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Passive treatment of acid mine drainage at Vryheid Coronation Colliery, South Africa

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Abstract

A novel passive bio-neutralisation water treatment process has been applied to treat an acidic mine drainage decant emanating from a closed colliery in northern KwaZulu Natal, South Africa. The process has been implemented to treat 200 m³/day of water and incorporates the following components: a 3.2 km pipeline from the decant point to the water treatment site, a molasses dosing station, a 1,000 m³ bio-neutralisation reactor, three aeration cascades to oxidise sulphides, passive sulphide gas extraction to a bio-filter to oxidise sulphide gas, three limestone reactors for pH polishing, and an aerobic wetland to remove residual nutrients. The bio-neutralisation technology is a strictly biological process utilising bacterial processes to treat an influent with a pH as low as 2.8 to remove the acidity, iron and aluminium. The plant has already been constructed and commissioning commenced in August 2015.

1 Introduction

Vryheid Coronation Colliery (VCC) is situated about 30 km east of the town of Vryheid in the hills of northern KwaZulu Natal Province of South Africa. Portals were established on the outcrops of three semi horizontal coal seams, which were extensively mined with different mining methods from 1923 to 1998, producing about 80 million tonnes of coking coal over the life of the mine. Because of the hilly nature of the area, the cover over the underground workings varied from a few metres to about 250 m and numerous access points to the mine workings are present on the outcrops of the seams. Total extraction mining methods were applied over extensive areas of the three seams, resulting in the overlying strata collapsing and breaking up, manifesting itself as cracks and subsidence on the surface. These features in turn act as conduits for precipitation and runoff into the now abandoned underground workings, where the water acidifies due to the presence of sulphides leading to the well-known sulphide oxidation process and production of acidity, and dissolution of available heavy metals. Eventually the polluted water finds its way to a mine opening somewhere on the lower outcrop, where it appears as a saline or sometimes acidic decant. As the decant is ultimately driven by precipitation, and as the Province of KwaZulu Natal experiences 90% of its precipitation over the summer season from October to March each year, the decants will follow this pattern, with a lag of about three months.

The acid decant, which is the subject of this paper, is known as the West Adit decant and is located 2–3 km upstream of where the main community associated with the mine resides. This is also the most acidic decant point from the mining operations and from that perspective the obvious choice for remediation. As the mine is located in a rural area with limited manpower and commercial resources, a water treatment technology had to be selected which was both simple and cost-effective. This ruled out active treatment technologies such as reverse osmosis and pointed the way to passive treatment.

VCC also played a critical role in the historical development of the passive treatment technology in South Africa, with pilot plant work being undertaken at VCC in the late 1990s and early 2000s. The earlier research work on the passive treatment technology is extensively described by Pulles et al. (2003) and a detailed discussion on the research work specifically undertaken at VCC is presented by Molwantwa et al. (2010).

2 Background to South African passive treatment research

The primary research initiative into passive mine water treatment in South Africa has been focused on the development of high-rate sulphate reduction technology capable of reliably and cost-effectively removing high loads of sulphate from mine waters. Whereas a range of active treatment technologies are available for treating any type of mine water to any desired product water quality, there is a specific need for the development of passive mine water treatment technology for closed mining sites where long-term water treatment is required.

The South African research programme into the high rate passive sulphate removal technology was started in 1994 by Pulles Howard & de Lange (PHD) Incorporated and in the 21 years since, the research has incorporated the inputs of a multitude of organisations, universities, research institutions, mining companies and researchers.

The research effort addressed the problem both at a fundamental science level and at the more empirical pilot plant level. Whereas there are numerous anaerobic sulphate reducing reactors in operation around the world on mine waters that remove some sulphate together with metals and acidity, these are typically plagued by low sulphate removal efficiency (<300 $mmol.m^{-3}.d^{-1}$), and gradual reductions in overall reactor efficiency with time. These same limitations on sulphate removal rate were also encountered in the early phases of the South African research effort. This finding is similar to results reported in the PIRAMID Consortium (2003) report:

> *Tentative design values for SO_4^{2-} removal in such systems range from 300 millimoles per cubic metre per day ($mmol.m^{-3}.d^{-1}$) (Gusek 1998; Lamb et al. 1998) to approximately 800 $mmol.m^{-3}.d^{-1}$ (Willow & Cohen 1998).*

On the other hand, the technology eventually developed in South Africa is able to operate at high sulphate reduction rates of between 1,700 and 9,200 $mmol.m^{-3}.d^{-1}$, (Pulles et al. 2004), and was subsequently patented in South Africa, Australia and the United States (RSA Patent No ZA 2002/03459; Australian Patent No 2002307808; and US Patent No 7,306,732). The full history of this research programme with all the insights that were gained and problems that were experienced is described in Pulles and Heath (2009).

While the high rate sulphate reduction technology was successfully developed and patented and is known as the degrading packed bed reactor (DPBR), a key feature of a successful passive sulphate reduction technology is the need to also develop a passive sulphide oxidation technology that is capable of removing the sulphides produced from sulphate reduction before they can be re-oxidised back to sulphate. Additionally, conventional passive anaerobic sulphate reduction technology has encountered a lower pH limit of 4.5, below which the reactors cease to function effectively and a need to develop passive treatment technology capable of operating successfully at the strongly acidic pH range also emerged from the earlier research.

