

OPERATING AND MAINTENANCE EXPERIENCE AT THE EMALAHLENI WATER RECLAMATION PLANT

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ABSTRACT

The eMalahleni Water Reclamation Plant was designed and built to recover potable water from acid mine drainage from several mines in the eMalahleni (Witbank) area. The Project is a joint initiative between mining companies (Anglo Coal and BECSA). The project was to be ground breaking with the following goals:

- Mine water being used to produce potable water for local municipality use
- A plant of a significant local impact at 20ML/day product
- Waste production at an extremely low level of less than 3% brine
- Positive waste utilization

This goal was shifted half way through construction by the Keyplan team scrutinizing the design and adding clever changes to the existing over-design and allowing the plant capacity to be increased to 25 ML/day.

The plant was commissioned in September 2007 and has been operating successfully since. Production was ramped up to the design level (20ML/d) by June 2008. The highest Average daily production in a month was achieved in September 2008 with a value of 24.2 ML/day. Further de-bottlenecking is being done to fully realize the 25ML/day target. A liquid waste production of less than 1% has been successfully achieved, even achieving monthly values in the order of 99.5%. This has increased the overall recovery design value from 97% to >99.0%. This exceptional water recovery is achieved using the Keyplan Hi recovery Precipitating Reverse Osmosis (HiPRO) process. This process has recently been awarded a Gold Medal by the South African Institute of Chemical Engineers. This process achieves these high recoveries by using membranes only as the recovery unit operation, resulting in low chemical and energy input.

The application of the Keyplan HiPRO process for the treatment of Acid Mine Drainage is a world's first and therefore the correct operating and maintenance of the eMalahleni Plant was a challenge and a learning experience from the very beginning. This paper details lessons that have learned and the challenges that have been overcome over the years whilst operating this truly groundbreaking Water Treatment Plant.

1. HISTORY

Acid Mine Drainage

Acid Mine Drainage (AMD) is formed when sulphide minerals found in mine rock or waste reacts with air and water to form sulphuric acid. AMD constitutes an environmental problem as it contributes to both ground and surface water pollution with elevated levels of sulphate in the water.

The eMalahleni Water Reclamation Plant (EWRP) receives its feed water from four coal mines in the eMalahleni (Witbank) Area:

- Greenside Colliery
- Kleinkopje Colliery
- South Witbank Colliery
- Navigation Colliery

Large reserves of surface and underground water exist at these mines and now through this process this now constitutes a major resource for the production of potable water. Treating the AMD will not only serve to significantly reduce the pollution of water sources in the area, but also provide high quality water to the Upper Olifants Catchment, which suffers from a water shortage.

Some of the AMD collected during opencast mining activities at Kleinkopje Colliery is shown in Figure 1.



Figure 1. Kleinkopje Colliery

Emalahleni Water Reclamation Plant

The concept for the High recovery Precipitating Reverse Osmosis (HiPRO) process was conceived in 1993 on the treatment of EDR Reject. Computer modeling, laboratory analyses and bench testing (1993 – 1996) were used to evaluate the feasibility of the idea. In 1996, Keyplan secured a Sasol EDR / RO Contract, with optional Brine Treatment Loop subject to pilot testing.

From 1998 to 2002 further modeling, testing and experimentation was undertaken using Ultrafiltration as pretreatment for RO. In 2003, a commercial offer was made to Anglo Coal South Africa subject to successful demonstration of the process. The Demonstration Plant was commissioned in 2004 – 2005 and the process was successful. Figure 2 shows the Demonstration Plant.



Figure 2. 4.5 m³/hr Demonstration Plant

The EWRP is divided into stages, from which low salinity product water is generated by the membrane process in each of the three stages:

Stage #1

- Oxidation and Neutralization Reactors
- Clarification
- Ultra filtration – RO pretreatment, removal of residual suspended solids for the production of low Silt Density Index (SDI<3) RO feed water
- Reverse Osmosis – desalination and production of a low Total Dissolved Solids (TDS<200mg/l) permeate, 65% recovery

Stage #2

- Precipitation Reactors
- Hydrocyclones – Solid / Solid Separation
- Clarification
- Ultrafiltration – RO pretreatment, removal of residual suspended solids for the production of low Silt Density Index (SDI<3) RO feed water
- Reverse Osmosis – desalination and production of a low Total Dissolved Solids (TDS<200mg/l) permeate, 65% recovery

