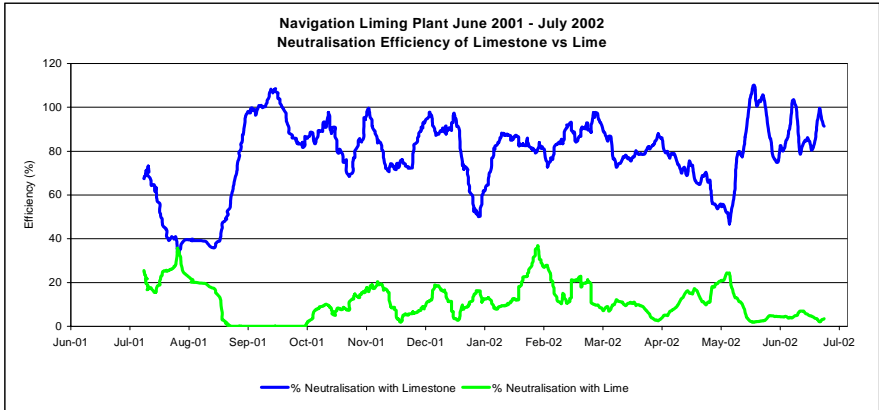


Figure 3. Navigation Liming Plant – Neutralisation Efficiency of Limestone vs Lime

### NAVIGATION COAL PROCESSING PLANT

Since the coal processing plant does not have a single point of acid water addition (due to the acid leachate generated from the raw coal, etc.), a different monitoring approach was required. The basic approach was to monitor both the pH and acidity exiting the coal processing plant. The overall control was based on the alkalinity residual in the underflow of the thickeners. This ensured that both the water entering the thickeners and the clarified water overflow exiting the thickeners was neutral.

Figures 4, 5, and 6 represent the lime consumption, limestone consumption, and tons of wasted alkali per month, respectively. As the limestone addition was gradually increased (due to improved performance from the limestone make-up and dosing system), the lime addition was reduced. The increase in wasted alkali per month is results from the lime addition competing with the limestone and the target of ~ 100 mg/l alkalinity as CaCO<sub>3</sub> in the underflow of the coal processing plant thickeners (to buffer return water from the co-disposal facility).

### KROMDRAAI LIMING PLANT

With the experience gained from the Navigation Plant, the Kromdraai Liming Plant was designed, built, commissioned and started operation after 4 months. At start up, the lime system was completely switched off and limestone has been used ever since.

### COST COMPARISON

Unslaked lime was purchased for the Navigation Liming Plant and slaked into slaked lime, while the Kromdraai Liming Plant used slaked lime. The main driving force for replacing lime with limestone was cost. Unslaked lime costs ~ R 670/ton, slaked lime costs ~ R 750/ton and powdered limestone costs ~ R 150/ton. When comparing the alkali sources on an equivalent CaCO<sub>3</sub> basis, the theoretical cost reduction is > 50%. With the extensive testing done by the CSIR at Landau Colliery since 1996 on limestone neutralisation, it was decided to convert to limestone.

