# EWRP management of clarifier sludge

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**Abstract.** The Emalahleni Water Reclamation Plant (EWRP) treats acidic mine water from five mining operations. The feeds vary from a pH of 6 to a pH as low as 2.3. Over the last few years, the water qualities have deteriorated drastically. Mine life-extension projects have also required the removal of more acidic water, which has altered the total feed composition to the EWRP. This change specifically came about in the form of iron load. The initial design of the treatment process was to treat iron levels up to 300mg/l. The incoming feed quality at the time was more than 450mg/l IRON. From November 2023 to January 2024, the mining operation was almost completely stopped due to an excessive amount of water. Due to significant production pressure, the operation had to adapt and treat the higher iron loads with no time to make significant design, construction or installation changes. The biggest challenge was clarifying the water, as iron is typically a low-density substance that struggles to settle at higher throughputs. This began an eight-month journey with many ideas, failures, theories, and eventually success. At the end of April 2024, all the water-related stoppages were resolved and by June 2024 the mine was dry and operations could continue.

## 1 Background

### 1.1 Water treatment at Thungela

Thungela is a producer and exporter of high-quality, low-cost thermal coal with seven operations across South Africa and Australia [1]. In 2005, Thungela (then Anglo American Thermal Coal) began building a R1.7 billion centrally-operated water treatment facility to deal with acidic mine water from five coal operations nearby. The Emalahleni Water Reclamation Plant (EWRP), which is located in the town of Witbank in the province of Mpumalanga, South Africa.

The need for a centralised water treatment facility arose after significant changes in national water use legislation, prohibiting the mines from conducting controlled water releases (polluted water) into the surrounding environment. To meet environmental legislation and continue underground and surface mining operations, the EWRP was constructed. It makes use of a high recovery reverse osmosis (HiPRO™) process to treat acid mine drainage to potable water standards. This choice of technology enables the minimisation

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of liquid waste by maximising the water recovery rate to above 99%. The plant produces on average 40 mega litres per day (Mℓ/day) and has a volumetric design capacity of up to 50Mℓ/day. The potable water is, in turn, sent back to the surrounding operations and support offices for mining and domestic use. Any excess water is supplied to the local municipality. The EWRP is a registered bulk water service provider and adheres to SANS 241 drinking water standards.

Maintaining a consistent water quality from active mining operations is extremely challenging. As mining progresses, water quality varies significantly, especially when old underground mining areas are opened from the top for re-mining purposes. All underground voids fill with water over time. Some areas experience more recharge than others, all contributing to a variety of water qualities. An acid mine water treatment facility must be flexible in its treatment philosophy, particularly when mining is still active and influenced by the water treatment facility's production rate. Over the years the EWRP has been faced with this challenge on numerous occasions, but none to the extent of the high iron challenge. In this instance, the water quality was significantly below the plant's design baseline, and there was no time or financial capital available to make design changes, as detailed in section 2. This paper aims to guide the reader to understand the value in breaking down each section of a conventional AMD process, and with the use of theoretical fundamentals, improve its individual performance. These small incremental changes might be insignificant on their own, however it moves the needle on a bigger scale.

## 1.2 The EWRP treatment process

### *1.2.1 The unique water sources*

The five mining sources that feed into the EWRP all have different chemical compositions and associated volumes, but all of them have high levels of calcium and sulphate and varying amounts of heavy metals such as manganese, aluminium and iron. Some sources (such as Greenside Colliery) are semi-neutral, with an average pH of 6.5, while others are extremely acidic, with an average pH of 2.6 and associated acidity of 1800mg/ℓ. The main acidic source is Navigation Colliery. This is due to old underground mining compartments that have filled with water over time. When exposed to water and air, the pyrite in the remaining deposits reacts with metal sulfides and causes acidity. Navigation Colliery is a life extension mine in which opencast methods are employed to mine the remaining coal stored in the old mine workings. This activity requires the removal of all the water in the underground compartments to facilitate mining.

The treatment of Navigation water is extremely difficult due to the high levels of iron that have been generated through the pyrite oxidation process during the last 15 to 20 years. The total iron concentration in the water varies from 350 to 850 mg/ℓ, combined with an average sulphate concentration of 3500 mg/ℓ as $SO_4$ and 400 to 500mg/ℓ of calcium. The Navigation water is typically blended down with a neutral water in the EWRP's feed pond before treatment.