The passive sulphide oxidation research originally focused on a floating biofilm type of reactor, as described by Molwantwa et al. in 2004. The research effort identified a linear flow channel reactor (LFCR) as the best configuration for a passive sulphide oxidation technology and this research is well documented by Molwantwa and Rose (2013) and Mack et al. (2009). This research showed that up to 88% of the sulphide that is produced by a DPBR can be removed by a LFCR and that based on a sulphur mass balance, up to 66% of the sulphur can be recovered from this reactor as elemental sulphur. While an earlier attempt to operate the LCFR at a demonstration scale at an operational mine site was undertaken and has been reported by Muhlbauer et al. (2010), this work was not successful. Further research work was then undertaken at the

University of Cape Town, South Africa and is reported in van Hille et al. (2011). The next phase would be to take the findings from this research and construct a second-generation field-scale unit at the VCC plant that is the subject of this paper. Funding for this next-generation field-scale plant still needs to be sourced but discussions in this regard are currently underway. Such work is critical to the overall effort to develop a passive sulphate removal technology as while the high-rate sulphate reduction component has been addressed in the patented DPBR, the sulphide oxidation technology is required to linearise the sulphur cycle and extract the reduced sulphide as elemental sulphur.

The second requirement to develop a passive treatment technology capable of operating at influent pH levels below 4.5 was initiated in 2003 and the background to this research effort is described in Section 3.

3 Background to South African passive bio-neutralisation research

The biological sulphate reduction process used in the DPBR depends on the use of anaerobic activities of sulphate-reducing bacteria (SRB) for the biogenic reduction of sulphate, a terminal electron acceptor, to hydrogen sulphide (H_2S) in the presence of carbon as an electron donor. The hydrogen sulphide produced can be used to remove and recycle heavy metals as metal sulphide (MS-) precipitates from the acid mine drainage (AMD). The use of SRB for AMD bioremediation also results in the production of alkalinity which leads to an increase in pH of the AMD. Over the years a variety of cost-effective carbon sources have been investigated, including sewage sludge and lignocellulose (Coetser et al. 2006), in order to produce small molecular weight organic acids and alcohols that can act as electron donors for SRB.

Known strains of SRB are sensitive to even mild acidity resulting in poor growth, if at all, at pH values less than 6 (Kolmert & Johnson 2001). This represents a potential problem in using SRB technology to remediate acidic effluents, as exposure to acidity may result in SRB being inactivated or killed (Kolmert & Johnson 2001). This limit can be overcome in active biological treatment systems by either installing an active pre-treatment step in order to raise the pH, or by instituting some form of recycle loop to utilise the alkalinity in the treated water to neutralise the acidic influent water. However, in passive treatment systems, recycle loops are not possible due to the need to then overcome process head losses without pumping systems.

PHD Incorporated therefore undertook studies aimed at obtaining and selecting bacterial cultures that could operate under very acidic conditions, around pH 3, and which could pre-treat/neutralise the acidic influent water prior to treating it in the passive sulphate reduction system. Samples were taken from various mine sites in KwaZulu Natal, including the VCC West Adit site where the passive treatment plant has now been constructed, that discharged strongly acidic water and these samples were cultured into two duplicate DPBR systems at PHD's laboratories.

Bacterial populations were isolated from mine effluents and selectively cultured over a period of around 150 days to produce populations that have subsequently been used in a 12-year research programme from 2003 to the present to develop the bio-neutralisation technology. Both column reactors have been in continuous operation since 1st July 2003 till July 2015 and have consistently succeeded in raising the pH of the water from around 3 to between 6 and 7, while removing up to 1,000 mg/ℓ of sulphate and reducing the redox potential to below –300 mV. Data for the period 2003 to 2012 for pH and redox is shown in Figure 1.