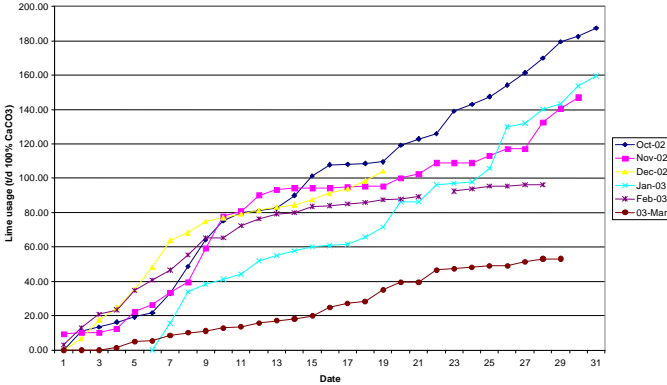


Figure 4. Navigation Coal Processing Plant – Lime addition

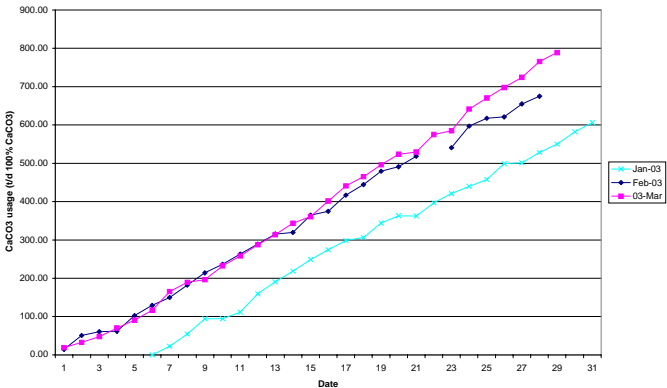


Figure 5. Navigation Coal Processing Plant – Limestone addition



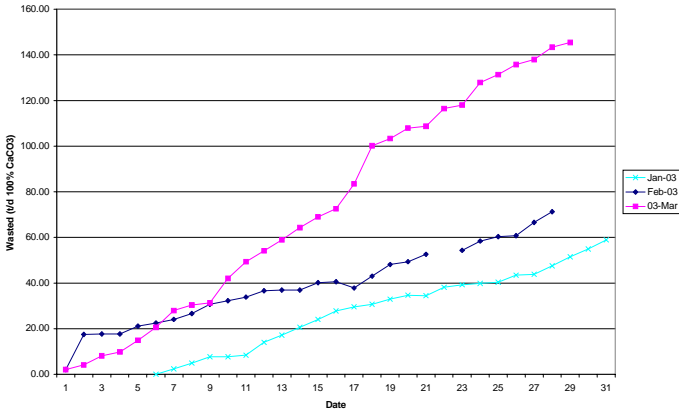


Figure 6. Navigation Coal Processing Plant – Alkali Wasted

The budget for 2003 will realise a savings from using lime to only using limestone of R 4.5 million/annum or a 55% cost reduction.

**PERFORMANCE OF THE LIMING PLANTS USING LIMESTONE**

The performance of the plants using limestone was based on the resultant pH achieved and the acidity and iron (II) removed.

Figures 7, 8, and 9 depict the pH, acidity, and iron (II) in the Navigation Plant from June 2001 to March 2003. The pH at the Navigation Plant was raised from an average of 3.0 to 6.8; the acidity was reduced by 95.9% from an average of 466 to 19 mg/l as CaCO<sub>3</sub>; and iron (II) was reduced by 86.2% from an average of 90 to 12 mg/l as Fe<sup>2+</sup>. Lime addition was stopped at the end of July 2002 and this is seen in the final pH averaging 6.5. Iron (II) and acidity removal rates did not change.

The pH exiting the coal processing plant into the thickeners averaged 6.1, while the iron (II) was restricted to ~ 35 mg/l as Fe<sup>2+</sup>. However, the alkalinity was maintained at an average of 84 mg/l (target 100 mg/l) exiting the thickeners, indicating that the water was well neutralised and buffered.

The pH exiting the Kromdraai Plant from January 2003 averaged 6.2 and the iron (II) and acidity were reduced in the same proportions as occurred at the Navigation Plant.

**MODELLING OF THE NAVIGATION PLANT WATER RETICULATION SYSTEM**

Modelling is a useful tool to select the most suitable water management strategy (van Tonder et al., 2000). Limestone neutralisation is a proven process for neutralisation of the acid mine waters at the Navigation Plant. However, this still leaves the coal processing plant in a neutralised but gypsum scaling environment due to the high sulphate concentrations of ~ 2500 mg/l to 11500 mg/l. The water management strategy includes the neutralisation and treatment for sulphate removal of certain selected mine water streams.

The objectives of the water management strategy include:

- Providing water that is fit for coal processing plant use with a limited corrosion and scaling potential.
- Mitigation of the environmental impacts associated with mine water discharges.
- Closure of mine water circuits
- Maximum re-use and utilisation of effluent streams.

