Producing High Quality Drinking Water From Mine Imapcted Water At High Recoveries Using Reverse Osmosis Membranes

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Abstract

Three Aveng Water designed HiPRO™ plants have been operating for a number of years. Each of these plants produce a product water that complies with the South African standards for drinking water (SANS241), two of which are currently supplying drinking water to the community. Key to producing this quality of water is the use of Reverse Osmosis Membranes. Management of these membranes is essential to maintaining consistent and reliable supply of water from the plant. The RO membranes on these plants are sensitive to inorganic scaling and biological/organic fouling due to the process and the feed water being reclaimed. The performance of these membranes is shown. The annual Salt Passage increase on the RO membranes is higher than the initial design but still within acceptable limits for potable water. A highly technical team is required to sustainably operate a plant of this nature.

Keywords: ICARD | IMWA | HiPRO™ | RO Membranes | Mine Water Treatment

Introduction

Water scarcity in South Africa and much of the world is becoming more pervasive. With a deficit in supply and demand of conventional sources, it is going to become paramount that alternate water sources are investigated as a way to augment the supply. It is estimated that there will be a shortfall of 83.3 Ml/day in the region around eMalahleni Mpumulang by 2030 (Coleman et al., 2011). Mine water reclamation presents one such augmentation strategy. It has estimated that mining activities in the upper Oliphants catchment area has created a need to treat between 200 and 250 Ml/day of Mine Impacted Water. These waters are complex and characterised by high levels of sulphate and a combination of balancing ions (Calcium, Magnesium, Acidity and monovalents) in various proportions, depending on the source. The resulting waters require rigorous treatment to remedy. One such active treatment process that can be used to remedy the mine impacted waters and produce potable water is Aveng Waters HiPRO™ process. This process combines chemical precipitation with advanced membrane processes allowing for large scale treatment of mine impacted waters. Currently four major installations use this technology and were all funded and owned by the senior coal miners in the Mpumalanga province. The four plants are the eMalahleni Water Reclamation Plant (EWRP) – (Phase 1 and Phase II), The Optimum Water Reclamation Plant (OWRP) and the Middleburg Water Reclamation Plant (MWRP). These four plants each are able to produce a product that complies with the regulatory requirements as specified by SANS241. Currently OWRP and EWRP produce water for the surrounding community.

Feed Water Quality

Table 1 summarises the design capacity of each plant, the year of commissioning, the plant owner, the plant designer and the typical feed water quality (major components only) currently being processed by the plant. It can be seen that the feed water quality differs between plants.

HiPRO™ Process

A detailed explanation of the process can be found Hutton et al (2009) so it will not be covered here, however Figure 1 shows the basic block flow diagram of the process.

The RO sections of the plant are the last

Table 1: Summary of Major Aspects of the plant installations

	EWRP Phase I	OWRP	MWRP
Plant Owner	Anglo American Thermal Coal	Optimum Colliery	South 32
Plant Designer	Aveng Water	Aveng Water	Aveng Water
Year Commissioned	2008	2011	2015
Design Capacity	25 Ml/day	15 Ml/day	25 Ml/day
Feed Water -Typical			
Calcium (mg/L)	520	414	460
Sulphate (mg/L)	2500	3000	3400
Magnesium (mg/L)	180	450	650
Sodium	130	160	60
Acidity (mg/L as CC)	80	0	0
Alkalinity (mg/L as CC)	10	180	180
pH	6	8.0	7.5
TDS (mg/L)	3500	5021.6	5000