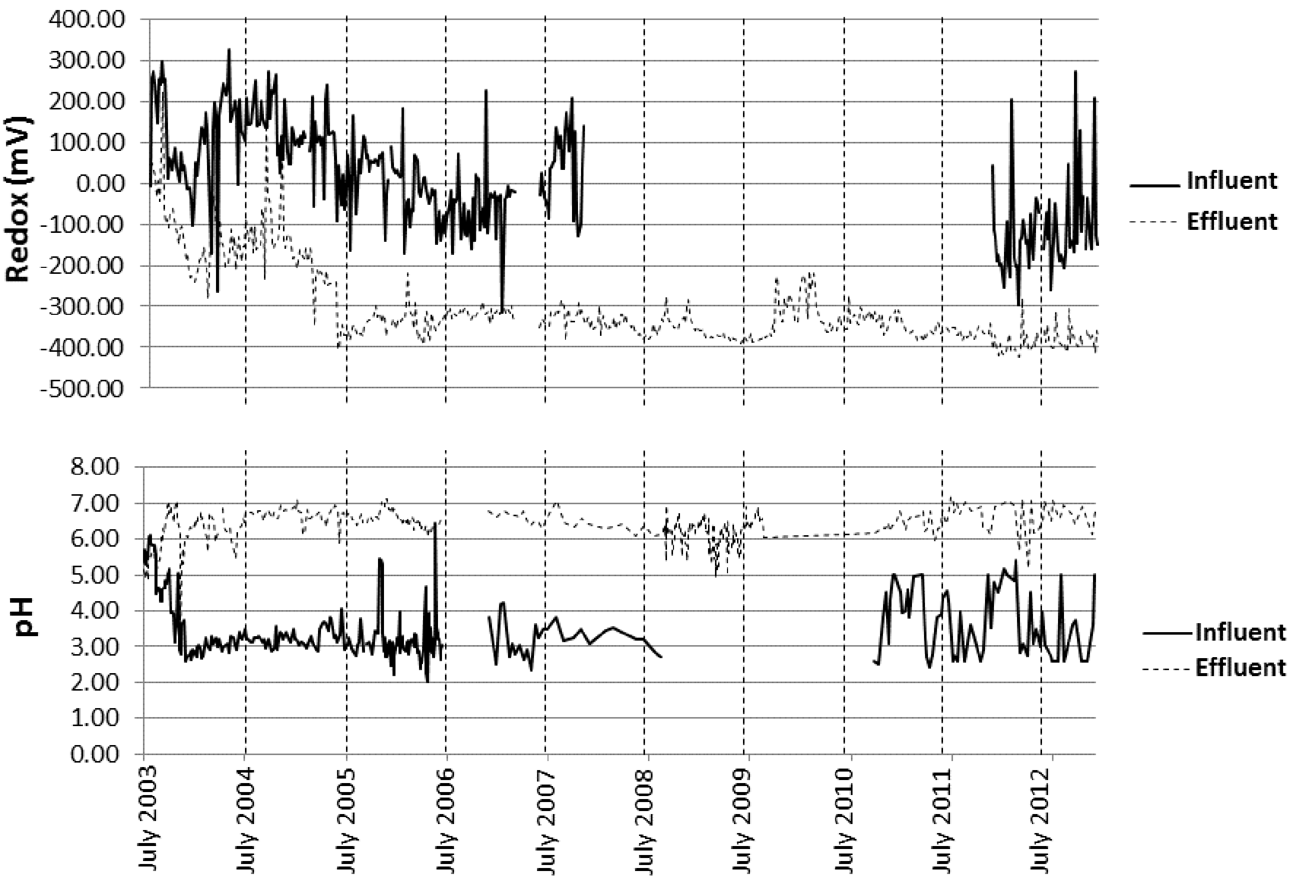


Figure 1 Results of bio-neutralisation reactors operated for nine years

A detailed descriptive model of the bio-neutralisation technology was developed using results from the following investigations:

- Six years of operational results and data.
- A number of depth profile studies to track reaction progression along the column.
- A molecular microbial ecology study of the system.
- Laboratory studies on metalliferous and highly acidic water.

Using the data referred to above, it was found (Pulles & Heath 2009) that alkalinity generation is clearly linked to biological sulphate reduction and this can be seen by the close linkage between datasets for alkalinity generation, sulphide generation and sulphate reduction. Furthermore, the microbial ecology study has demonstrated the presence of SRBs and associated bacterial populations that have previously been isolated from acidic, anaerobic, lignocellulose-degrading environments.

Previous literature on acidophilic sulphate reducing systems have suggested that neutral-charged, small organic compounds are used as the nutrient source rather than organic acids. Microbial ecology studies have demonstrated the presence of a complex consortium of microorganisms involved in the degradation of lignocellulose compounds relating to acidic, anaerobic environments such as sphagnum peat bogs, Phragmites rhizosphere, wetland sediments and acidic root zones. It is significant that together with these, Clostridium species have been found that were previously isolated from the gut of termites and which are likely to be involved in the fermentation of sugars and acids into neutral compounds such as alcohols, including methanol and glycerol. Microbial ecology studies have shown the presence of the various elements of the consortium needed to effect the abovementioned sequence of reactions.

It was also found that both the SRB and the cellulose degrading and fermenting microorganisms require substantially reducing environments and operate at low redox. It is evident that facultative anaerobes need to be present to purge residual oxygen and to poise redox conditions to below -250 mV in order for sulphate reduction to occur effectively under the highly acidic conditions. Microbial ecology studies have also shown the presence of facultative anaerobes such as Cytofaga and others closely related to facultative anaerobic metabolic forms. The presence of these organisms indicates that the molasses feed provides the nutrient source for rapid respiratory removal of dissolved oxygen and poising of redox to below -250 mV.

Furthermore, it is evident from chemical analyses, that in addition to proton acidity, a substantial metal acidity contributes to the overall low pH of the system. The formation of metal hydroxides and metal sulphides contributes to both reduction of metal acidity but also to alkalinity consumption, thus exerting a complex effect on the bio-neutralisation reaction.

An unexpected observation of the depth profile studies (chemical and microbial) indicated that, in stable operating columns, the complete reaction was taking place in the first functional part of the column (200 mm of the available 2,000 mm) with the rest of the column not appearing to play any useful role in the neutralisation function. However, it should be noted that with system perturbation, the additional portion of the reactor column may play a stabilising function in managing feed fluctuations and process upsets. This observation suggests a tight spatial relationship between the three components of the biological system, namely:

- Redox poising.
- Production of simple carbon substrate.
- Sulphate reduction.

Based on the above information that has been gleaned from the various studies, together with more recent studies on acclimatising this system to metal-rich water, the following model may be proposed:

- Population 1: Acts to remove oxygen from the system and is composed of facultative anaerobes that can scavenge residual oxygen and rapidly reduce redox to -250 to -350 mV in the presence of high H^+ concentrations.
- Population 2: Poising of redox enables anaerobic degradation of lignocellulose structures to simple, charge-neutral carbon compounds by a number of organisms, including Clostridium spp.
- Population 3: SRBs that, in the presence of poised redox, can utilise the charge-neutral carbon compounds as electron donors for the reduction of sulphate to sulphide and bicarbonate, where the generation of bicarbonate and sulphide both contribute to the increased alkalinity observed in the process. Although no observations were made to support the presence of feedback loops, it is probable that the increased alkalinity and elevated pH may exercise a feedback effect on populations 1 and 2, relieving the stress of functioning at low pH conditions.