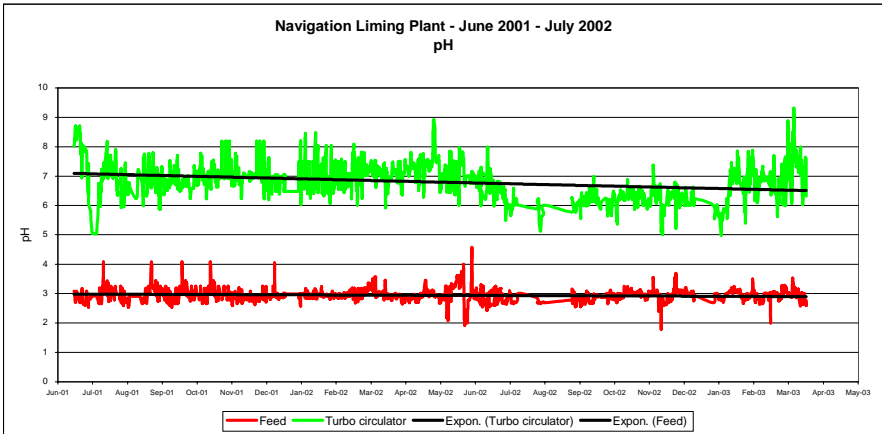


Figure 7. Navigation Liming Plant Performance – pH

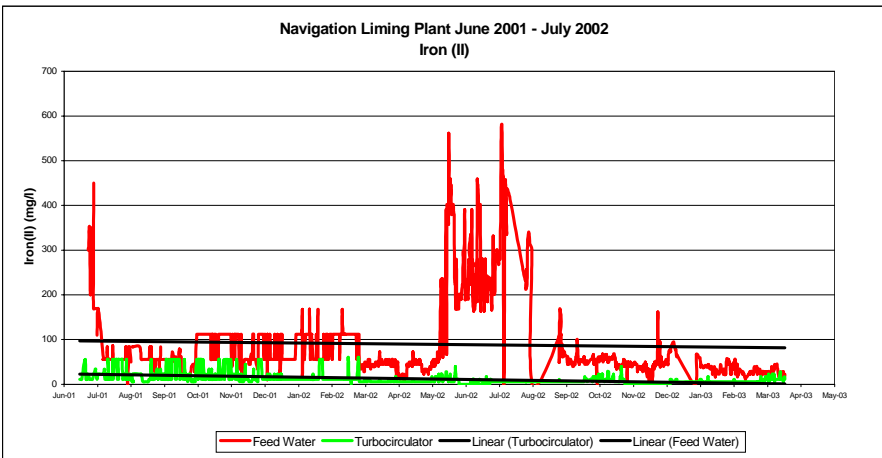


Figure 8. Navigation Liming Plant Performance – Iron (II)

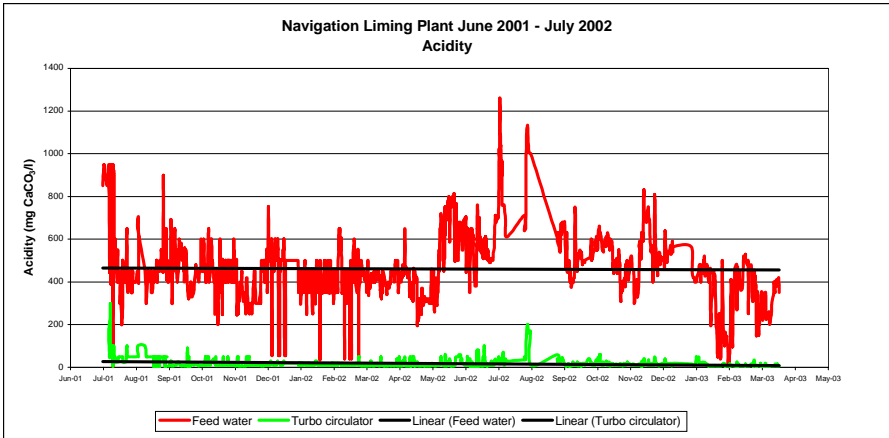


Figure 9. Navigation Liming Plant Performance – Acidity

The toe seep (coal discard leachate, acidity ~ 12000 mg/l as CaCO<sub>3</sub>, and sulphates ~ 11500 mg/l) neutralization project has been identified as the next component of the overall water management strategy to be constructed. Modelling was undertaken to determine the following:

- The degree of gypsum crystallization that occurs with the existing system in the navigation liming plant and in the coal processing plant.
- The effect of gypsum crystallisation on the gypsum saturation index after separate and joint treatment of toe seep water and less polluted streams (treated in the current navigation liming plant).
- The effect of gypsum crystallisation 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.
- Capital and running cost associated with various treatment options.