Stage #3

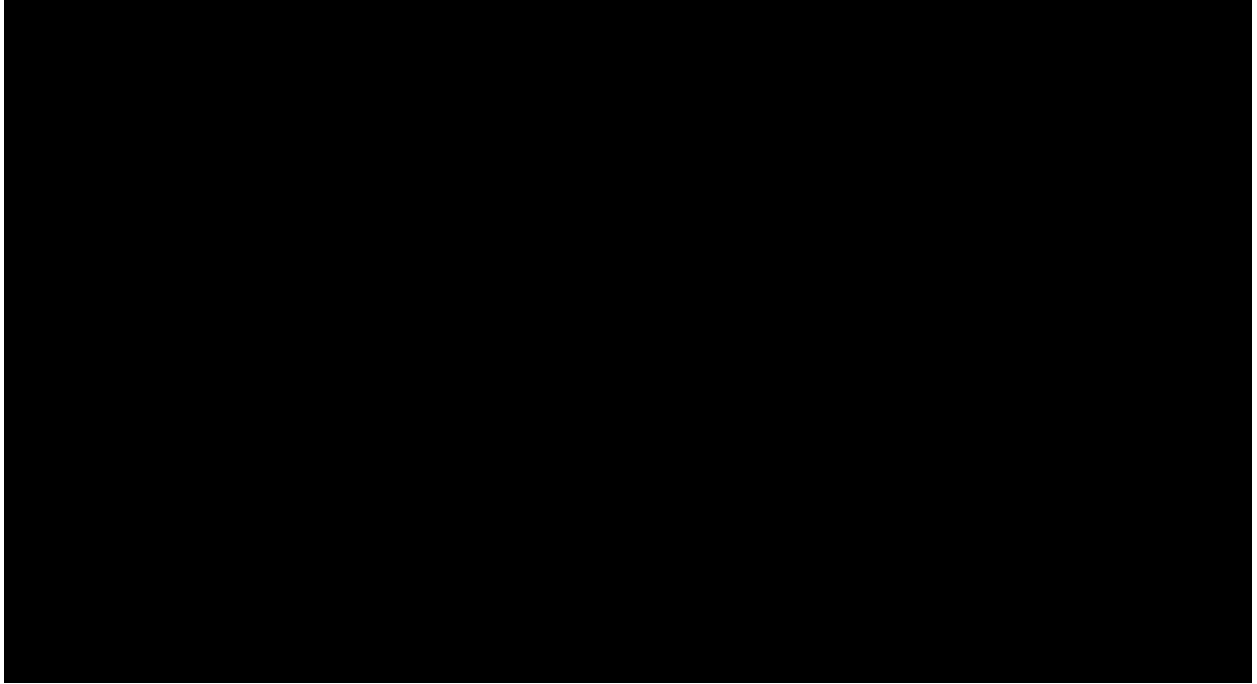
- Precipitation Reactors
- Hydrocyclones – Solid / Solid Separation
- Clarification
- Ultrafiltration – RO pretreatment, removal of residual suspended solids for the production of low Silt Density Index (SDI<3) RO feed water
- Reverse Osmosis – desalination and production of a low Total Dissolved Solids (TDS<400mg/l) permeate, 60% recovery

This design's chief characteristic is that it makes use of Reverse Osmosis to concentrate the water and produce supersaturated brine from which the salts can be released in a simple precipitation process. This technology offers the following key features:

- Very high recovery
- Simple system configuration
- Easy operation
- Low operating costs
- Low capital costs
- Minimum waste

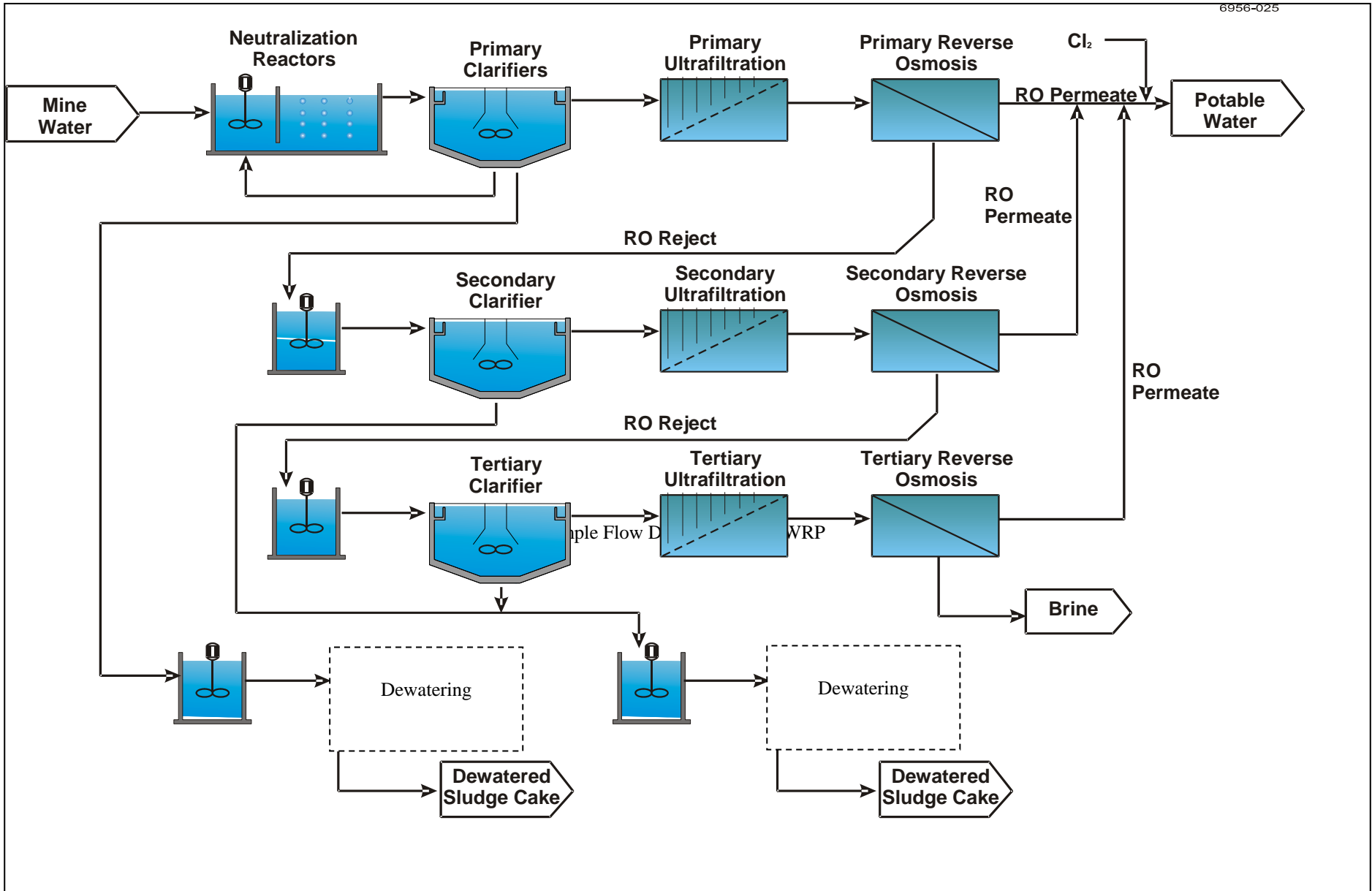
The Plant is designed to treat 25MI/d of AMD with a recovery consistently greater than 99%, producing potable water with a guaranteed TDS of under 450mg/l (SABS Class 0). Table 1 compares the original permeate design specifications with laboratory analysis on permeate samples taken as an extended snapshot from September 2008 to February 2009 (6 months):