The tightly constrained spatial location of these three components of the reaction contrast sharply with the previous studies undertaken on the distribution of microbial structural functional relationships in the DPBR which occurred in linearly sequential zones along the length of the reactor. This suggests that feedback influences between the various components of the populations are critical to the operation of the system and account for the absence of a spatial distribution of the populations within the reactor.

Conclusions that were drawn from the long-term evaluation of the bio-neutralisation reactors were:

- Reactors need to be based on the patented DPBR technology, although reactors can be much shallower at around 1 to 1.5 m effective depth.
- Reactors only perform effectively when reactor redox potential is maintained at levels of -300mV or lower.
- Reactors are negatively affected by temperatures below 15°C and are therefore not suitable for very cold climates.

- Reactors are capable of removing up to 1,000 mg/l sulphates in the process of effecting bio-neutralisation.
- Bio-neutralisation reactors can be operated in series ahead of a DPBR, allowing for effective high-rate passive sulphate reduction of highly acidic mine effluents.

This long-term research programme demonstrated that the bio-neutralisation DPBR technology was capable of sustained neutralisation of acidic mine waters and this technology was therefore selected for application at the VCC West Adit decant site.

4 Process design for the VCC West Adit treatment site

The location of the West Adit decant point in relation to the passive treatment plant site is shown in Figure 2. As can be seen, it was necessary to convey the decant stream in a 3.2 km underground pipeline from the actual decant point to a suitable location where the treatment plant could be constructed. The terrain is extremely rocky and steep and only two alternative potential sites were identified where geotechnical and environmental impact assessment (EIA) investigations were undertaken. The selected site is shown in Figure 2.

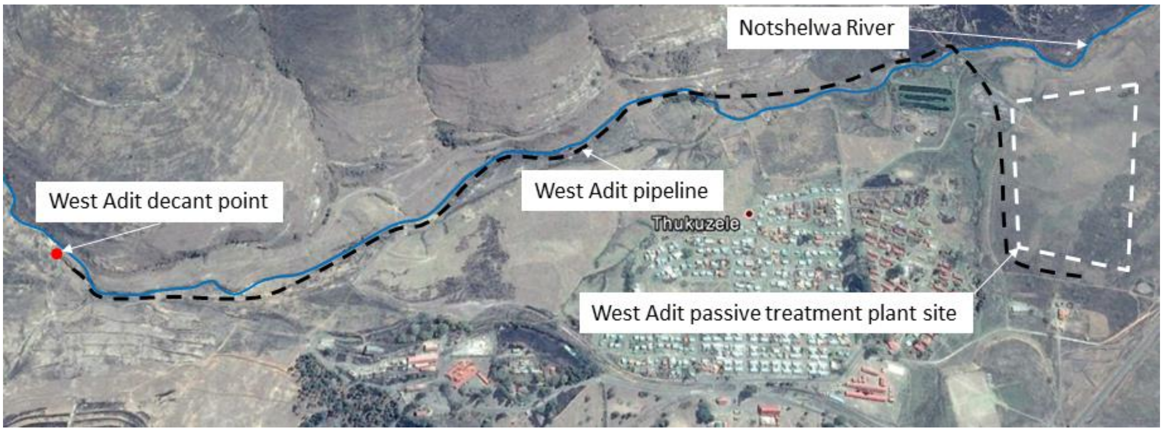


Figure 2 Location of VCC West Adit Passive Treatment Plant

The historical water quality and flow data from the West Adit previously collected by the mine was evaluated to determine the Basis of Design (BOD) for the Passive Treatment Plant. The mine water quality is acidic as reflected by the low pH values measured (Figure 3). The pH has been variable in the past but seems to have stabilised in a relatively narrow range around a pH of 2.9.

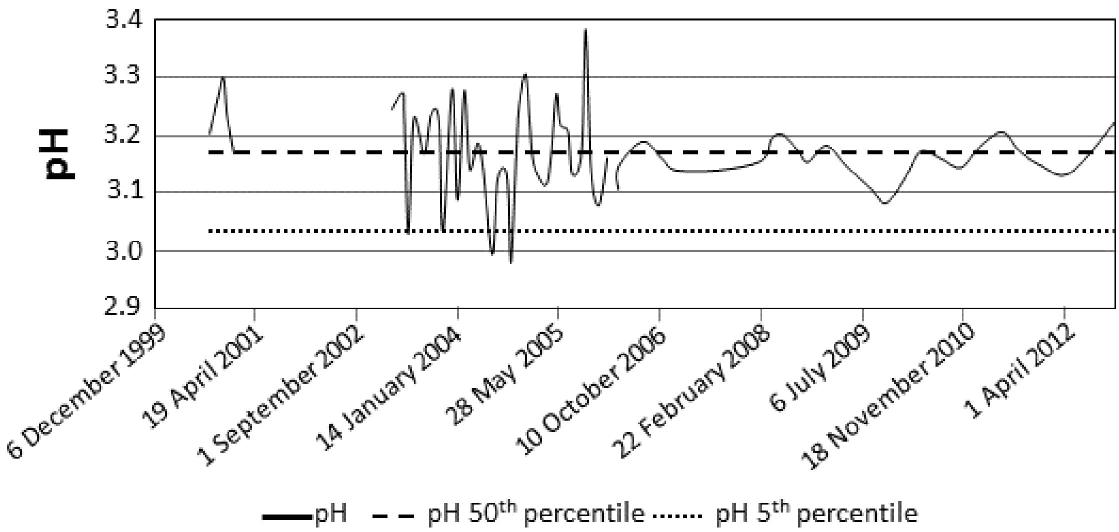


Figure 3 Historical pH records for West Adit

The historical records were evaluated for flow, pH, sulphate, iron, manganese, aluminium and acidity and the 5th, 50th and 95th percentiles for the quality parameters were determined as shown in Table 1. These values formed the basis of design for the treatment plant.