A water flow and chemical mass balance model was developed that made provision for the following stages of the water network:

- The existing Navigation Liming Plant
- New gypsum crystallization plant after existing Navigation Liming Plant
- New Toe Seep plant which includes or excludes gypsum crystallization
- Biological sulphate removal plant
- Coal processing plant
- Sludge disposal pond
- Waste disposal area for fine coal and coal discard.

Various input parameters:

- 5 flow rates (liming plant, toe seep (discard leachate neutralisation) plant, sulphate removal plant, thickener underflow to discard dump and penstock return water),
- Chemical composition of 3 feed waters (feed to the liming plant, toe seep plant and penstock)
- Chemical composition of treated water from the sulphate removal plant.

- Percentage sulphate removal through gypsum crystallisation in the stages where gypsum crystallisation occurs (discard dump and the coal processing plant and crystallisation treatment plants).
- Alkali consumption (in the liming plant and in the coal processing plant).

Various output parameters: flow rate, chemical composition and gypsum saturation level of all other streams, as well as, estimated capital and operating costs.

The model is based on the following principles:

- Steady state equilibrium at each point;
- Electron neutrality [the mole equivalents of the cations (acidity, iron(II), iron(III), calcium and magnesium) is equal to that of the anions (sulphate)];
- Over-saturation index (OSI) =  $[\text{SO}_4]_{\text{solution}}/[\text{SO}_4]_{\text{equilibrium}}$   
where:  $[\text{SO}_4]_{\text{equilibrium}} = 1500/48 + [\text{Mg}^{2+}]$  (determined empirically) and [ ] = concentrations in mole equivalent per litre

Figure 10 shows the process flow diagram of the various treatment options listed above with the main input and output values. The following treatment options were evaluated:

1. The current situation
2. Joint treatment (neutralisation and gypsum crystallisation) of Toe Seep water and less polluted streams
3. Separate treatment (neutralisation and gypsum crystallisation) of Toe Seep water and less polluted streams
4. Gypsum crystallisation of water from the coal processing plant
5. Tertiary sulphate removal
6. Pre-washing

#### **GYPNUM CRYSTALLISATION UNDER CURRENT CONDITIONS:**

The water is oversaturated with respect to gypsum after neutralisation with lime in the liming and coal processing plants. This results in scaling of pipelines, screens and other equipment (e.g. cyclones and spirals). The model can be used to calculate the percentage of gypsum crystallisation in the various stages. Table 1 shows that 30% of the gypsum crystallisation occurred in the primary neutralisation plant and 60% took place in the coal processing plant.

#### **SEPARATE VERSUS COMBINED TREATMENT OF STRONG AND WEAK ACIDIC STREAMS:**

Table 2 shows the benefit when the Toe Seep water with an acidity of 11.5 g/L is neutralised separately from the less polluted streams with an acidity of ~ 600 mg/l. The flow rate of the Toe Seep water is 40 m<sup>3</sup>/h while that of the less polluted streams total 120 m<sup>3</sup>/h. During separate treatment, the cost of the capital construction is much lower than during combined treatment, namely R3.0 million vs R10.3 million, and only slightly less gypsum removal is achieved, namely 8.9 t/d versus 9.5 t/d.

