Treatment of acid mine drainage water at the Blaauwkraanz South discard facility

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Abstract. The Blaauwkraanz Mineral Residue Facility (MRF) is a coal discards facility designed to accommodate coarse and fine coal discards from the Navigation Coal Processing Plant in South Africa. The Southern extension of the MRF was operated from 1992 and decommissioned in 2012 due to less-than-acceptable safety factors. The MRF was designed with a concrete penstock to decant supernatant water from the slurry pool. The penstock was also decommissioned. The supernatant water in the dormant slurry compartment became impacted by the coarse discards and became highly acidic and concentrated with heavy minerals, making it unsustainable for the site to treat within the available water treatment plants. The water was then managed through pumping from the seepage collection compartments to the top of the slurry compartment and allowed to seep through the MRF. This created a heap leach effect that further concentrated the salts and heavy metals in the water. An engineering capability study and test work was conducted on-site to evaluate the treatment capabilities and potential management options for the toe-seepage. Through this study, the site was able to optimise the operation of the existing water treatment plants to cumulatively treat more than 100 ML of the highly acidic water.

1 Introduction

The Blaauwkraanz Mineral Residue Facility (MRF) is a coal discards facility designed to accommodate both coarse coal discards and fine coal discards from the Navigation Coal Processing Plant at Khwezela Colliery North, which is owned by Thungela Operations (Pty) Ltd. Khwezela Colliery North operates the Blaauwkraanz MRF, which is situated on its mining and coal processing site. Blaauwkraanz MRF is located about 15 km southwest of the eMalahleni Local Municipality of the Nkangala District Municipality of Mpumalanga province, South Africa. Fig. 1 shows the historical development of the Blaauwkraanz MRF over the past 30 years.

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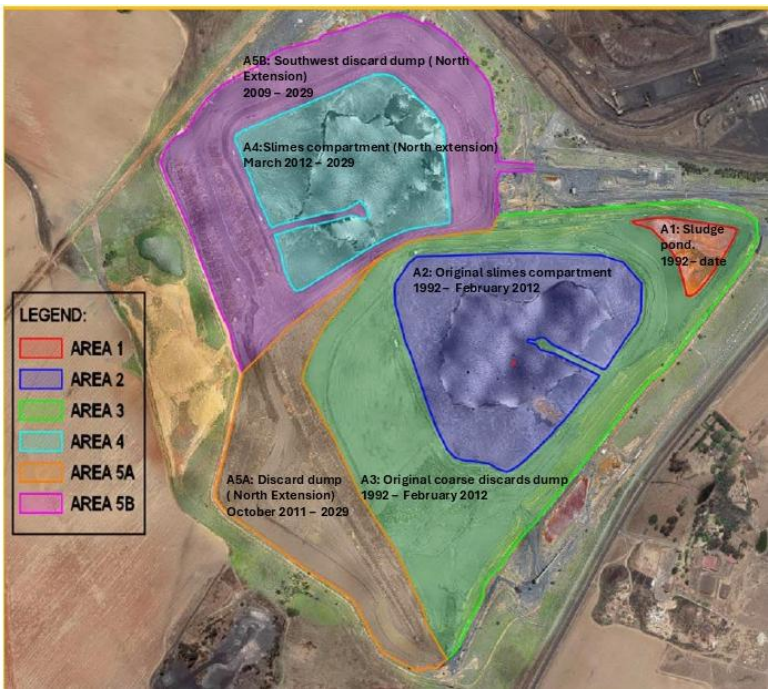

Fig. 1. Historical development of Blaauwkraanz MRF

Operationally, the MRF was managed through the fine coal discard slurry being hydraulically pumped from the delivery pumps located at the Navigation coal processing plant. Two HDPE delivery pipes were installed from the processing plant to the original slurry compartment (southern extension). The two delivery pipes eventually formed an open ring around the old slurry compartment. The slurry compartment was designed with a concrete penstock to decant supernatant water from the slurry pool. After the site stopped depositing into the original southern extension of the MRF, the penstock was sealed.