### *1.2.2 Neutralisation reaction and clarification stage*

The blended feed water is fed into reactors that are dosed with lime in a high-density sludge (HDS) process. Alongside agitation for oxidation, a lime slurry is dosed until the pH is increased to 9.5 to ensure that all the heavy metals are precipitated. The reactors then feed

into a clarifier to allow the calcium sulphate precipitate and metal hydroxides to settle down for removal and for clean water to overflow at the top. The sludge at the bottom of the clarifier is then either recycled to seed the precipitation reaction and to increase the driving force or it is dumped to a filter press for dewatering.

In 2020, the plant became significantly constrained due to the minimisation of alkaline feeds and the increase in acidic feed volume. A previous acidity limit of 400mg/ℓ (as $CaCO_3$) could not be maintained. It was found that increasing the blend to an acidity above 1000 mg/ℓ (as $CaCO_3$) resulted in the reaction having a greater driving force. This meant that low levels of calcium sulphate precipitation potentials could be achieved, which is a key control factor in water being fed to a reverse osmosis membrane. Although this provided a huge benefit with regards to suitability for membrane treatment of the clarifier overflow, the 'super charged' reaction resulted in extremely coarse gypsum formation in the reactor and in the eventual feed to the clarifier. The clarifier design parameters could not process the coarse material and this resulted in continuous clarifier rake trips and damage to rake drive gearboxes. The total salinity load also exceeded the filter press dewatering capacity.

A modification project was completed in 2021 with the addition of cyclones in-between the reactor and clarifier to remove the coarse material for dewatering in an underutilised vacuum belt filtering section of the plant. This project was a great success as it managed to balance out the solids across the circuit at minimum capital cost.

The change in treatment of more acidic water could, in this instance, be resolved with a design change and implemented with available capital funds. The operational pressure was significantly lower as well, allowing time for a full capital project implementation. The subsequent challenge discussed in section 2 had none of these advantages.

## 2 Dewatering challenges in 2023

In the third quarter, Navigation Colliery struggled significantly with water levels in the mining pit. The pit was located at a geographically low point, with the result that all surrounding water drained into the pit, causing significant delays in the mining plan. The operation therefore required the EWRP to increase its treatment capacity to an average of 18Mℓ/d rather than the typical 10 to 12 Mℓ/d. The pit water was also severely contaminated with iron, deviating from the average concentration of 300 to 400 mg/ℓ to above 600 mg/ℓ. Therefore, not only was a volume increase required, but a greater iron load had to be removed in the pre-treatment step.

The increased iron load caused significant issues on clarifier performance. The iron hydroxide precipitate has a very low density, settles slowly and is extremely sensitive to any change in flow dynamics within the clarifier. If the iron floc does not settle sufficiently, it enters the clarifier overflow and subsequently the ultra-filtration (UF) membranes. Overflow quality is typically monitored via online turbidity meters and the overflow should be below 10 NTU. Should this limit not be adhered to, the UF membranes foul prematurely and extensive cleans are required to recover the flux across the membranes. This results in extended downtime that impacts on the required dewatering rate from Navigation.

A secondary challenge was the buildup of sludge inside the clarifier itself. The sludge that forms at elevated concentrations of iron has a high viscosity and the precipitate does not stratify/settle well. The result is that the sludge seems to 'stick' to the outside walls of the clarifier and continues to build up until the rake torque switch engages and trips. The clarifier must then be manually drained and cleaned with a vacuum truck, which is extremely costly and results in an average downtime of 10 days. The clarifiers had constant rake trips, which necessitated cleaning every three to six weeks in the October 2023 to February 2024 period.

# 3 Methodology

## 3.1 Improvement areas identified

In October 2023, the EWRP did not meet the required dewatering rate for Navigation and considerable intervention was required. Since the plant was already behind on its treatment schedule, there was no time for extensive upgrades that would require construction and capital. The production team had to focus on each process component and optimise it to the maximum for performance to improve. Every single step if the process was taken as a single unit and all its variables analysed.

A number of technical optimisation areas were identified and pursued over the course of the next six months. These included:

- Trialling an alternative polymer/flocculant that is more effective than the current product
- Changing polymer dosing points from the channel to inside the clarifier
- Installing flow measurement devices on the clarifier feed channel
- Installing load cells on the clarifier rake to pick up when a bed is forming
- Cyclone split investigation
- Creating a mass balance model
- Improving sludge recycling/dump efficiency.
- Improving filter press-up time and availability.
- Optional removal of iron before treatment at EWRP

# 4 Results

## 4.1 Summary of lesser findings

A few improvements were made, although some initiatives were less successful than others. The following is a summary of these findings, with a detailed discussion of the most significant findings provided in the next section.