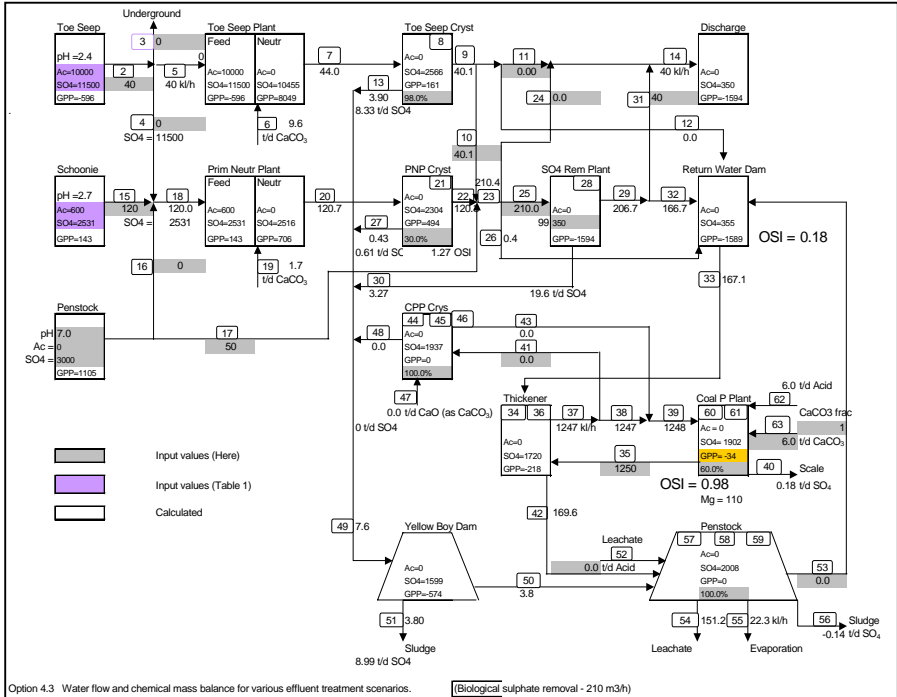


Figure 10. Example of Model for treatment of Navigation Plant water

Table 1. Gypsum crystallisation in the liming and coal processing plants.

| Parameter  | Liming Plant | Coal Plant |
|--|--------------|------------|
| Feed water (ML/d)                                | 4.08         | 4.08       |
| Feed sulphate (mg/L SO <sub>4</sub> )            | 2 400        | 2 224      |
| Acid leachate from coal (t/d CaCO <sub>3</sub> ) |              | 6          |
| Sulphate from coal (mg/L SO <sub>4</sub> )       |              | 1 471      |
| Sulphate from feed water and coal                |              | 3 695      |
| Equilibrium sulphate (mg/L SO <sub>4</sub> )     | 1 812        | 1 935      |
| Effluent sulphate (mg/L SO <sub>4</sub> )        | 2 224        | 2 640      |
| Sulphate removal (%)                             | 29.9         | 59.9       |

Table 2. Effect of separate and combined treatment (neutralisation and crystallisation).

| Parameter                                 | Separate Treatment | Combined Treatment |
|---|--------------------|--------------------|
| Flow: Toe Seep plant (m <sup>3</sup> /hr) | 40                 |                    |
| Liming plant                              | 120                |                    |
| Combined                                  |                    | 160                |
| SO <sub>4</sub> Feed : Toe Seep (mg/L)    | 11500              |                    |
| Liming                                    | 2531               |                    |
| Combined                                  |                    | 4773               |
| SO <sub>4</sub> Treated (mg/L)            | 2289               | 2086               |
| OSI                                       | 1.16               | 1.05               |
| Gypsum (t/d)                              | 8.9                | 10                 |
| Capital Cost (Rands)                      | 3 000 000          | 9 800 000          |
| Operating Cost (R/m <sup>3</sup> )        | 1.08               | 1.08               |

### GYPSUM CRYSTALLISATION IN THE COAL PROCESSING PLANT:

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

1. The make-up water of the coal processing plant need to be sufficiently under-saturated with respect to gypsum. This option will be discussed in the next section, using the biological sulphate removal process.
2. Acid that leaches out in the coal processing plant can be neutralised with Mg(OH)<sub>2</sub> instead of lime. MgSO<sub>4</sub>, which is formed when Mg(OH)<sub>2</sub> is used for neutralisation, is highly soluble and does not form scale as gypsum does after neutralisation with lime or CaCO<sub>3</sub>. A disadvantage of this approach is that it requires a separate stage where Mg<sup>2+</sup> is precipitated with lime at pH 12, followed by gypsum crystallisation. The Mg(OH)<sub>2</sub> could be recycled.
3. The water in the coal processing plant can be treated for gypsum crystallisation to a level near its saturation level. Table 3, however, shows that a large volume needs to be treated for gypsum crystallisation to make an impact. At a high flow rate of 200 m<sup>3</sup>/h, the OSI is still 1.25, compared to 1.37 when zero treatment is applied. The total flow of 1 250 m<sup>3</sup>/h would need to be treated to prevent gypsum scaling, which would not be affordable.

Table 3. Effect of the capacity of a gypsum crystallisation plant on the OSI value of the coal processing plant.

| Feed rate (m <sup>3</sup> /h) | OSI  |
|-------------------------------|------|
| 0                             | 1.37 |
| 100                           | 1.30 |
| 200                           | 1.25 |

4. Biological treatment--from the previous section, it would appear 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. The purpose of this section is to determine what volume would need to be treated and what level of sulphate would need to be removed. Table 4 shows the effect of biological treatment on the OSI value in the coal processing plant. A flow of 210 m<sup>3</sup>/h needs to be treated for removal of sulphate to 350 mg/l to

obtain an OSI value of 0.98 (less than 1) (Figure 1 and Appendix A). The capital cost of a 222 m<sup>3</sup>/h biological sulphate removal plant is estimated at R21.8 million (R4.1 million/(ML/d)) and the running cost is estimated at R4.10/m<sup>3</sup>.