Table 1 Summary of historical West Adit water quality

Percentile	pH	Sulphate (SO_4) mg/l	Iron (Fe) mg/l	Manganese (Mn) mg/l	Aluminium (Al) mg/l
5th	2.6	1,120	11	15	14
50th	2.9	1,520	21	19	46
95th	3.2	1,970	30	22	67

The designed passive treatment plant consisted of the following unit processes (Figure 4):

- Mine water collection system:
  - West Adit collection box.
  - Pipeline from West Adit to treatment plant site.
- Flow splitter box.
- Molasses make-up, storage and dosing system.
- Bio-neutralisation reactor (degrading packed bed reactor).
- Sulphide removal unit/oxidation cascades.
- Limestone reactor (pH correction).
- Polishing aerobic wetland.
- Discharge to river.

The plant layout also caters for future installation of sulphide removal units.

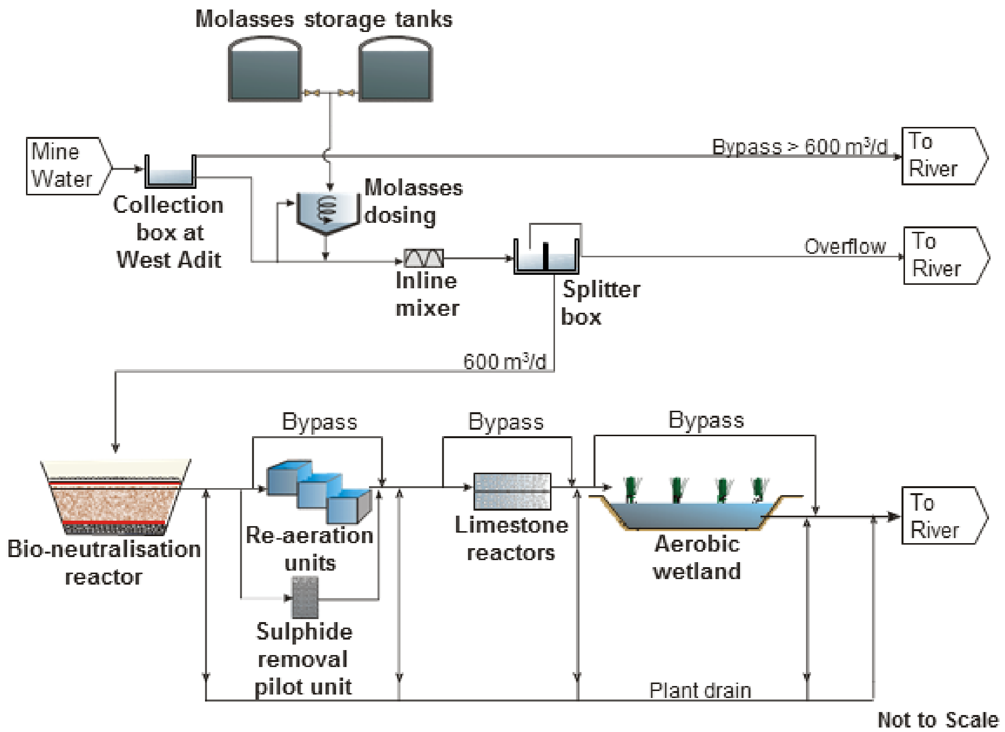


Figure 4 Schematic process flow diagram

The process illustrated in Figure 4 will function as follows. The mine water will naturally seep into the collection box at the West Adit. Here a maximum of 600 m^3/d of water will be allowed to the plant through the dual pipeline system. This is achieved through manipulating the installed valve in the collection box. Any water in excess of the 600 m^3/d will be directly discharged to the river, as would be the case without intervention. The mine water will then flow down the feed pipeline to the plant. At the plant a portion of the feed water will be routed to the molasses dosing station for make-up of diluted molasses which will then be drip fed into the feed water stream at a dosing rate of between 0.025–0.05% volume/volume.

The primary portion of the feed stream will then enter the splitter box. The original design was to allow for the delivery of 600 m^3/day of West Adit decant, which would have been split equally into the three Bio-neutralisation Reactors in operation at the time (this will be controlled by the installed V-notch plate). A provision has been made at the splitter box inlet to hydraulically divert any flow exceeding the prescribed 600 m^3/d in the extreme event that this will be exceeded. The first phase of the construction is only for 200 m^3/day and the splitter box simply serves to control the flow to a maximum of 200 m^3/day with all flow being routed to the single bio-neutralisation reactor.

The splitter box feeds the bio-neutralisation reactors. These reactors are down flow packed bed reactors containing a specified mix of lignocelluloses material layers that will facilitate the neutralisation of the mine water, as well as the precipitation of aluminium and iron. Prior work has shown that both the aluminium and iron precipitate and are captured in the upper layers of the reactor, progressively moving downwards into the reactor. The reactor is expected to have a retention capacity for around 25 years of metal precipitates, after which the reactor will need to be decommissioned, domed and capped for in situ rehabilitation. The reactors are fed through a distribution system over the total area of the reactor. A similar system is used at for the collection at the bottom of the reactor. The level is controlled in the reactor through a u-shaped pipe outlet system.