*Trialling alternative polymer for better iron removal*
Laboratory scale test results showed better settleability of a SC510 polymer product than the current use of STR 285A. However, in the field, the alternative polymer only increased the stratification effect that caused additional buildup on the sides of the clarifier. A larger dose of polymer was also required to maintain the stability, which had a negative effect on the performance of the UF membranes.

*Changing polymer doing points from the feed channel to inside the clarifier.*
When looking at polymer dosing, a variable to consider is the contact time and conditions the floc is exposed to. It was hypothesized that the newly formed flocs are exposed to excessive mixing in the channel and are subsequently being broken apart before agglomeration can occur. Changing of the dosing point resulted in no significant change/improvement in clarifier conditions. Floc sizes were similar before and after the change.

*Installing flow measurement devices on the clarifier feed channel.*
Open channel flow measurement is not a typical practice at the EWRP. A specialist vendor was used to design and implement these measurement devices. The team

found that these devices added little value as the accuracy was always questionable and multiple calibration attempts could not resolve the issue. The scaling nature of the water also added to the troubles of the devices.

*Installation of load cells on clarifier rake drives*.
It was hypothesized that one would be able to get an online, "live" feedback of the sludge bed conditions with these load cells. However, due to the low density of this iron rich sludge, the load cells were not sensitive enough to pick up the changes. Once a change was noted, it was too late, and the rake tripped within minutes of the load cell picking up a variance. These devices did not add more value than the rake motor amp monitoring.

*Cyclone split investigation.*
The operational team noted that a change was made on the cyclone spigots. The original spigots were smaller and caused frequent blockages. Larger spigots were installed to prevent these continuous process upsets. A portion of the cyclones were changed back to the smaller spigots, and PSD comparisons noted the smaller cut in the underflow as expected. The team acknowledged the necessity of some coarse material in the clarifier to give added weight to the sludge for better settling. Therefore, the decision was made to only change out 40% of the spigots to the smaller size. Subsequent settling data of the clarifier feed showed improved settling rates (targeted between 800-900 measured on an Imhoff cone after 10 minutes).

*Improving filter press up time and availability.*
Effective removal of the sludge/slurry at the bottom of the clarifier is key to the management of sludge build-up in the unit. As different sections of the plant all feed to the dewatering presses, it was imperative to make programming changes to preferentially dump from the constrained area first. Should one of the presses be unavailable, production needs to be reduced in tandem to ensure removal rates are maintained. Press cycles are also manually initiated, therefore clear guidelines on targeted number of cycles were set to ensure maximum operational throughput. This initiative contributed significantly to the overall efficiency of the process.

*Removal of iron before treatment at the EWRP.*
The question was raised if the small liming plant located at the Navigation mine could be used for upfront removal of iron. After detailed investigation this option was not pursued further. The addition of limestone upfront would increase the scaling exposure on the 3km pipeline to the EWRP, causing flow limitations and blockages. It would also add to the calcium concentration of the water and increase the resulting calcium sulphate scaling potential (referred to as saturations) which would render the RO membranes inoperable.

## 4.2 Significant process interventions

### *4.2.1 Feed variance control*

The EWRP had no control over the incoming feed concentrations. The iron values fluctuated depending on where the mining operation was dewatering at the time. Therefore, the EWRP team had to implement more stringent controls on the feed blending to minimise the variability of the incoming iron load. Although a simple principle, it was much harder to

control in practice and under high production pressure. The focus needed to shift from controlling based on acidity to using a blend based on iron concentration. These control implementations required that the production be ramped down at times to allow for dilution, but overall plant availability improved significantly. The improved control can be seen in the iron load graph below in figure 1. After the intervention, the deviation of data is vastly improved.