The dormant slurry compartment became a catchment for rainwater due to its design. At the time of decommissioning the slurry compartment, the site assumed that evaporation of the rainwater that accumulates over the large surface area of the slurry compartment would be sufficient to manage the water. However, during the peaks of the rainy season, the rate of evaporation would not match the volume of water that would accumulate in this catchment, and it would be left to seep through the MRF. As a result of the reaction between the water and the discards, the toe seepage water became very acidic with pH values less than 2.5

In terms of reticulation, toe seepage from the MRF would be diverted into two seepage collection compartments, colloquially referred to as the 'Kopseer' (headache) dams, for temporary storage. This naming was due to the difficulty in treating the water sources. The seepage collection compartments are earth-dug basins and are unlined. Due to the acidity and elevated heavy mineral content, the water could not be treated at capacity through the Navigation toe-seep treatment plant nor through the Emalaheni Water Reclamation plant. Over the years, several attempts had been made to treat this water, but they were unsuccessful. Due to the concentration of heavy minerals, specifically Fe2+ (ferrous) ions, which present a treatability challenge as opposed to the Fe3+ (ferric) ions, the impact seen on the treatment plant clarifiers often took the form of high sludge blankets. The total Iron concentration of the Kopseer water ranged between 6000 and 8000 mg/l. This led to frequent breakdowns, which necessitated completely draining and washing out the clarifiers. This, in

turn, impacted on the uptime of the plant by as much as 3 to 4 days per occurrence, resulting in up to 10 tonnes per day of iron precipitate being removed from the plant.

Due to the frequent challenges experienced when attempting to treat the water, the site had a net positive water reticulation. When attempting to manage surface water impacts from rain, the site resorted to recirculating the water stored in the seepage collection compartments back into the slurry compartment. This was done to mitigate for a seepage collection compartment overspill and became the standard method of managing toe seepage from the old and dormant slurry compartment. This method proved to be unsustainable, but it was the site's way of managing water in the old Blaauwkraanz South MRF to prevent overtopping and spillages from the seepage collection network.

Fig. 2 is an illustration of how water was managed at the Blaauwkraanz South MRF. The red dotted line indicates water seeping from the MRF to the seepage collection compartments. The water would be collected in the Kopseer seepage collection compartment (KP) main dam. When the level in the KP main dam reached 50%, the water would be pumped back to the slurry compartment. This activity is indicated by the red solid line. During heavy rainfall periods, the water would overflow from the Kopseer main dam to the Kopseer middle dam and the Kopseer trench. The water would be pumped back to the main dam and recirculated to the slurry compartment. The yellow line indicates the direction in which water would be pumped for treatment at the Toeseep liming plant and the EWRP.

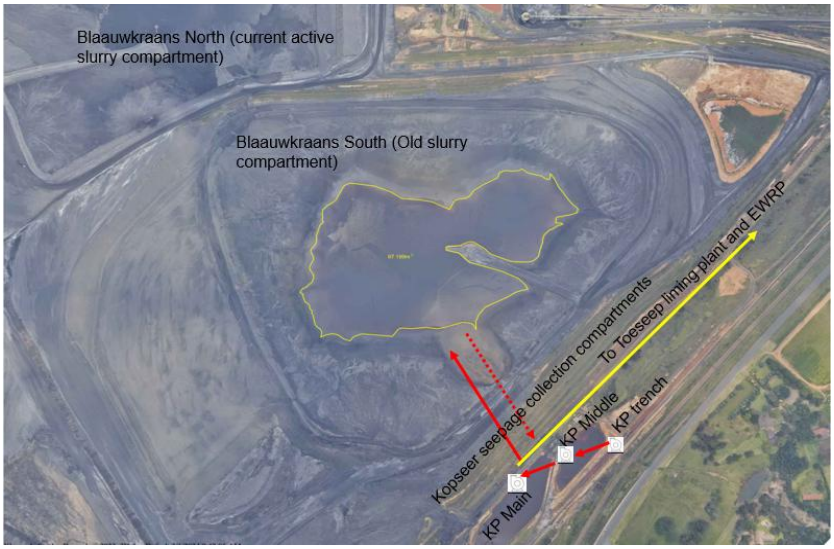

Fig. 2. Water management at Blaawkraanz South MRF

2 Literature review

Acid mine drainage forms because of the reaction between water and iron sulphides. These iron sulphides are common in coal discards and dumps. Primary pollutants in acid mine drainage include Iron, sulphates, manganese and hydrogen + ions with iron being the most critical [1]. Below is the equation that describes the formation of acid mine drainage.

$$4FeS_2 + 15\,O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 8SO_4^{2-} + 16H^+ \quad (1)$$

AMD needs to be effectively managed to reduce and prevent negative effects on the environment and people. Some of the negative impacts of AMD include:

- Pollution of ground water;
- Contamination of water resources;
- Devastation of aquatic life;
- If consumed, harm to humans and animals;
- Reduction in biodiversity;
- Reduction in availability of clean water for farmers (water security);
- Damage to infrastructure such as bridges and pipelines [2].