The product from the operational bio-neutralisation reactors is combined in a small collection and distribution box. From here the mine water is split to the re-aeration units and the sulphide removal pilot units (to be constructed in future). The re-aeration units are cascade units designed to introduce oxygen into the water to convert the system from an anaerobic to an aerobic state. It also converts the hydrogen sulphide to elemental sulphur. The re-aeration units are covered and fresh air is drawn into the first unit and then through the second and third units before entering a biological H_2S scrubber where remaining H_2S is converted back into sulphate.

The product from these units is then routed to three limestone reactors operating in series to ensure that a feed with a minimum pH of 6 reaches the aerobic wetland. The feed water entering the limestone reactors is depleted of iron and aluminium and clogging of the reactors with these metals (a common problem on anoxic limestone drains) is therefore avoided. The aerobic wetland is designed to operate as a sub-surface flow wetland to remove residual nitrogen, phosphorus and organic compounds released by the bio-neutralisation reactor. The final component of the wetland is a small final limestone reactor. The product from the wetland is discharged to the river.

Detailed construction drawings were produced and the complete construction package was put out to tender and eventually awarded to a local contractor. The construction process consisted of two parallel processes: firstly, development of acidophilic seed material to enable the seeding of the full-scale bio-neutralisation reactor and; secondly, construction of the feed pipeline and passive treatment plant. These two components are discussed separately.

5 Operation of bio-neutralisation seed reactors

The original bio-neutralisation seed reactors that were started up in 2003 (and for which the pH and redox results are shown in Figure 1), were used to seed five additional columns in the Golder Associates Research Laboratories in Johannesburg. These five seed reactor columns (volume 22 L each) were transported from Johannesburg down to the VCC site and were used as seed material for five 2,000 L seed reactors constructed from plastic tanks that were to be developed for use in seeding the full-scale 1,000 m³ bio-neutralisation reactor. The 5 seed reactors are shown in Figure 5.

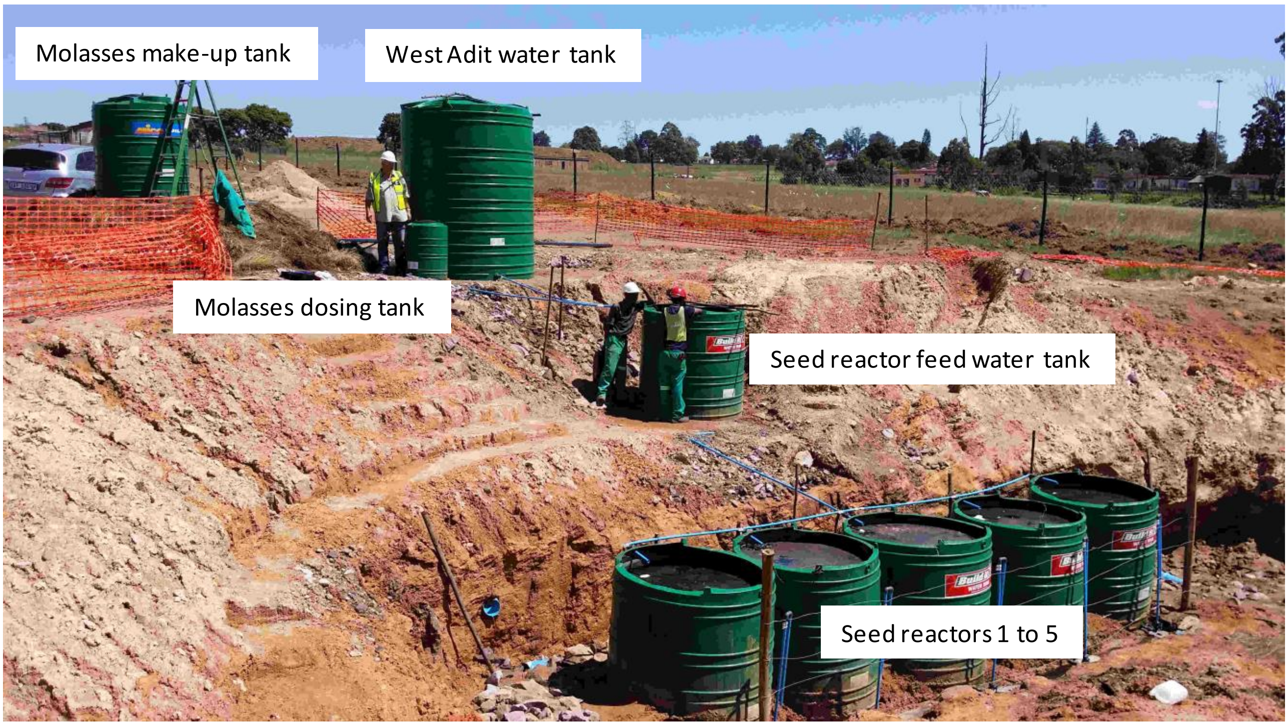


Figure 5 Seed reactors at VCC

The seed reactors were loaded with 16 layers of lignocellulose material, being repeat 'sandwiches' of grass, blue gum chips, wattle chips and cattle manure with a specific portion of the seed material from the 5 seed columns being added to each layer, together with dilute molasses. The seed reactors were filled with water as they were being filled with the carbon layers in order to ensure that the column seed material was immediately submerged after placement in the seed reactor. A thin layer of 19 mm stone was placed above each lignocellulose sandwich in order to prevent the material from floating as it was being filled with water. All five seed reactors were constructed and were then started up in early March 2015 and operated till the end of May 2015, when they were decommissioned to be used as seed material for the full-scale bio-neutralisation reactor.