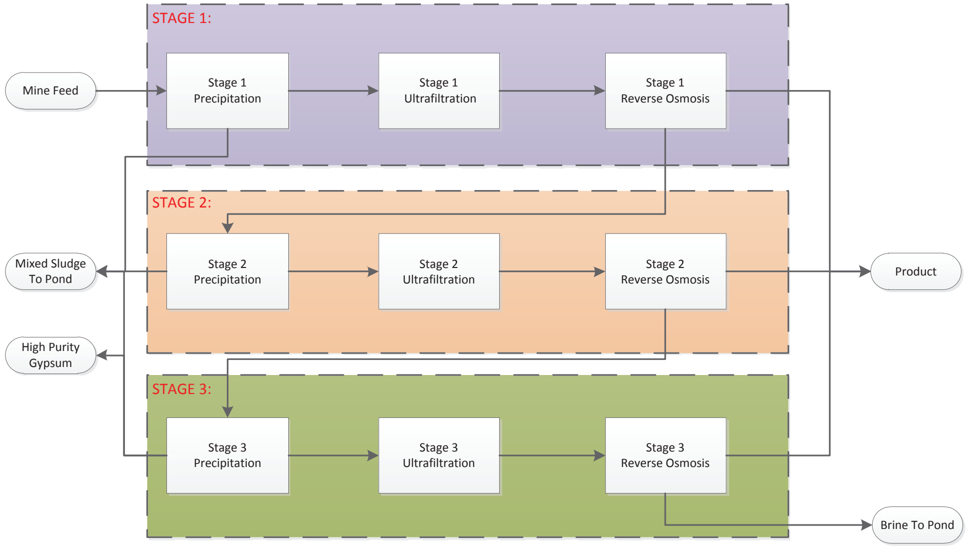

***Figure 1:** Basic Process Flow of HiPRO™*

step in each stage of the process. Once an ultralow suspended solids water is produced from the UF membranes, the RO membranes desalinate the water and produce a low TDS product and a moderately high TDS brine. The brine from the RO then proceeds to the precipitation reactors. In these reactors, the salinity is reduced through chemical precipitation. Due the nature of the feed water, the main aim of the reactors is the sequential removal of sulphate from the feed. The effect of the inter-stage precipitation on the removal of sulphate is pronounced and can be seen in Figure 2.

When looking at the typical concentrations of sulphate through the plants (Figure 2) of EWRP Phase I, OWRP and MWRP, it can be clearly seen how efficient the precipitation steps are at removing sulphate. The Stage 2 precipitation removes the largest mass of sulphate relative to the feed (~70%) and the Stage 3 precipitation removes ~12.5% relative to the feed. The monovalents present in the feed water that cannot be precipitated

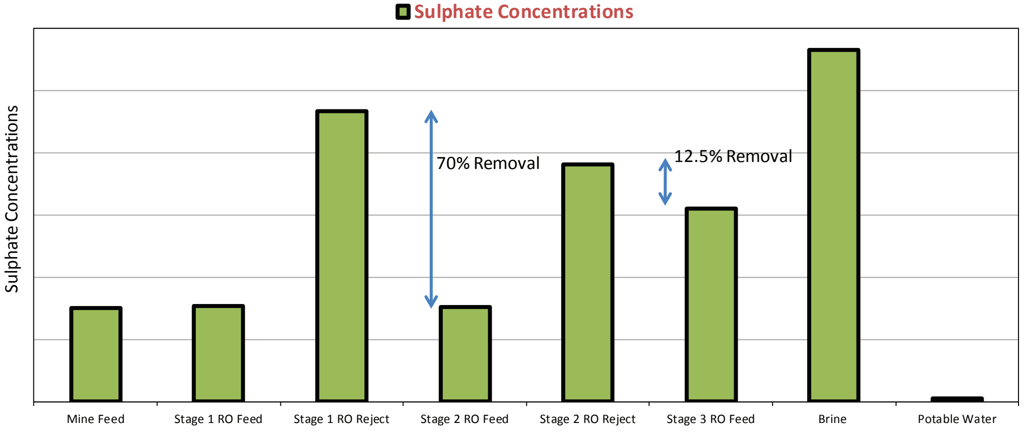

***Figure 2:** Effect of Inter-stage Precipitation on sulphate on OWRP*

are either permeated via the RO membranes or concentrated through the plant and discharged as a high salinity final reject stream. The secondary benefit of the staged precipitation is the recovery of water while minimising the required electrical power. The combination of targets to save energy on one hand and provide a well-controlled water quality on the other has been reached by employing this staged precipitation and high-rejection low energy RO elements. The average plant power consumption per m^3 of product ranges between 1.8 and 2.0 kWh/m3 while achieving water recoveries between 97% and 99% (water quality dependent).