AMD can be managed through treatment for re-use in the mines, to potable water standard for distribution to local communities through municipalities or for disposal to rivers. There are various treatment methods that have been successfully used to treat AMD. The selection of a treatment option is dependent on the water quality and water use that the operation aims to achieve. Common treatment methods for AMD include, freeze crystallisation, neutralisation, adsorption, membrane separation and microbial methods [3]

The most common treatment method of AMD is neutralisation through liming. Conventional neutralisation through liming involves creating a reaction between the lime and the AMD in an aerator, which is followed by the separation of solids through a clarifier or thickener [4]. Neutralisation of AMD through liming occurs in three stages, namely: ferrous iron (Fe2+) chemical oxidation, acid water neutralisation and precipitation of iron oxides (Fe3+). These specific chemical reactions are summarised below [5].

Reaction 1: Ferrous iron chemical oxidation (Fe^{2+})

$$4Fe^{2+} + {}^{1}/_{4}\ O_2 + H^+ \rightarrow {}^{1}/_{2}\ H_2O + Fe^{3+} \quad (2)$$

Reaction 2: Acid water neutralization with Limestone

$$CaCO_3 + H^+ \leftrightarrow Ca^{2+} + HCO_3^- \quad (3)$$

$$CaCO_3 + 2H^+ \leftrightarrow Ca^{2+} + H_2O + CO_2 \quad (4)$$

Reaction 3: Precipitation of Fe3+ oxides

$$Fe^{3+} + 3H_2O \leftrightarrow Fe(OH)_3 + 3H^+ \quad (5)$$

The effectiveness of AMD neutralization is dependent on several factors, including:

- Concentration of Fe^{2+} ions in the AMD
- Quality and type of Limestone
- Concentration of lime mixture
- Effectiveness of aerators
- Residence time in the aeration tanks
- Throughput through the liming plant
- Effectiveness of solid separation [6].

3 Methodology

3.1 Water quality assessment

Samples were collected at surface pollution control dams and boreholes across the site. The purpose of this was to assess water quality across the site and determine how the highly acidic Kopseer water could be blended with water from other sources to improve its treatability. The water was assessed for pH, acidity, total iron as Fe and sulphates contents. Fig. 3 below shows the Navigation water reticulation system and the different points within the reticulation

that were sampled. Samples were collected daily over a period of a month. The averages of the daily samples were used as an indication of the water qualities of that stream.

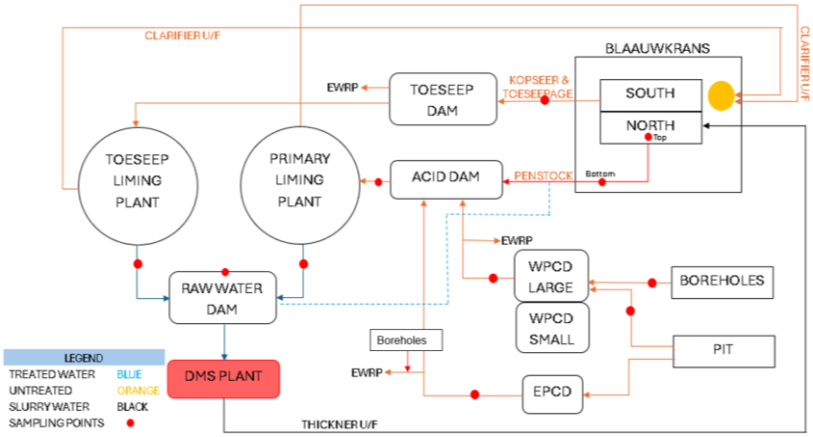

Fig. 3. Navigation water reticulation system and water quality sampling points

3.2 Review and baselining of existing infrastructure on site

The Navigation site has two neutralization plants for treatment of AMD, namely: Primary liming plant and the Toeseep liming plant. The existing liming plants consists of three stages:

- Oxidation via aeration for metal removal, specifically for iron
- Neutralization Reactor: To neutralize the acidity and aid in the formation of sulphate precipitation.
- Clarifier: For the removal of formed solids from the effluent

Table 1 below summarizes the equipment sizing of the infrastructure on site:

Table 1. Toeseep liming plant existing equipment sizes

Existing equipment	**Size**
Oxidation Reactor	32.5 m^3
Neutralization Reactor	32.5 m^3
Combined reactor size	65 m^3
Clarifier (Diameter)	8 m

In this study, the condition of the available equipment on site was assessed to determine the potential impact on water treatment. The following was assessed on the plant infrastructure:

- Condition and functionality of agitators.
- Effective volume within the oxidation and neutralization reactors (Sludge buildup)
- Clarifier performance
- Flocculant performance
- Validation of instrumentation measurements
- Quality and consistency of lime preparation and dosage