Table 1. Feed / Product Water Parameters



The Suspended Solids (SS) of the pure RO permeate is 0 mg/l. The permeate is passed through a limestone saturator so that it can be stabilized and made less aggressive to concrete structures. The limestone saturator has been found to add suspended solids and hence the value of 3.2 mg/l in the table.

A simple flow diagram of the EWRP is shown in Figure 3 on the following page:



2. OPERATING AND MAINTENANCE

Planning Ahead

From the outset it was clear that operating a world's first plant would present a unique challenge. Several complex components of operations would have to be managed simultaneously, not only to ensure that the plant met its design criteria, but also making the satisfaction of all stakeholders a priority, as well as strict adherence to the Mine Health and Safety Act and the Occupational Health and Safety Act.

Operating and maintenance staff was brought in early on in commissioning, some having been involved in the demonstration plant trials. Strict operating procedures were drawn up and enforced. These procedures have undergone several iterations over the past two years, as the plant created many “teething” challenges whilst it began to live up to its full potential.

Personnel

The EWRP is fully automatic, requiring human intervention only for chemical change-over, monitoring and routine maintenance. With this in mind, the original staff quota for the plant was set at 20 – consisting of a few operators and a small maintenance team for plant purposes only.

Over the years, however, the plant scope has increased and it has proved that a higher level of human interaction is required to achieve the plants design capacity safely, smoothly and consistently. Today, the number of staff has increased to 35, with each member being actively involved in maintaining the plant operability. The additional scope includes 2 front-end loader drivers and a site safety officer. The construction of the new Phase 2a plant, which produces up to 10 MI/day of process water on the various mines, required the addition of 1 operator per shift (i.e.4 staff) and 2 artisans as well as a cleaner. Standby functions on the electrical, laboratory and operator front required the employment of extra staff. The handling of significant levels of processes, from buying to data capturing etc. resulted in the need for an administration controller. Due to the complexity of the plant and the shortage of skilled labor on this type of plant, it was decided to have a permanent training officer who will ensure there is no lapse in skills amongst the staff and that any turnover of staff is managed carefully to reduce risk to safety and plant. The process staff, operators etc., have a unique opportunity on this plant to gain experience on a complex and sophisticated membrane plant and they have taken full advantage of this, developing a good understanding of the plant chemistry and all of the subtle nuances that go into operating the plant.

It was also made clear early on that the maintenance staff required a solid process understanding if they were to locate, identify and resolve any mechanical or functional problems that arose. The maintenance staff, having gone through the commissioning phase, is well experienced to handle all related maintenance issues pertaining to Ultra filtration membranes and Reverse Osmosis membranes and equipment. Their process knowledge places them in a position to anticipate and respond timely to the process staff's concerns. Figures 4 is a typical commissioning procedure in action.



Figure 4. Vessel Flushing

Although the operations and maintenance staff started out under the Keyplan design and construction department, it was decided to move this function under its own operating umbrella. The team has been amalgamated together with the Engineering and Project Company's metallurgical division and the new team is called the Engineering and Project Company Operations division and it has competency in the water, metallurgical and processing industries. Reasons for the change are to ensure there is a common focus and to provide a support structure that is unique to the operations business.

Figure 5 below shows the first sip of the very first potable water produced:



Figure 5. First Water

Awards

The plant has received several awards including the Mail and Guardian and Nedbank Sustainability award and most recently the South African Institute of Chemical Engineers Gold Medal award for the HiPRO process development.