Sustainable RO Operation

As with any membrane installation, the control and measurement of the feed water quality is paramount in maintaining sustainable operation. In these particular waters, this can be broadly be broken into control of the scaling potential and control of fouling.

Scaling Control

Antiscalant dosing and control is of essential importance in controlling scale formation within each stage of the process. Preventing the formation of calcium sulphate crystal formation on the membrane surface, key water quality parameters are measured a minimum

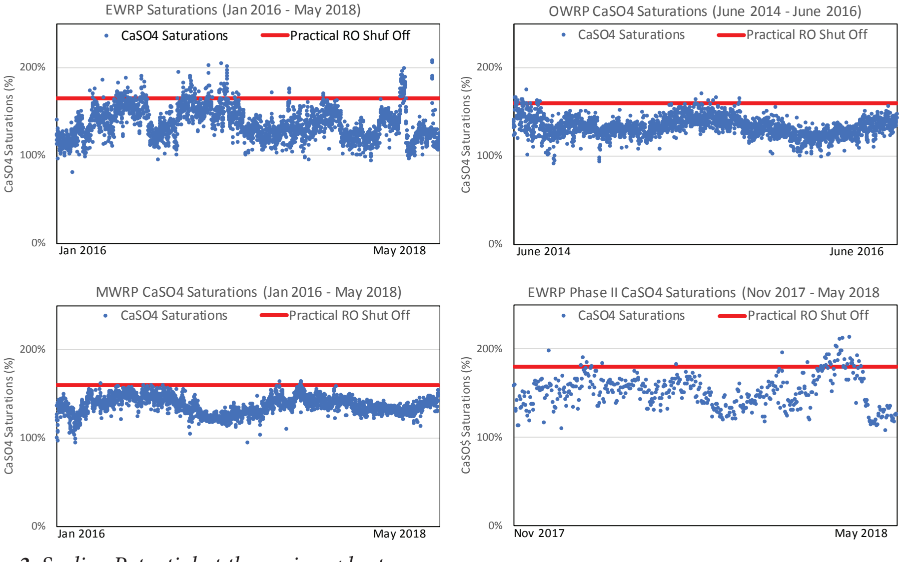

***Figure 3:** Scaling Potential at the various plants*

four times daily to ensure the scaling potential of the water is known at all time. Understanding the practical limitations of the antiscalant in terms of the water quality being processed and the RO unit configuration governs the practical RO recovery that can be managed in these complex scaling waters. The scaling potential is reduced by the precipitation reactors on each stage. Figure 3 shows the scaling potential as measured by the calcium sulphate saturations.

The horizontal lines indicate the practical maximum RO recovery that can be operated until scaling begins to occur. Should these boundaries be exceeded, rapid irreversible and severe scaling can results. However, the closer one operates to the maximum RO recovery, the greater instantaneous production that one can achieve from a given plant. It is apparent to see that the greater the standard deviation of the scaling potential, the greater the risk of scaling incidents. The precipitation steps in the process are able to reduce the scaling potential of the reject by between 3-5 times depending on the plant feed water quality. The impact of poor control of scaling potential is on the second bank of RO membranes installed. An increase in the DP without an increase in temperature indicates scaling. Figure 4 below shows the differential pressure increase on Bank 2 of one of the Stage 2 RO units at OWRP since the membranes were installed and the associated scaling potential of the water. The data has not been normalised. What one can see is that the rise in the DP is faster at the beginning period of the operation when there is greater variability of saturation data.