3.3 Process modelling

This involved a detailed analysis of the various water sources and blends to determine the most effective blend that would enable treatment of Kopseer water. The initial target treatment rate per day was 100 m^3 per day for the purposes of neutralising for further use in the Navigation CHPP. However, the initiative reached a constraint due to the objective of achieving perfect water quality in terms of acidity, sulphates and pH levels that would approach potable water quality. Kopseer water was blended with other sources of water across the site, which had lower levels of acidity. The ratio of Kopseer toe-seepage volume to other feed sources was varied. The blended water was then treated through the Toeseep liming plant and effluent water qualities were analysed internally as well as at an external laboratory. From this analysis, the optimal blend was determined. Throughout the study, the throughput to the Toeseep plant was kept constant at 0.5 ML per day. The sludge precipitation was monitored to ensure that the solids build-up within the clarifier was still within the allowable range to be able to monitor torque. This was monitored through instrumentation on the bed pressure, thickener underflow density and torque measurement on the clarifier rake.

4 Results and discussion

4.1 Site infrastructure assessment

4.1.1 Aeration tanks

The on-site aeration tanks were inspected prior to the commencement of the trial. It was found that the tanks had a 50% reduction in effective volume due to build-up of residual lime and gypsum due to scaling. The volume of the aeration tanks proved crucial in ensuring that the reactions could occur to completion by ensuring the required residence time. The tanks were descaled and cleaned to recover the complete treatment volume for optimal efficiency.

4.1.2 Clarifier

The clarifier was found to have leaks in the feed well. These leaks lead to contamination of the clarified water with fresh feed. The leaks were resolved prior to commencement of the test work trail.

4.1.3 Instrumentation

The clarifier was previously operated without a torque indicator. The torque indicator is a critical instrument for monitoring sludge build-up at the base of the clarifier to ensure that the clarifier is not overloaded. The torque indicator was restored prior to commencement of the trial.

4.2 Site water qualities

The actual water quality data in this study was normalized between 0 and 1, indicating minimum and maximum values of the data set respectively. The formula below was used for normalization of the data sets;

$$\bar{x} = \frac{x - min}{\max - min} \tag{6}$$

Where $\bar{x}$ is the normalized value and x is the actual value. Min and max indicate the minimum and maximum values within each water quality data set.

4.2.1 pH analysis

The graph below indicates the pH values of surface and ground water across the site. pH values ranged from a minimum of 2.69 to a maximum of 3.96 at 25˚C. Kopseer and Schoonie water showed the lowest pH levels while in-pit water had the highest pH. The in-pit water is water stored in previously mined-out underground workings. Due to a lag in groundwater abstraction from the storage compartments, this water seeps into the pit during open-cast mining operations.

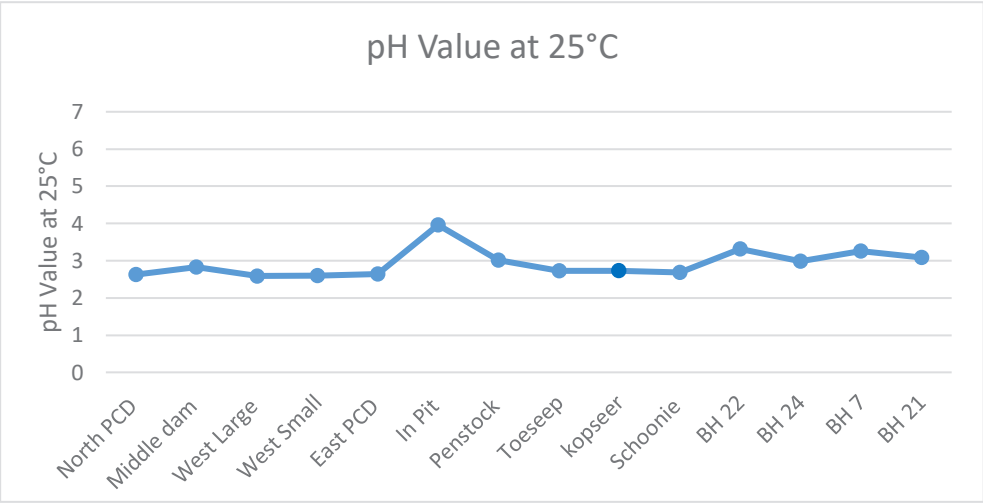

Fig. 4. pH values of surface and ground water across site.