Figure 6. Scan of the Mail & Guardian Green Award

Safety

The EWRP safety regime is comprehensive in that it operates between two safety guidelines. These guidelines are the Mine Health and Safety Act and the Occupational Health and Safety Act.

The EWRP is currently sitting on 707 Lost Time Injury free days as at the end August 2009. This is the result of the combined initiatives and discipline of the Client, Anglo Coal, and the Contractor, E+PC Operations. This is a good accomplishment considering that there are over eight hazardous chemical on site for various process functions, that there is a filter press operation and a site laboratory.

All chemical storage / dosing areas are clearly marked and barricaded, and staff trained and tested on safe working procedures in all potentially hazardous areas of the plant. Similarly, all areas of the plant that carry an inherent risk are marked and / or barricaded and the staff trained.

The plant layout was designed with ergonomics and safety as its key cornerstones, and over the years minor modifications have been made to specific areas to improve the operational “comfort” and safety of the staff. Some initiatives that have been implemented are:

- The automation of certain process valves that were difficult to access or unsafe to access
- The automation of the chemical make-up systems for the UF and RO cleaning systems to reduce material handling and chemical exposure.

- Level detection instruments have been placed in critical chemical bunds to alarm the operator as to any leaks as soon as possible.
- The upgrade of the sulphuric acid lines to PTFE lined piping.



Figure 7. Safety First!

Plant Control

An ADROIT Supervisory Control and Data Acquisition (SCADA) system has been installed in the eMalahleni Water Reclamation Plant. All process control procedures and sequences are programmed in the Siemens Programmable Logic Controller (PLC).

The SCADA system provides the interface between the operator and PLC in the following manner:

- It provides the operator with the ability to place plant systems into a specific operating mode in a coherent and safe manner (programmed within PLC)
- It provides a visual confirmation of the operational status of a specific piece of equipment (actuated valve, pump etc)
- It displays plant measured variables from online instruments or devices
- It allows for the trending and recording of critical process parameters
- It generates alarm or warning messages during abnormal or fault conditions within the plant
- It provides detailed feedback as to why a specific sequence step failed so that the operator can correct the fault

Each plant section is able to be placed online independently of any other section, as long as there are no interlocks that prevent the required action. Placing a specific section online will automatically start the relevant drives and actuate the respective automatic valves into their correct positions for normal operation.

In addition to the automatic control, a complete quality assurance and operating control system is in place. Critical control samples are taken on a shift basis to verify that the on-line instrument results are accurate at all times. Complete manual procedures for all systems are available and the staff trained in its implementation.

To ensure that the plant is being well maintained, the PRAGMA maintenance information system has been introduced to optimize and record maintenance activities per item. This produces weekly updated reports pertaining to legal compliance work, work schedules as well as unplanned break down work.

Feed

The feed ponds have capacity for 2 days storage and the waters feed from four different mines. The feeds from Greenside Colliery and Kleinkopje Colliery are close to neutral pH and the feeds from South Witbank and Navigation have high acidity. It has been found over time that it is important that a blending program be put in place to try and avoid feed chemistry swings caused by excessive flows from any one source. Although the plant would accommodate this, for operator security and for optimized controls, continuous blending throughout the day would be best. Although EWRP has 2 feeds supplying at the outlet of the feed ponds to reduce sludge build-up in the pond, it is suggested that in future installations, these be placed further into the pond to facilitate a dilution of any peaks into the system.

Below are some graphs showing some trends on plant feed Total Dissolved Solids, Acidity and Sulphate:

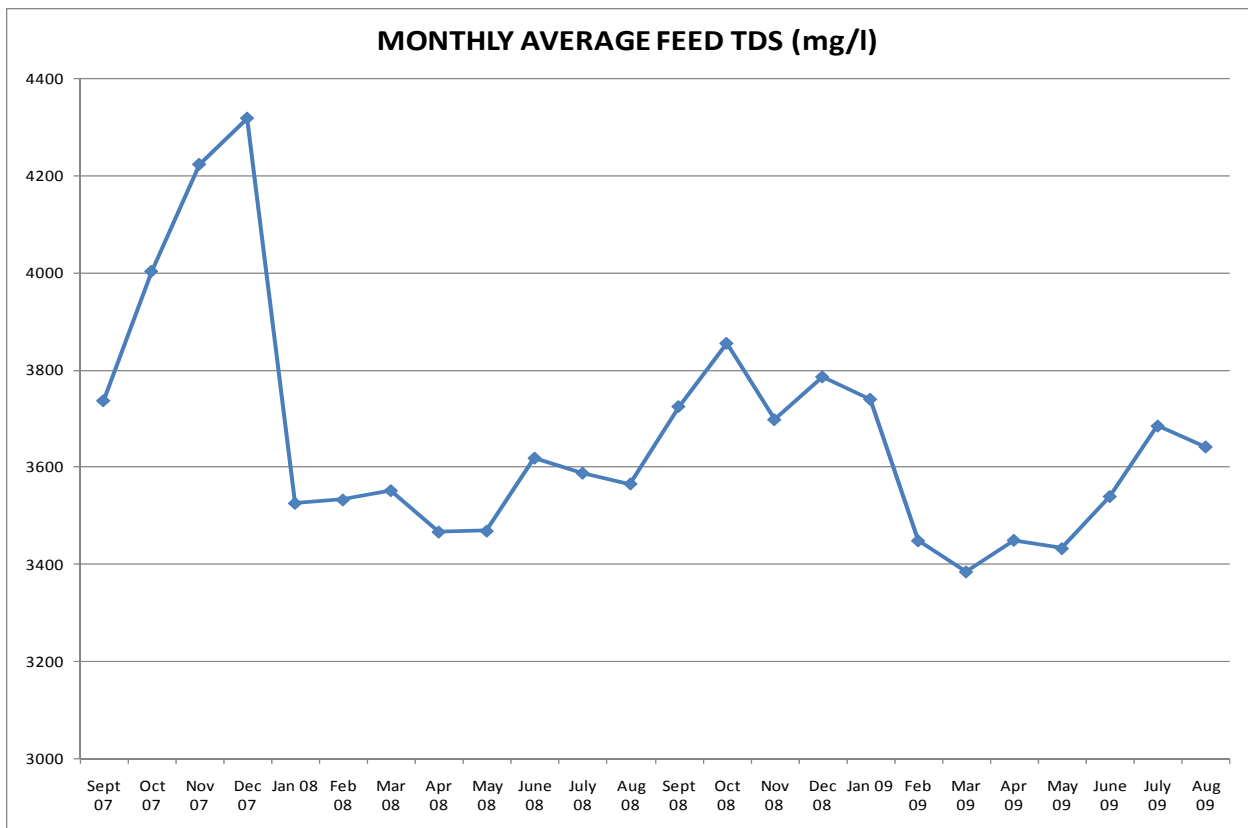


Figure 8. Monthly Average Feed TDS

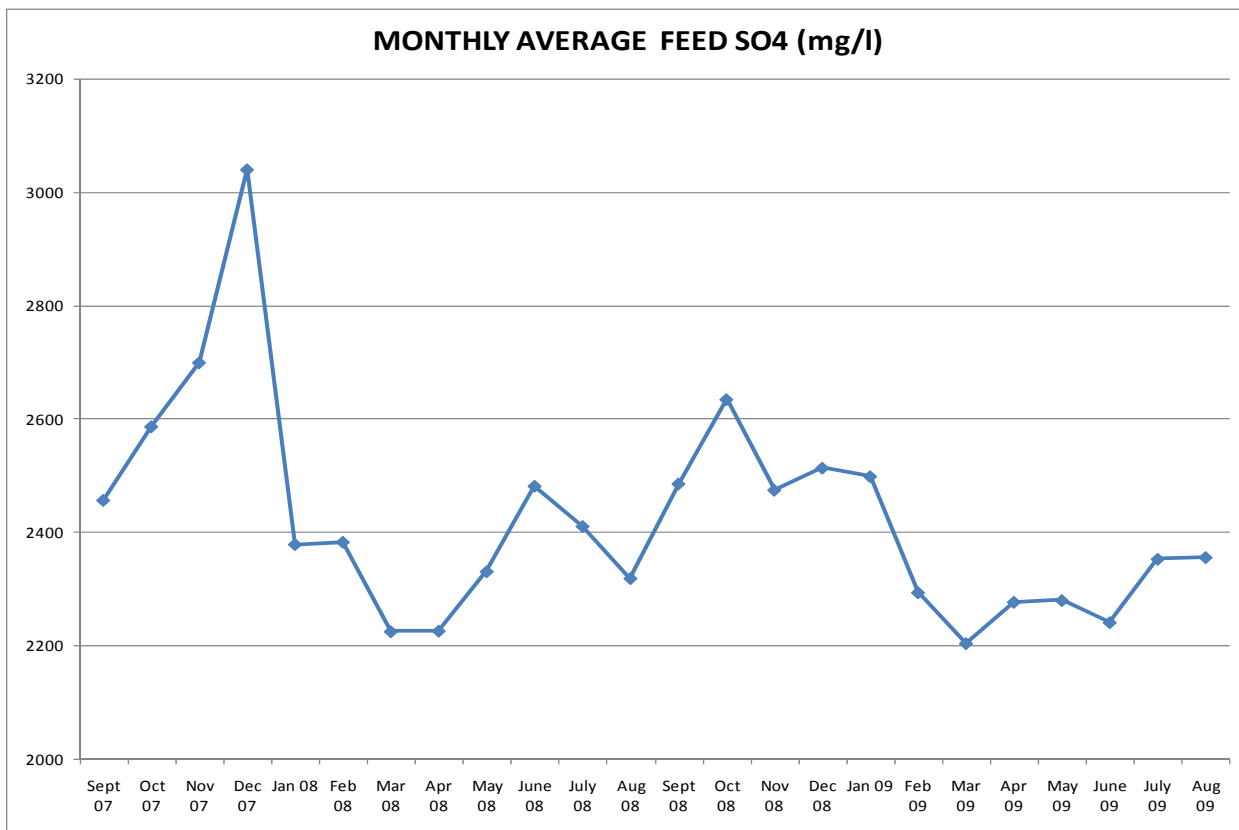


Figure 9: Monthly Average Feed Sulphate