Table 4. Effect of 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 <sub>4</sub> ) | 22.4     | 24.4     | 28.8     |
| Plant capacity (m <sup>3</sup> /h)      |          |          |          |
| Toe Seep                                | 40       | 40       | 40       |
| Sulphate removal                        | 50       | 105      | 222      |

- Pre-wash of ROM in coal processing plant--leachate studies showed that when ROM coal is submerged in water, acid is washed off from the coal within 5 minutes. This option would require the following modifications to the current operation at Navigation:

Install a pre-wash system for the coal. Neutralised 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.

Neutralise the acid water resulting from the washing operation in the proposed Toe Seep Neutralisation plant. Although the acid load from the ROM coal will remain the same, this change will offer the benefit that less acid needs to be neutralised in the coal processing plant and hence, scaling in the coal processing plant will be reduced. The reduction in scale will be directly related to how much acid is redirected to the Toe Seep Neutralisation plant. The aim should be to transfer 80% of the acid load currently neutralised in the coal processing plant to the Toe Seep Plant. The remaining 20% of the acid could be neutralised by dosing powdered CaCO<sub>3</sub>-slurry at one or more places in the coal processing plant (similar to the current situation where lime is dosed).

This effect of such a change in the operation of the coal washing plant was determined from the model. Table 5 shows the effect when the alkali consumption in the coal processing plant is reduced from the current 6 t/d (as CaCO<sub>3</sub>) to 3 and 1 t/d respectively. Implementation of such a washing operation would reduce the required capacity of a sulphate removal plant from 222 m<sup>3</sup>/h for when 6 t/d acid is neutralised in the coal processing plant to 150 m<sup>3</sup>/h and 105 m<sup>3</sup>/h for 3 and 1 t/d acid respectively. These capacities include the volume of 40 m<sup>3</sup>/h to be discharged. If the alkali dosage is reduced from 6 to 1 t/d (as CaCO<sub>3</sub>), the capital cost will be reduced from R25.3 million to R14.5 million and the running cost from R13.4 million/a to R8.5 million/a.

Table 5. Effect of pre-washing coal on the OSI in the coal processing plant.

| Parameter  | Alkali Dosage to CPP (t/d) |      |      |
|--|----------------------------|------|------|
|  | 6                          | 3    | 1    |
| OSI  |                            |      |      |
| Feed to CPP  | 0.16                       | 0.58 | 0.86 |
| In CPP   | 1.00                       | 1.00 | 1.00 |
| SO <sub>4</sub> removal plant (m <sup>3</sup> /hr) | 215                        | 150  | 105  |

## CONCLUSIONS

1. Powder calcium carbonate can be used as an alternative to lime for neutralisation of acid water.
2. Iron (II) is oxidised by 86% and acidity is reduced by 96% by using limestone instead of lime.
3. Annual alkali cost have been reduced from by 55% or R 4.5 million by using limestone instead of lime.
4. Modifications to the Limestone Make-up and Dosing plant design have improved the operability of the plant.
5. Gypsum crystallisation in the liming and coal processing plants amount to 30% and 60% respectively.
6. During separate treatment of Toe Seep (coal discard leachate) water and the Liming plant, the capital cost for a neutralisation/gypsum crystallisation plant amounts to R3.0 million, compared to R10.3 million during combined treatment. Only slightly less gypsum removal is achieved during separate treatment, 8.9 t/d versus 9.5 t/d.
7. Gypsum crystallisation from the water in the coal processing plant is an inefficient method for controlling the OSI value.
8. 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<sup>3</sup>/h needs to be treated for removal of sulphate to 350 mg/L to obtain an OSI value of 0.98 (less than 1). The capital of a 222 m<sup>3</sup>/h biological sulphate removal plant is estimated at R21.8 million (R4.1 million / (M/d)) and the running cost at R4.10/m<sup>3</sup>.
9. Pre-washing of the coal will result in reduced capital and running costs.

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