4.2.2 Acidity analysis

The acidity of water sources across the site was analysed. The acidity of water is a critical parameter that indicates the capacity of water to react with a strong base to a determined neutral or higher pH value. In this study, the acidity represents the capacity of a specific water source to react with $CaCO_3$ to a pH of 8.3. Fig. 5. indicates the normalized acidity of the various water sources. Kopseer water showed the highest acidity levels as compared to all other water sources. The higher the acidity, the more difficult it is to neutralise the water. As indicated by the data below, Kopseer water has the highest acidity and is therefore the most difficult to neutralise.

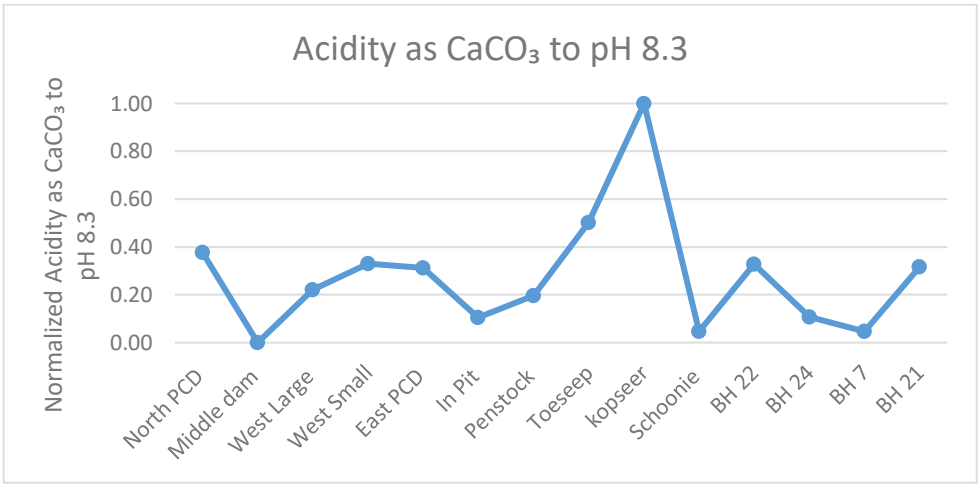

Fig. 5.Acidity of surface and ground water across Navigation site.

4.2.3 Total iron as Fe

The total iron was also analysed for the various water sources across the site. Iron is one of the most important water properties affecting its treatability. Fig. 6. shows the normalized total iron as Fe for various water sources across the Navigation site. Kopseer water consisted of the highest total iron content as compared to all other sources across the site.

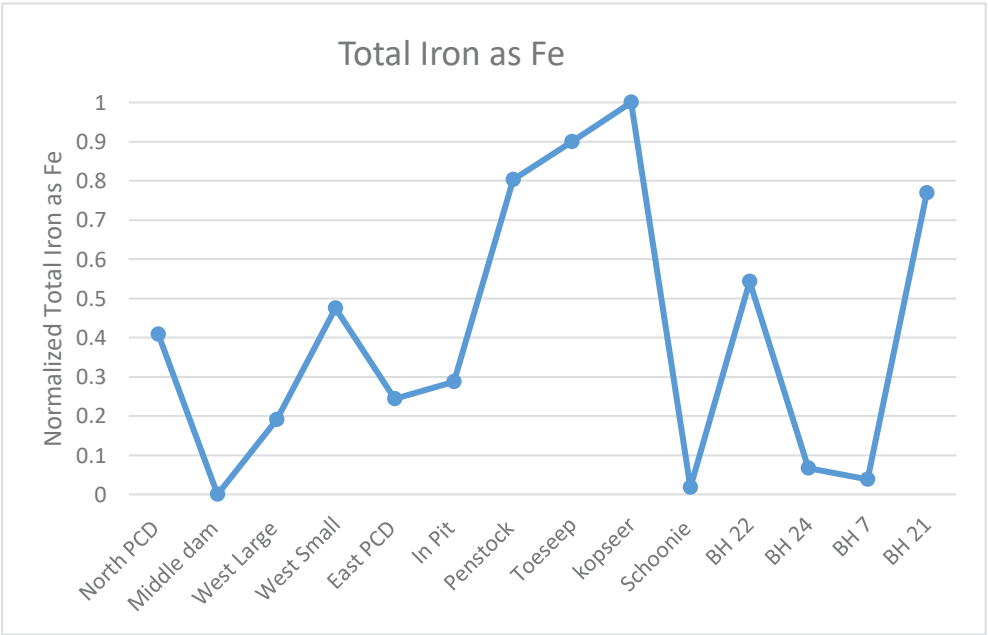

Fig. 6. Total iron content for various water sources across the site.