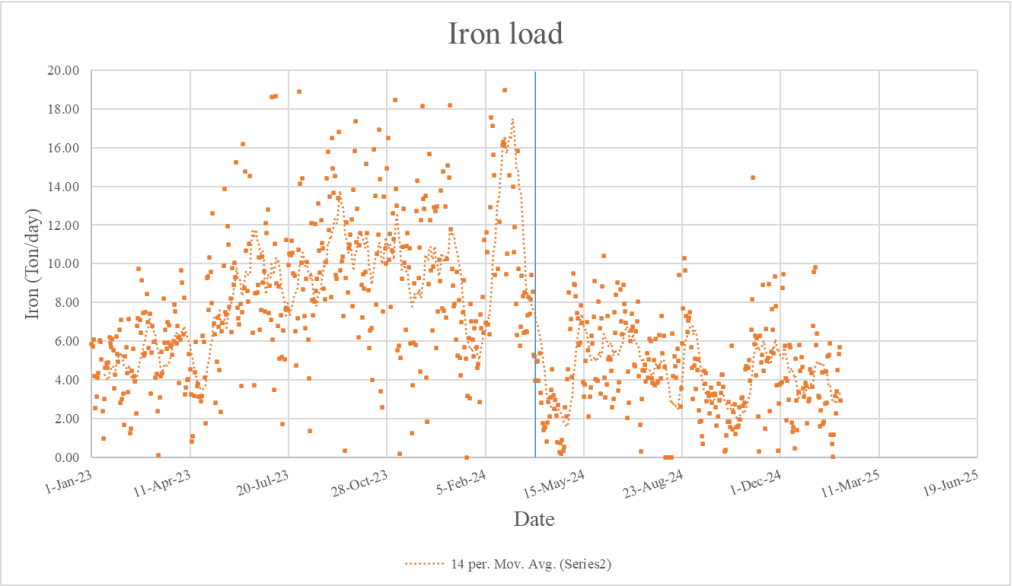


**Fig. 1:** Iron load control, significant improvement noted from March 2024 as indicated by the vertical line in the graph.

### *4.2.2 Using state-point analysis*

State point analysis (SPA) is a tool typically used in biological water treatment to optimise clarifier performance, and not typically in acid mine drainage water treatment. The clarification step in biological treatment has a key similarity with acid mine treatment, which is return activated sludge (RAS). The clarifier returns or recycles in AMD, is also used to drive the initial calcium sulphate reaction in the upfront mixing reactor through seeding (providing an already formed nucleus for the particle to grow on). Many clarifiers are designed based on the surface overflow rate (SOR) and not specifically the solids loading rate (SLR) which is of particular concern in this instance. The below equation illustrates the basic theory [2]:

$$SLR=\{Q/A\}X_{ML}+\{Q_{RAS}/A\}X_{ML} \qquad (1)$$

With:
SLR = Solids Loading Rate
Q = Influent flow
$Q_{RAS}$ = Return flow
A = Surface area of the clarifier
$X_{ML}$ = solids concentration

SPA utilizes mass balance principles but provides a graphic representation of settling flux versus solids concentration [2]. The mass entering the clarifier must equal the mass leaving the clarifier and the "State Point" referred to is the "state" of the mass balance in the unit.

The EWRP utilised this tool by determining the unique settling characteristics of the acid mine water sludge. Through lab-scale settling tests, one can create a settling velocity curve that will guide the operating state. The aim is to always be underneath the settling flux curve. Should the concentration or flow increase, but the removal rate not be adjusted, a secondary line can be drawn to show the effects of the change [2]. The state point analysis tool was a turning point in the operation of the clarifiers. It allowed the operator to adjust and check operating conditions and not over- or under-dump to control the mass balance.