The seed reactors were initially operated at a 5-day hydraulic retention time which was reduced in a step-wise fashion, down to a 3-day retention time. The seed reactors were fed with West Adit decant water that was dosed with dilute molasses at a 0.025% v/v dosing rate. The performance of these seed reactors was monitored daily by taking temperature, redox and pH readings. The results of the pH readings are shown in Figure 6.

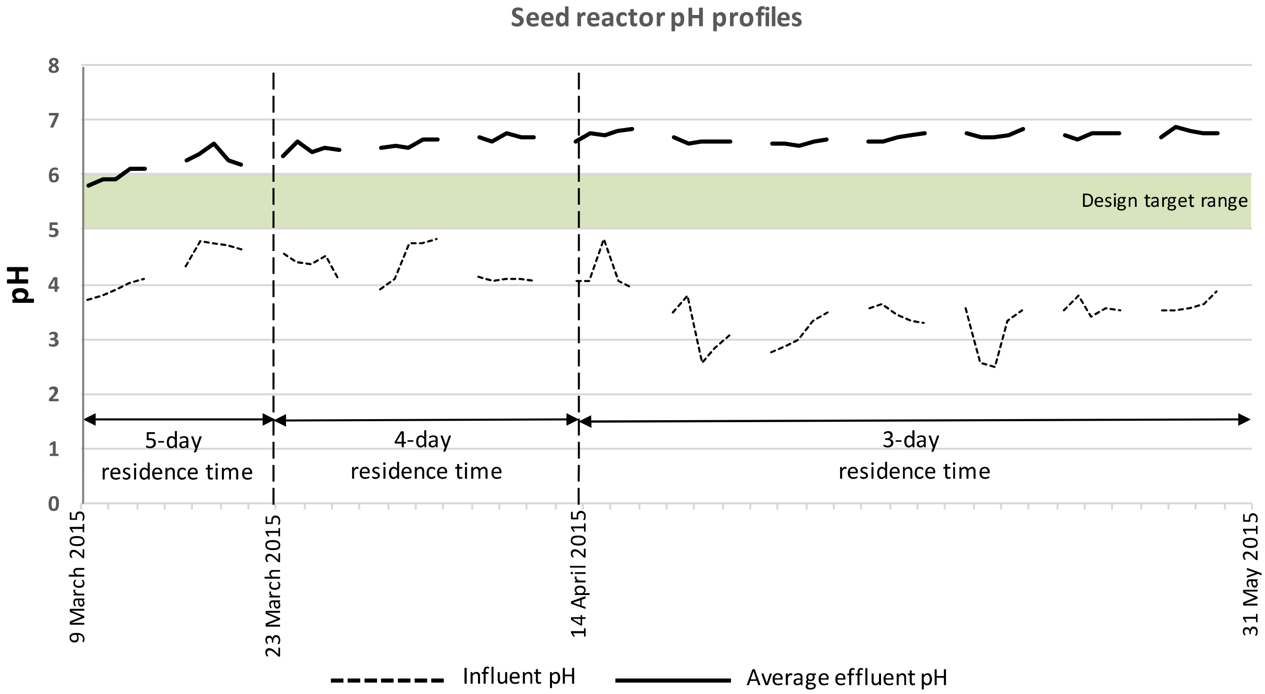


Figure 6 pH results for VCC seed reactors

The collected data for the seed reactors indicated that the seed material in the 5 laboratory columns was successfully transferred to the seed reactors as all seed reactors were able to operate successfully at a feed pH of around 3, while increasing the outlet pH to between 6.5 and 7.0. The seed reactors also converted the positive redox of the feed water (>100 mV) to between -250 to -300 mV in the outlet water.

While very limited water quality samples were taken, the results from the final samples just before the reactors were decommissioned are summarised in Table 2. These results show good neutralisation and sulphate removal and excellent iron and aluminium removal. Manganese removal was higher than expected and the addition of the nutrients ammonia and phosphate was in line with expectations. While the data in Table 2 is taken from two sample sets, the results are in line with expectations based on more than 12 years of experience with operation of bio-neutralisation reactors.