4.2.4 Sulphates analysis

Fig. 7 depicts a comparison of the normalized sulphates concentration across the various water sources. Kopseer water was found to contain the highest concentration of sulphates. Sulphates affect the treatability of water. Water that is high is sulphates exhibits a strong driving force towards gypsum formation. Formation of gypsum is problematic as it leads to several operational challenges such as blocked pipelines, increased maintenance interventions that drive up costs and silt build-up in dams, reaction and storage tanks. At Navigation Plant, scaling due to gypsum formation makes magnetite recovery very difficult and results in increases magnetite consumption. Similar to the observed highest amount of iron Kopseer water showed the highest concentration of sulphate ions.

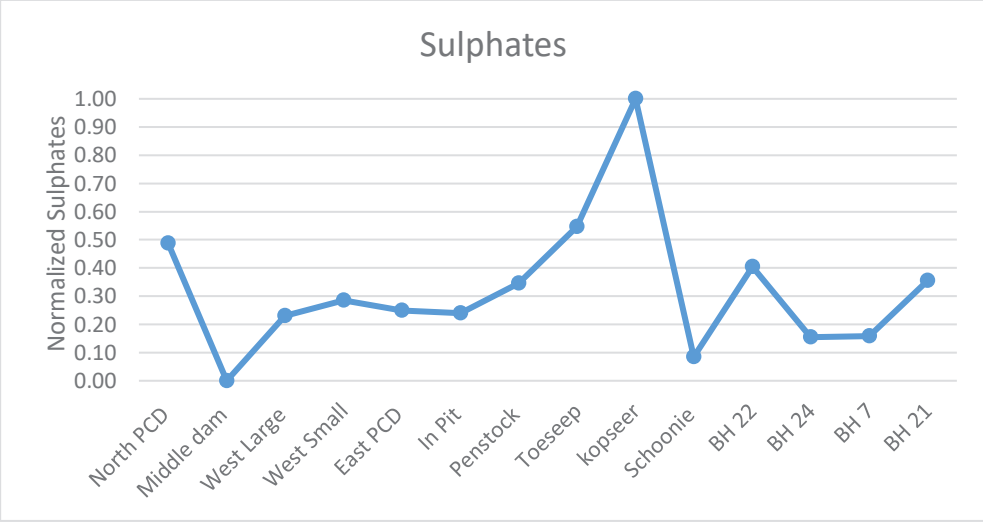

Fig. 7. Sulphates concentration of various water sources on site.

4.3 Toeseep clarifier effluent qualities for various blends

A trial was conducted to determine the treatability of Kopseer water through the available Toeseep liming plant. The Toeseep liming plant is designed for neutralisation of AMD-affected water, specifically seepage from the MRF. The Toeseep liming plant is capable of neutralising AMD and separating precipitated solids from the neutralised water. In this study, Kopseer Water was blended with fresh seepage from the active Blaauwkraanz North portion of the MRF. The trial was conducted by gradually increasing the ratio of Kopseer to Blaauwkraanz North seepage. Kopseer is the toe seepage from Blaauwkraanz South (the dormant facility), while seepage from Blaauwkraanz North (the active MRF) is referred to as Toeseep.

Fig. 8 to Fig. show the effluent water qualities from the Toeseep liming plant for the different Kopseer to Toeseep ratios (Kp: Tp). pH, acidity, concentration of sulphates and iron are the major parameters that were analysed. For this trial, the limestone dosage to the Toeseep liming plant was kept constant at 20 m^3/hr throughput at a constant density of 1.02 t/m^3.

Fig. 8 shows the pH of the Kopseer blends before and after treatment. From the graph below, it was found that as the ratio of Kopseer to Toeseep water is increased, there is little variability in the feed blend pH. The effluent pH ranged from 6.64 to 7.02. Little variability in the effluent pH was also observed. The data below indicates that Kopseer water,

irrespective of the blend, could successfully be neutralised to a pH that is greater than 6 through the Toeseep liming plant. For the purposes of the coal handling and processing plant, a pH of 6 is sufficient to mitigate against the corrosive impact of AMD-affected water on the coal washing plant's infrastructure.