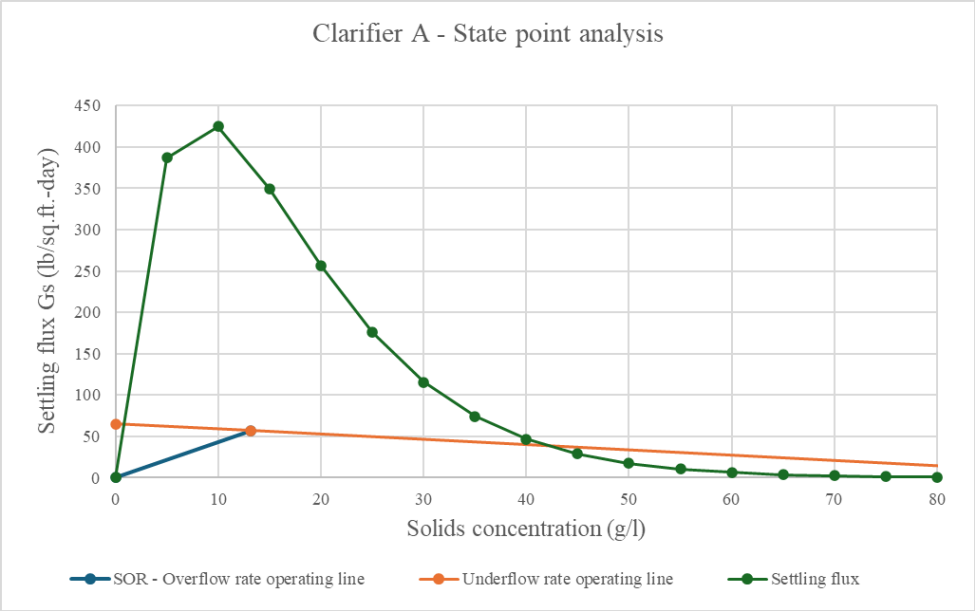


**Fig. 2**: Example of state point analysis graph for EWRP clarifier A.

The application of an unconventional theoretical tool in the acid mine treatment space provided the breakthrough needed. Adjusting inflow, recycle and out flow rates based on the model had an immediate effect. The sludge beds formed were minimal and consistent. Excessive buildup was prevented as the mass balance was maintained at all times. The success is also due to an operating team that remains vigilant and constantly updates the model and operating points to remain in control of the constantly changing input conditions.

### *4.2.3 Mass balance control*

To capitalize on the guidance provided by the state point analysis, the pre-treatment section's mass balance had to be exact. Typically, volumetric balances are done and maintained across a process step, but the plant needs to improve the actual mass balance of the precipitates. Strict control had to be exercised over individual chemical constituents that feed into the process. As well as the exact number of outputs (precipitates & dissolved ions) of the process in order to prevent the buildup issues encountered in the clarifiers. This initiative required the installation of additional flow measurement equipment on certain portions, which had to be monitored and controlled.

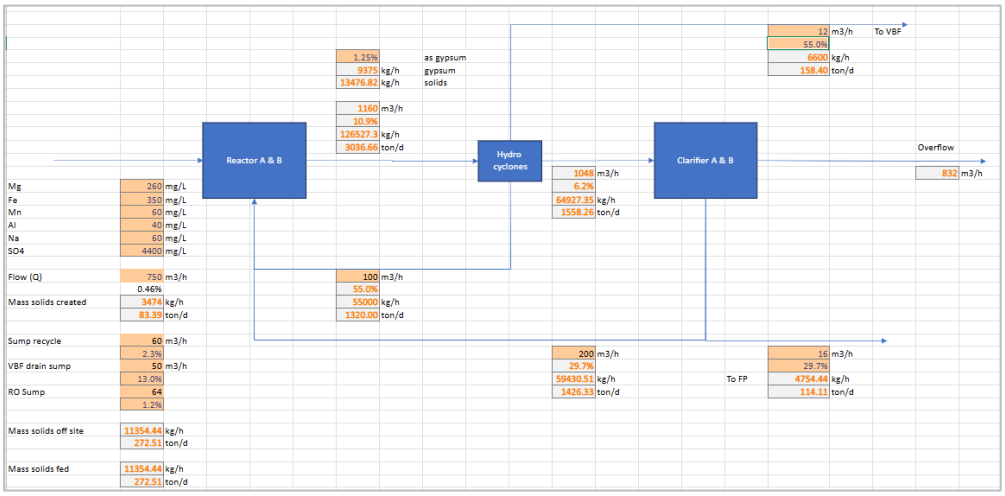


**Fig. 1:** Example of the mass balance tool used to control pre-treatment.

## 5 Conclusion

The combination of these interventions enabled the plant to firstly stabilise the feed concentration of Iron and Sulphates, to reduce the variability of feed and improve process control. The additional flowmeters allowed better understanding of the mass balance around the clarifier and circuit. Combining these with the State Point Analysis which enabled the plant to understand the settling characteristics of the sludge and based on the recycle rate understand the underflow operating line to predict if a sludge blanket would form and whether the rate of sludge removal exceeded the settling rate of the sludge. This allowed the plant to configure their clarifier feed rate, recycle rate, feed concentration and underflow operating line to sit below the settling flux curve.

This was further supported by having a process engineer work on shifts with the operational staff and review the state point analysis and recommend adjustments to ensure sustainability and to support the operators with the technical analysis. Continuous close monitoring and embedding these interventions into business as usual had played a significant role in turning around the clarifier challenges. Similarly, it has also enabled a demonstration of the applicability of the State point analysis for not just biological water treatment but also acid mine drainage water treatment.

## References

1. www.thungela.com/about-us
2. www.maine.gov/dep/water/wwtreatment/state_point_article.pdf