Fouling Control

Ultrafiltration membranes are utilised as a pre-treatment to the RO membranes. The selection of these membranes over conventional pre-filtration was due to the ability to process water of a high scaling potential and produce a filtrate that has very low suspended solids. Typically, the water that is produced from the UF membranes will have an SDI of below 3 and more generally below 2. It has been observed that the SDI will drift towards the 3 value as the membranes age. In general, a five year life can be obtained from the UF membranes in all of the installations. However, this is a function of the feed water being process and it UF fouling potential. However, if one looks at TOC profile within the plants, one can see that there in an increase through the plant. This is shown for OWRP graphically in the figure below. This increase can be observed through all the installations but the extent of the increase varies across the plants.

The implication of the increasing TOC through the plant is an increase in the fouling potential due to accelerated bacterial growth rates (as measured by change in weekly plate counts) and increased risk of organic fouling. What has in fact been observed is that higher fouling rates through Stage 3 are observed at MWRP and OWRP when one compares the cleaning frequency of Stage 1 and Stage 3 RO operation. However, this is not observed at EWRP where the reverse trend is observed.

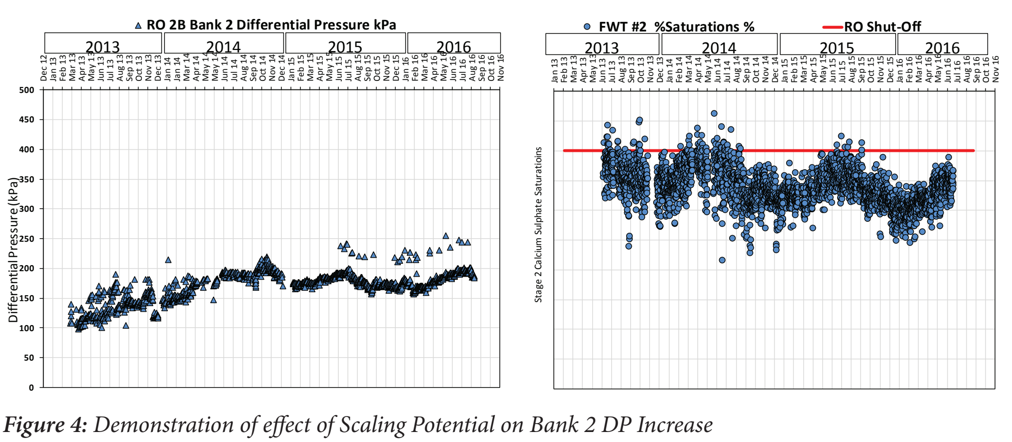

Figure 4: Demonstration of effect of Scaling Potential on Bank 2 DP Increase

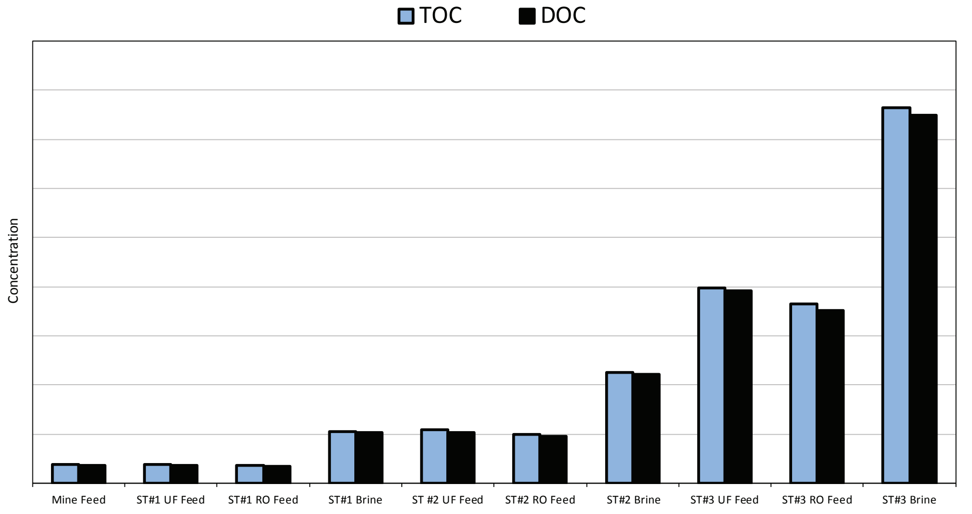

Figure 5: *TOC and DOC from feed to brine at OWRP. Similar trend observed on all installations*