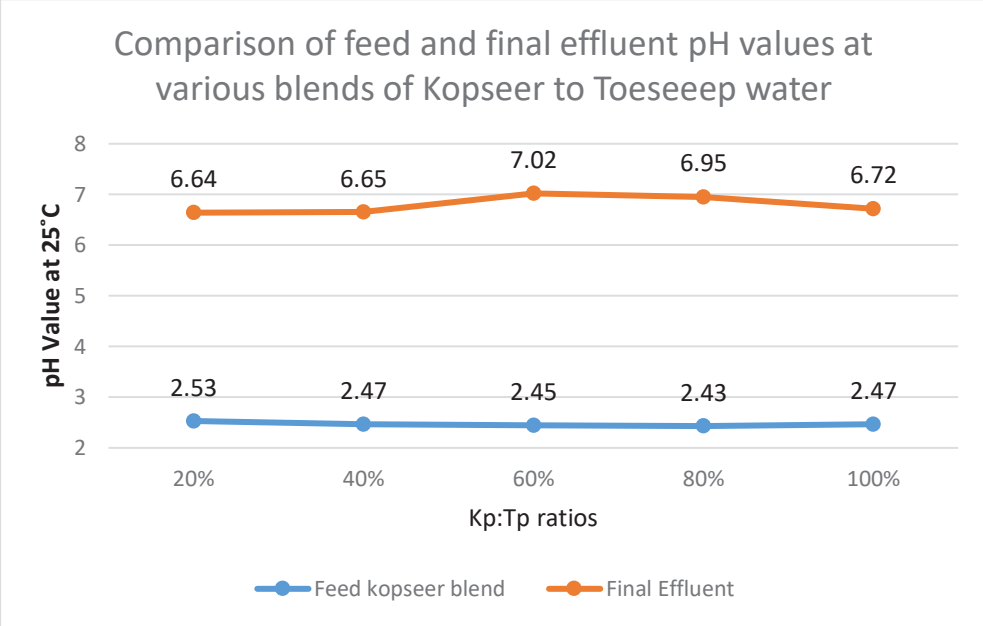

Fig. 8. Toeseep plant feed vs effluent pH values at various Kp: Tp blends.

For all Kp: Tp ratios, the acidity of the water treated through the Toeseep liming plant was reduced by 99.8% and 99.9%.

The total iron in the effluent was analysed at the different Kp:Tp ratios. The results are shown in Fig. 9 below. As the ratio of Kp was increased in the feed, the total iron increased as expected. However, similar to the effluent pH and acidity trends, the total iron in the effluent did not seem to be influenced by the Kp: Tp ratio. The data below indicates that the Toeseep liming plant performed successfully at all ratios by successfully reducing the iron content in the effluent by at least 99.60% at all ratios of Kp: Tp.

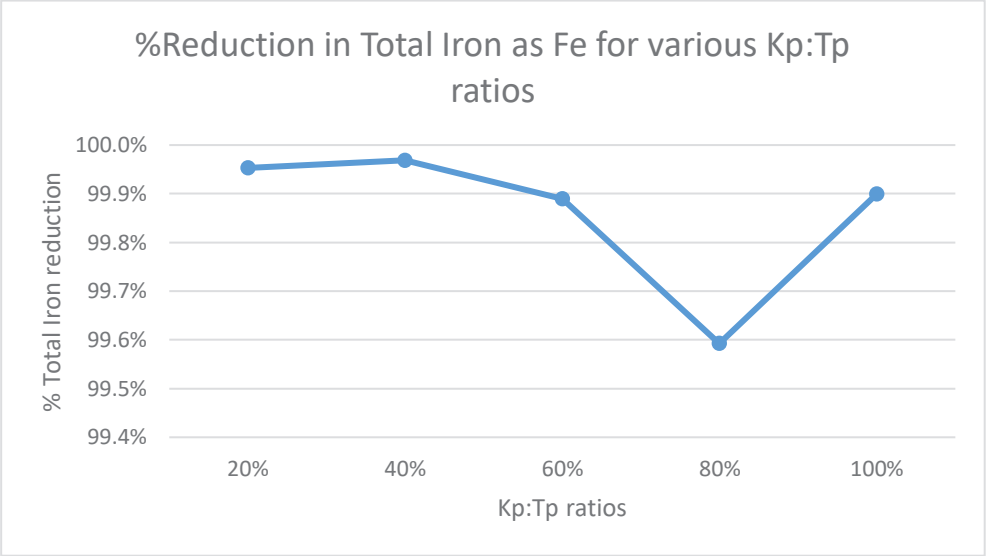

Fig. 9. Toeseep plant total iron as Fe at various Kp: Tp ratios

Lastly, the sulphates in the effluent were analysed. Fig. 10 indicates the % reduction that was achieved at the various Kp:Tp ratios. The sulphates concentration in the feed water increased with an increase in the Kp:Tp ratio. The concentration of sulphates could be reduced by at least 50% by treatment through the Toeseep liming plant. The lowest concentration of sulphates was 2900 mg/L and it was achieved at a 20% Kp:Tp blend. However, the sulphate concentration reduction is insufficient. Studies show that process water needs to be treated to a sulphate concentration lower than 2 400 mg/L to inhibit gypsum formation. In this study, we found that the Toeseep (liming) treatment plant does not have the capability to treat the water to a sulphate concentration below the threshold for gypsum formation. This is problematic because gypsum results in multiple operational impacts that are undesirable in the coal handling and processing plant. As the Kp:Tp ratio was increased in the feed, the sulphates in the effluent were proportionally higher. This indicates that treating Kopseer water at the current throughput, would lead to an effluent water quality that results in an increased driving force towards gypsum formation in the processing plant.