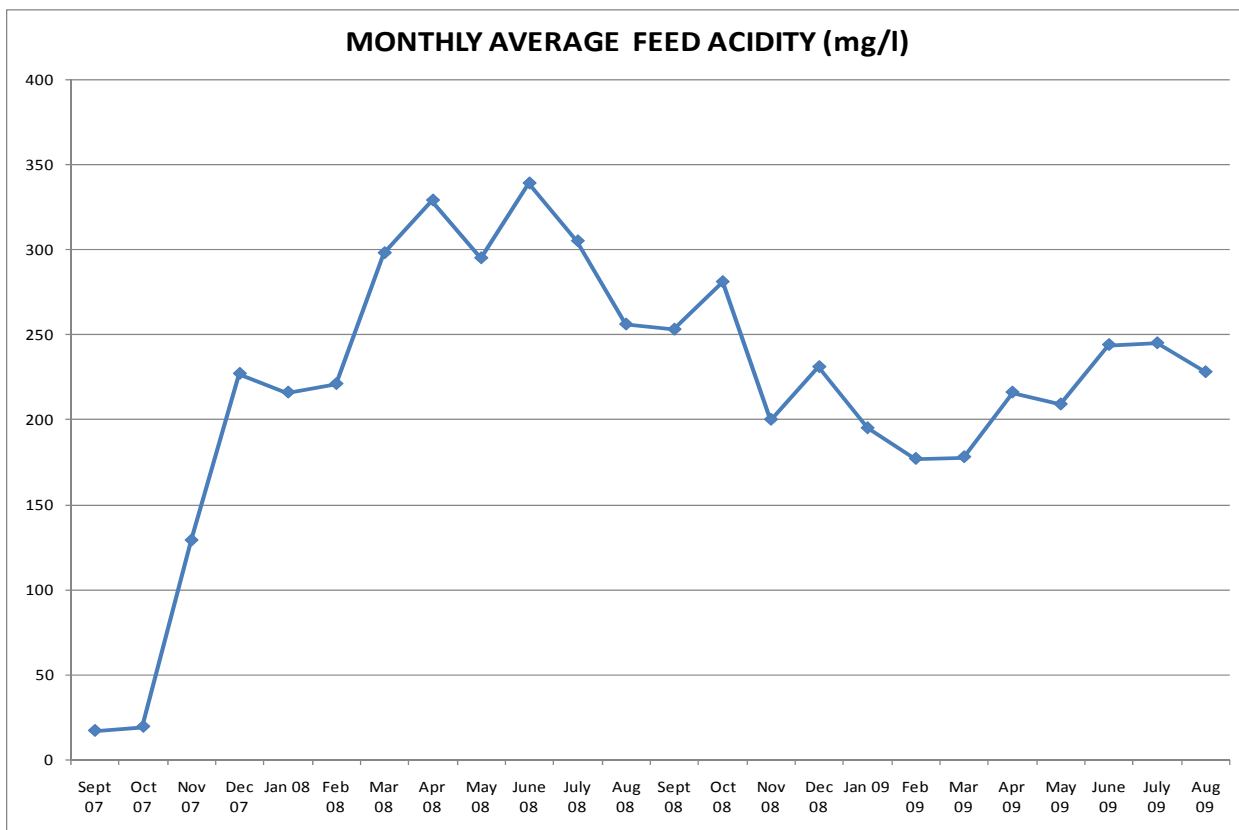


Figure 10. Monthly Average Feed Acidity

Production

The production ramp up can be placed into the following challenging phases:

- The build-up of stage sludge's. The stage 2 and 3 sludge, after several weeks of running, grew so large in particle size that it required the fitment of hydro cyclones to remove the coarse material from the clarifier feed. The heavy material was causing choking of the clarifier rake mechanism.
- Stage 1 RO's were run well before stage 2 was ready to commission, resulting in cycling up of salts throughout the system. The oversaturation of the system during stage 2 shutdown periods resulted in the plant being taken off or reduced flows applied. The process only allows for brine dump from the stage 2 or 3 RO's.
- The struggle to keep the filter press availability high enough to sustain higher plant flows. Failures of the first versions of fetter bags used to close the plate type press and teething problems. The plant was often taking off-line or on reduced flow in the early days as a result of the inability to remove solids from the clarifiers.
- The need to improve feed supply reliability. There were short patches where there was insufficient feed to sustain the increasing plant flows.
- The need for significant plant downtime for access to complete construction activities and punch lists items.
- The introduction of Kleinkopje feed from the dam and the resulted algal bloom in the plant with a loss of operating flux on the UF's and the need for a different cleaning regime. Currently sodium hypochlorite is used predominantly for UF membrane cleans.
- Partial blockage of the Green Sand filters due to poor backwashes and solids clogging. Additional backwashes launders were fitted to assist in the removal of solids.
- Changing the Green Sand Filter Backwash program to prevent the need to reduce production during this process. A future backwash tank will be necessary.
- Some break through of suspended solids through the UF's onto the RO membranes. This was a result of some o-ring failures on the headers as well as a small number of membranes having one or two fibre breaks. This was repaired and the RO differential pressures stabilized on the first banks. The suspended matter that broke through allowed for a soft slimy film formation in the RO feed tanks and this peeled off resulting in some rapid increases in the bank 1 differential pressure. This poses a risk of too high a differential pressure across the individual membranes and some signs of "coning" was evident on some RO feed side membranes. A comprehensive monitoring program on the UF performance is in place to prevent this occurring again and all slime was removed by high pressure cleaner.
- Periodic failure of the Stage 1 RO feed pumps. Additional pipe supports were installed to alleviate any strain on the discharge side. Vibration monitoring over time has now indicated that the problems lies in the inadequate reinforcing on the base plates and repair is imminent.
- Replacement of some bank 3 and bank 2 RO membranes damaged during the oversaturation of the plant as well as deficiencies on the antiscalant dosing system. There were occasions when the antiscalant line was worked on for maintenance and the line not adequately primed before start-up of the RO's. The monitoring programs on Calcium Sulphate saturations were increased to ensure plant is sooner removed from service when saturations are too high for any particular reason. Much tighter trip controls were placed on all monitoring parameters for the RO membranes – flux, differential pressures and recovery ratio. Although this is RO membrane damage is not desirable, the specific causes of RO damage have all been identified and actions taken to prevent such a re-occurrence.
- Periodic difficulties in optimizing the clarifier performance with changes in plant conditions. The nature of the sludge, the clarifier turbine speed, the step changes in plant flows, the underflow sludge density and the numerous recirculation possibilities all play a part and constant adjustment is necessary.
- The polyelectrolyte used is in the emulsion form. The supply of emulsions is proving to be quite restrictive in terms of making quick changes or finding alternate products. A dry powder make-up system is preferred as it has less volumes and lower associated transport costs. They are also more readily available from suppliers. The plant polymer is mixed in an eductor and this is prone to blockages, and has resulted in numerous high turbidity results on the clarifiers. There is only one preparation tank on this system, which means there is less back-up should the make-up process fail for any period of time and it also introduces make-up strength errors as one is drawing from the tank while a batch make-up is in progress. The process of purchasing a dry powder make up system is under way.
- The installment of additional RO vessels to allow for increased production, this being on stage 1 and 2.
- The fine control measures needed to manage the plant saturation levels with the higher plant flows and hence lower residence times, especially on the pre-treatment. It has taken time to develop a feel for how the various plant controls affect the saturation levels on the plant. It is believed that is now well understood.

- The decline in the UF fluxes to approximately 30% of design capacity. Numerous cleaning methods were adopted until it was found that a Citric acid clean recovered the fluxes back to the design capacity.
- The significant foam formation on the plant, resulting in regular plant trips due to level transmitter failures. This foam is still prevalent, but the plant trips have been resolved through the use of guided radar level transmitters as a short term solution. The foaming causes a mess and occasionally affects the clarifier turbidities to the point where production is affected. Strong Oxidants are currently being trialed to try and reduce the biological content of the overall system. An algal content has also been recorded, and it's expected that the oxidants will destroy the algae until only a minimal residual content remains.
- Currently the plant is being restricted by the ability to remove the ~200 tons/day sludge being produced. There are adequate numbers of presses, however the sharing of common equipment between presses is resulting in sequences holding and lost pressing time. The presses should, where possible, have dedicated auxiliary equipment and this is currently being priced.

The EWRP has proven time and again its ability to meet the demand requirements, having attained a peak flow of 26MI/day and recoveries have now stabilized around 99.5%. This kind of recovery has huge cost benefits as it will prevent the need to build an additional brine dam in the near future. The up-rate of the plant has proven successful, but it is clear that it has made the system a little more sensitive to plant fluctuations, having reduced residence times on the pre-treatment reactors. Given this, the system can be managed through good operating procedures coupled with the good process understanding of the EWRP staff. Figure 11 shows the plant average permeate production from October 2007 to June 2009.