This implies other factors besides just the levels of TOC are important when it comes to predicting fouling rate. It must be noted that the cleaning frequency is severe across all installations and is higher than what is expected through the industry for brackish water membranes. The current observed average cleaning frequency of the membranes across each plant is between 4 days and 14 days depending on the process Stage in operation and the time of year. The operational control of fouling on the plants is not elegant and combines a series of offline interventions (biocide, manual cleaning) done periodically to manage the situation. Further work is underway to better find better mitigation measures.

Salt Passage Increase

During the design phase of the plant, the default salt passage increase of the membrane supplier is used to determine the RO vectors within the plant. This results in an expected salt passage increase of 15% per year. However, the actual salt passage increase is substantially higher. What has been observed is that there is a much higher increase in the salt passage increase in the first few years of operation after which the salt passage increase flattens out. This can be seen in the figures below. Figure 6 shows the salt passage increase of a Stage 1 RO skid at OWRP from the first three years of operation and a second RO skid being the last three years of operation. For the new skid, the first years operation there was the greatest increase in permeate conductivity at 109% with this deterioration decreasing in years 2 and 3 from 89% and 59% respectively. This is compared to that of the skid of the last three years of operation where the last three years of salt passage increase can be seen at 4.27%. If one looks at a Stage 1 RO unit at MWRP (Figure 7) from new, the permeate conductivity increase over the first three years of operations is still higher than the design at 100% for the first year but only 2% in the second year and 23% after year three. It remains to be seen if MWRP Stage 1 RO skid will exhibit the same trends as the OWRP skid as the membranes age. However, even with this higher than expected salt passage increase, the product water produced from the RO skids is still well within the specification for SANS241. Showing that sustainable operation can be realised.

Figure 6 (Right) indicates that baring mechanical damage or scaling, there is a high deterioration of the permeate quality produced from the RO membranes in the early years of operation until it reaches a high point after which it flattens out. What is also interesting to note from the trends in Figure 6 is that the impact of temperature on the permeate quality is more pronounced as the

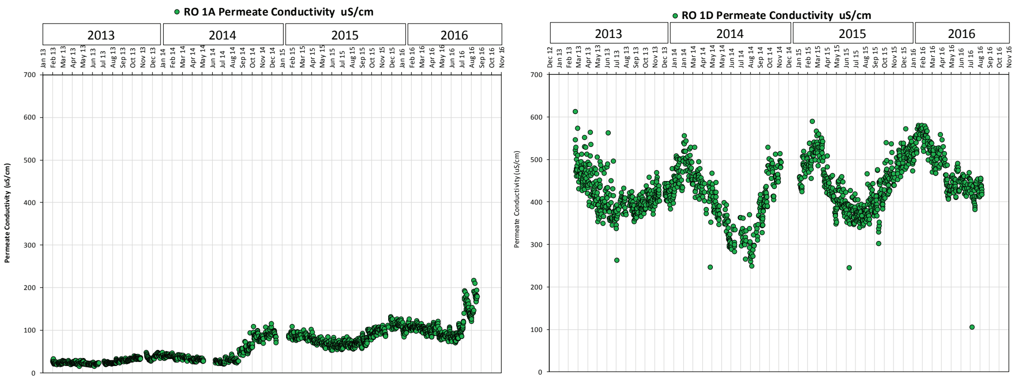

Figure 6: *Permeate Conductivity increase of New Membranes (left) and Old Membranes (right) at OWRP*