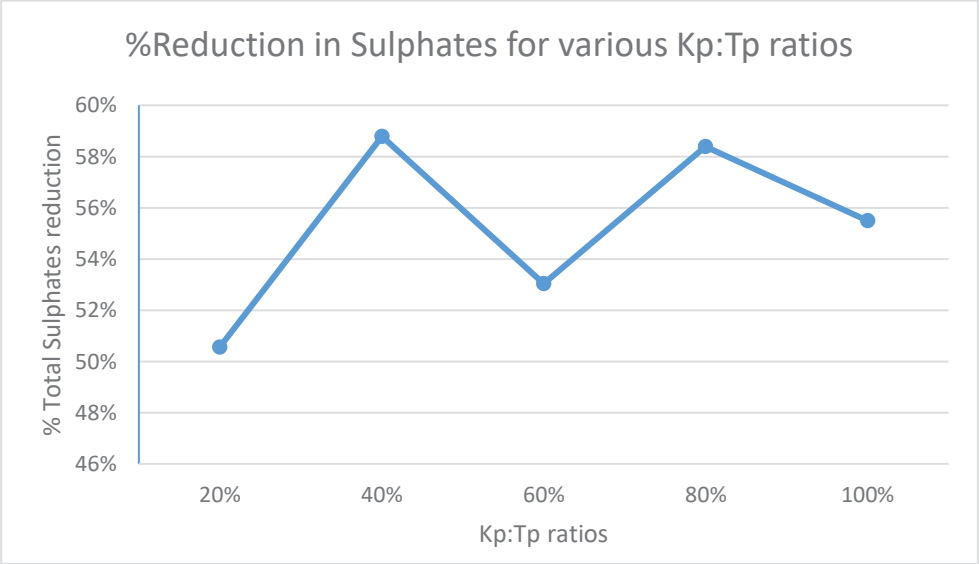

Fig. 10. Toeseep plant concentration of sulphates in effluent at various Kp: Tp ratios.

5 Conclusion and recommendations

From this study, the navigation team was able to gain a better understanding of the Kopseer water qualities and treatability through existing site infrastructure. Furthermore, the site was able to establish a sustainable treatment recipe and improve the operational practices at site for consistent treatment of Kopseer and toe-seepage sources of AMD affected water.

- Kopseer water could be successfully neutralized through the existing Toeseep liming plant infrastructure without any modifications. The requirement around achieving perfect quality water as opposed to neutral quality water in terms of pH was a great enabler in the optimization of blends for water treatment volumes that approach the rated capacity of the treatment plants.
- The Toeseep liming plant has a capability to reduce the iron content in Kopseer water by 99.9%
- The acidity of the Kopseer water can be reduced by 99.8% through the available Toeseep liming plant.
- The concentration of sulphates can be reduced by over 50% in the Toeseep Liming plant. The %Reduction in sulphates through the Toeseep plant is insufficient to prevent gypsum byproduct formation.
- The site was able to treat more than 100 ML of Kopseer water - cumulatively during this trial.
- The site can explore blending Kopseer water with other softer water qualities such as boreholes and Middle dam water.
- The site is currently conducting test work to assess the feasibility of using an anti-scalant for the inhibition of gypsum precipitation.

References

1. P. Gunther, J. P. Maree, G. Strobos, J. S. Mtimikulu, Neutralisation of acid leachate in a coal processing plant with calcium carbonate in Proceedings of the 8th International Congress on Mine Water & the Environment, Johannesburg, South Africa (2010)
2. G. Tichatonga, Management and Mitigation of Acid Mine Drainage in South Africa, 44 (2016)
3. Y. Jiao, C. Zhang, P. Su, Y. Tang, Z. Huang, T. Ma, J. Clean Prod, **170,** 1240 (2023)
4. C. T. Pretorius, Design, Construction and Operation of a High Density Sludge Lime Treatment Plant in Proceedings of the WISA Biennial Conference 1998 (1998)
5. I. D. Brăhaița, I. C. Pop, C. Baciu, C. Modoi, G. Popița, R. M. Truță, Carpath Earth Env, **12,** 347 (2017)
6. J. P. Maree, P. Günther, G. Strobos, F. B. Waanders, Int. J. Mine Water, **23,** 87 (2004)