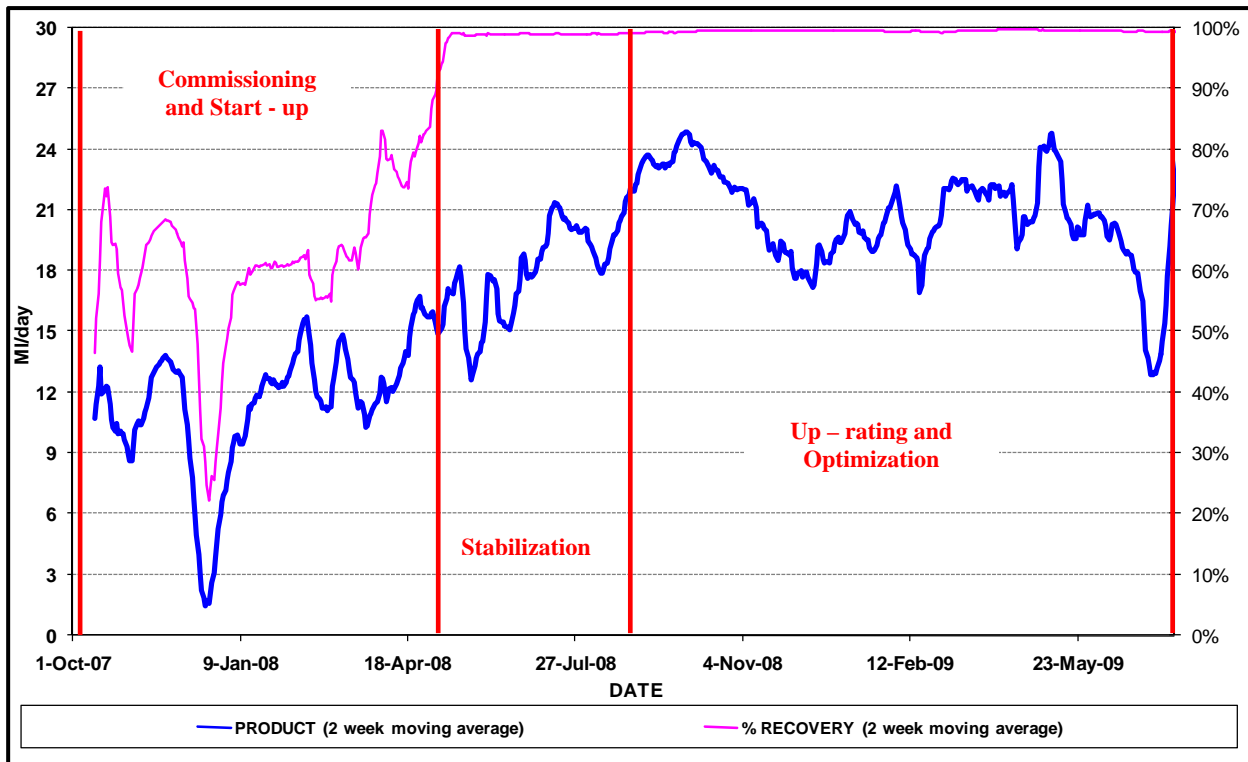


Figure 11. EWRP Flows and Recoveries since Commissioning



Figure 12. Section of the Membrane Plant

Detailed records of the plant performance are kept electronically and a hard copy is filed for future reference. Regular checks and balances are carried out to ensure that the plant is meeting all compliance standards. There have been no problems meeting the SANS 0241 Class 1 specification, except on turbidity, where the limestone saturator adds turbidity to around the 1 NTU mark. The media used in these saturators is under review to eliminate this problem. It is fair to say that this poses no threat to anyone's health.

Future plant expansion projects are a possibility. To meet this requirement, Keyplan have developed a new modular system layout in standardized AMD Treatment Plant configurations. This will enable plants to be constructed and commissioned within shorter times.

Another HiPRO Plant is currently being built for Optimum Coal Holdings in the Middleburg area, with a capacity of 15MI/d at a recovery greater than 98%.

Figure 13 below shows the foam generated on the plant:



Figure 13. Foam in the Precipitation Reactor

Co-Ordination

It has been a great accomplishment for this plant to have pushed through the numerous challenges that were faced. One of the significant benefits has been a close relationship between the design, construction and operations teams. This has ensured regular feedback between parties and got some speedy solutions to looming problems. All the learning from this plant has been addressed in some form on the new designs. One looks forward to the future achievements together.

3. CONCLUSIONS

Anytime one begins to attempt something that no one else has done before, it becomes clear that there will be challenges, “ups” and “downs”, and a great learning experience. This plant is no different.

It is evident that the commissioning of such a process should not be started prematurely but only once at least 2 stages are available in order to allow for brine dump at a reasonable TDS levels and prevent the cycling up of salts, thus risking the RO membranes.

It is invaluable for the Operations and Maintenance team members to go through the commissioning process and be a part of the early problem solving phase of the plant. This ensures that they are well versed with the design basis of the plant as well as the control philosophy and sensitive areas of the process. It is also clear that this type of sophisticated water treatment plant does need an above average staffing strategy to ensure its well being.

Membrane health and performance are paramount in keeping this process going. There are numerous factors that risk the membranes and a comprehensive monitoring plan must be rigorously adhered to and firm guidelines established as to how staff are to react to these risk factors.

One can easily focus on the main process, but it is often the auxiliary systems that can pose the delays, for instance the ability to remove sludge, the reliability of the feed sources and the chemical treatment capability.

The EWRP has taught us that it is a very sensitive process, yet very reliable if managed correctly. The plant requires constant qualified care and monitoring, occasional tweaking of operating parameters, and sometimes aggressive solutions to maintain the plant on its pioneering journey. It is clear that without the dedication of the staff that the plant would not have experienced the enormous successes and won the numerous awards that it has. It is clear that

one should not cut a fine line when it comes to staffing, as understaffing will only result in reduced monitoring and possible increased risk that could result in a transient scaling or fouling condition is missed.

It is credit to the Keyplan design team that has ensured that there is additional capacities build into the design and there are flexibilities to cater for different production limiting scenarios. The operations, design and construction teams worked closely together to achieve a good result.

Safety, as always, remains a core value for the production team and much effort needs to go into plant improvements as well as competency improvement on a daily basis. A safe environment makes for a pleasant work environment.

Looking to the future one can say with surety that water treatment will undergo radical changes, not only in the field of treating previously “un-treatable” water, but also in what one believes is and is not possible. The EWRP will stand proud for decades to come as a testament to mankind’s ability to persevere, innovate, and accomplish.

4. REFERENCES

Kahan, I (2009) “eMalahleni Water Reclamation Plant – Towards Zero Waste” WISA Membrane Technology Conference 2009