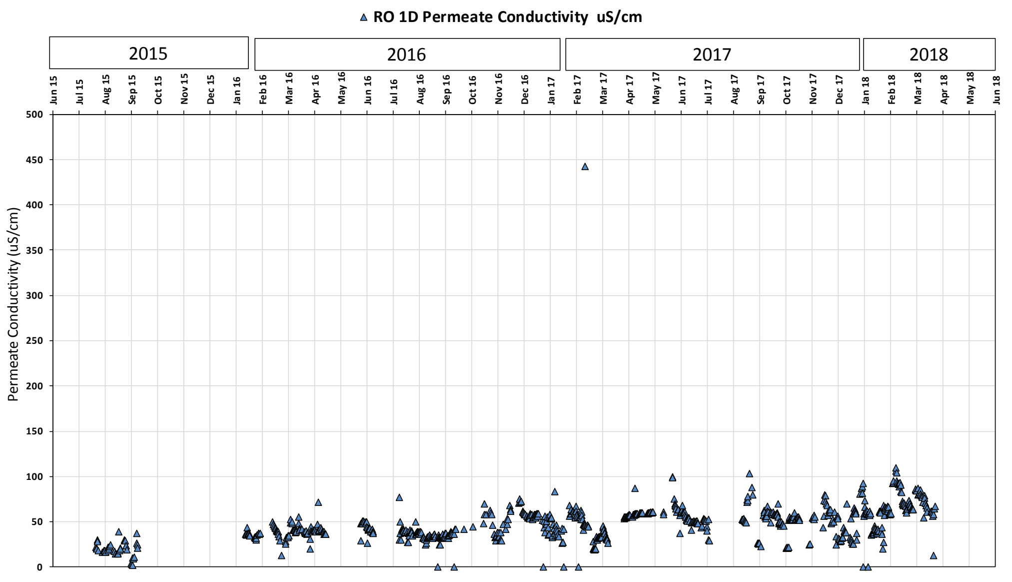

Figure 7: *Permeate conductivity increase of New Membranes at MWRP of New Membranes - Stage 1 RO Skid*

membrane ages. This can even be seen in the new membrane case, where in the first year, the difference between the permeate quality in the low temperature is not too dissimilar to the high temperature case but the cyclical variance becomes more pronounced in year 2 and year 3. The cyclical component on the older membranes is apparent. This is not only observed on the skids presented but on a number of skids of different ages within OWRP and EWRP but is not obviously seen at MWRP. The increased salt passage variability observed is due to the higher basic salt passage coefficient of the aged membrane, on which temperature acts as a multiplier.

Operations

The control of the upstream pre-treatment and the RO membranes requires careful management. Loss of control of any aspect of the plant will have a direct impact on the quality and quantity that can be produced from the plant. As a result, utilisation of this type of plant for the augmentation of water supply to the community will require a highly skilled team. In addition, continuous monitoring of the quality of the plant as well as the various process units require sophisticated control narratives and automation. Lastly, the operations team will need to be well versed in the operation of membranes specifically in terms of when it is required to take offline to clean as well as what cleaning recipes to use. These recipes fluctuate as the risk of both biological and inorganic foulants within the membrane are both present within these installations.

Conclusion

It has been shown that RO membranes can be used to produce a product water that complies with the required legislative parameters. This can be seen by the sustainable operation of three plants, each running for more than three years. The key to producing acceptable quality water is the use of RO membranes to desalinate the feed water. Sequential precipitation minimises scaling potential and energy costs associated with operations of the membranes and allows for high plant recoveries. Management of the scaling potential of the feed water with respect to Calcium Sulphate precipitation is paramount for sustained RO operation, failure of which will cause either a loss of membrane area or a loss of production. In addition to scaling, the levels of TOC increase substantially through the plants. This increases the risk of organic and biological fouling of the RO membranes. Salt passage increases of the ROs on these plants exceed the initial design expectation by a substantial factor. However, it is viewed that the initial sharp decline in permeate quality stabilises as the membranes age but there is an increased sensitivity of the permeate conductivity to temperature. The product water quality is still within the tolerances allowed for drinking water despite these challenges. The plants are operationally complex and require highly skilled staff to manage the various aspects of the membrane operation. The HiPRO™ plants that have been in operation for a number of years and all comply with the SANS241 specifications. Two of which are currently servicing the community for potable water showing that mine impacted water can sustainably be used to augment existing drinking water supplies.

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