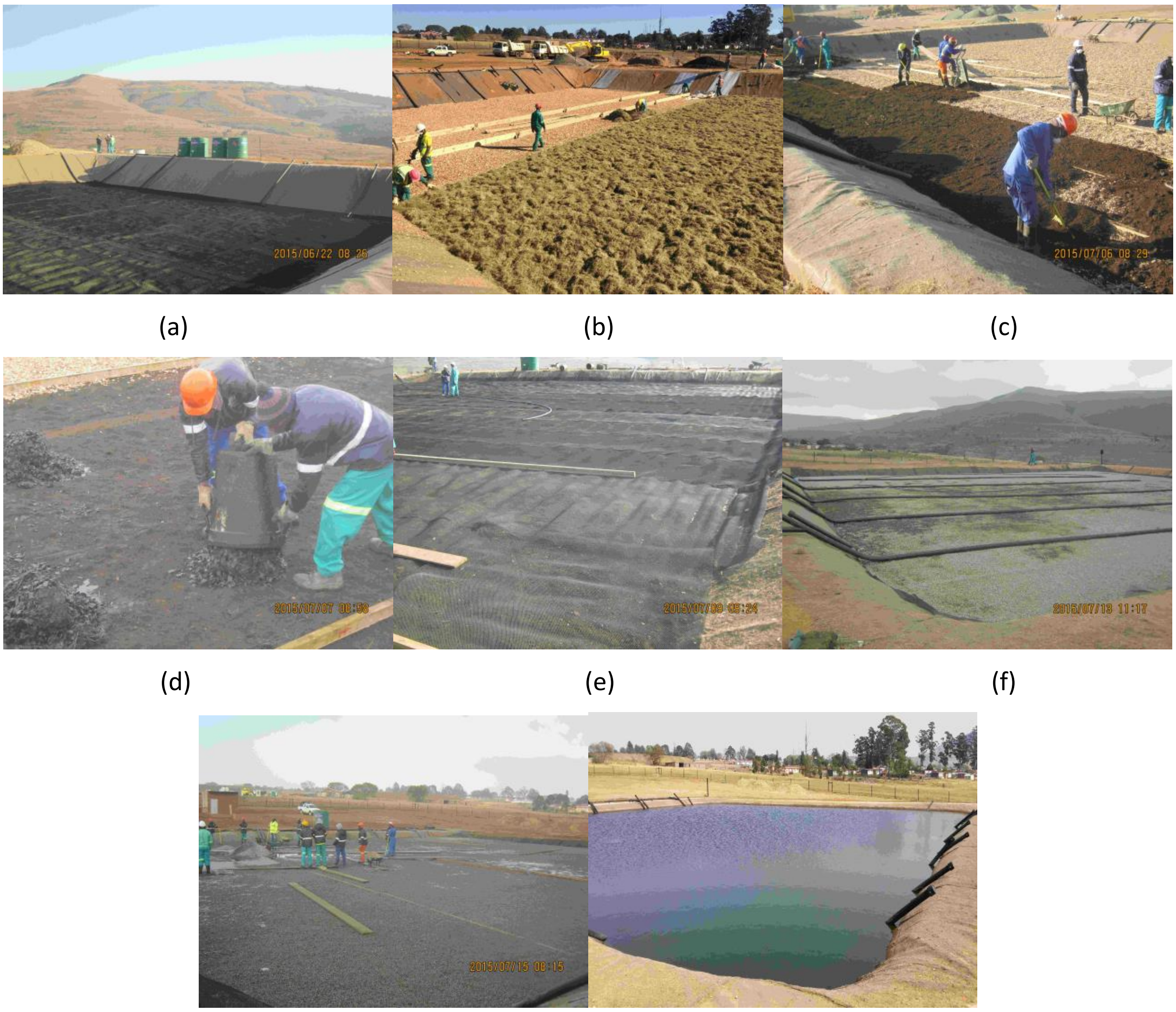
Table 2 Water quality results for VCC seed reactors

Parameter	Unit	West Adit feed water	Average seed reactor outflow	Change
pH	-	3.03	6.94	+3.91
Sulphate	mg/l	1,594	621	-973 mg/l
Alkalinity	mg/l $CaCO_3$	0	487	+487 mg/l
Aluminium	mg/l Al	33.64	0.45	-98.7%
Iron	mg/l Fe	25.45	0.31	-98.8%
Manganese	mg/l Mn	14.38	7.12	-50.5%
Ammonia	mg/l NH_3	0.3	17.48	+17.18
Phosphate	mg/l PO_4	0.86	10.7	+9.84

Based on the good performance of the seed reactors, it was decided to decommission them in June 2015 for use in the construction of the 200 m³/day full-scale bio-neutralisation reactor.

6 Construction of VCC passive mine water treatment plant

The construction of the pipeline and treatment plant commenced in December 2014 and was completed by the end of August 2015 when the commissioning process commenced. Photos showing the construction process of the bio-neutralisation reactor are included in Figure 7.



(a) (b) (c)

(d) (e) (f)

(g) (h)

Figure 7 Photos showing construction of bio-neutralisation reactor. (a) Reactor with inlet manifold, stone and mesh; (b) reactor with first layer of chips and second layer of grass; (c) reactor with manure layer being added; (d) reactor with seed material being added; (e) reactor top mesh layer; (f) inlet manifold on top of mesh and stone; (g) reactor final stone layer; and, (h) completed reactor

The VCC plant is currently in the start of the commissioning phase which is scheduled to take around 5 months to complete. During the commissioning phase, the bio-neutralisation reactor is brought up to full operational flow rate in a slow step-wise manner in order to allow the seed material containing the acidophilic bacteria to colonise the complete reactor. Once the commissioning phase is complete, the plant will enter an 18 month operational period during which time detailed monitoring of all components of the plant will continue and adjustments will be made, where necessary, to ensure that the plant is capable of meeting the design duty.

While a plant operator has been appointed for the purpose of taking daily data readings, the intention is to operate the plant on a basis where management and operational intervention is only required once every two weeks. The definition of a passive treatment plant is as follows (Pulles et al. 2003; PIRAMID Consortium 2003):

> *A water treatment system that utilises naturally available energy sources such as topographical gradient, microbial metabolic energy, photosynthesis and chemical energy and requires regular but infrequent maintenance to operate successfully over its design life.*

In this context, "regular but infrequent maintenance" is defined to be every two weeks. The primary functions to be undertaken during the regular maintenance visits is to top up the molasses dosing tanks and inspect the plant to ensure that there are no hydraulic blockages anywhere in the system. The bio-neutralisation reactor has been filled with sufficient carbon material (electron donor) to last an estimated 25 years, while the limestone reactors also contain sufficient limestone to operate for 25 years. The bio-neutralisation reactor inlet and outlet manifolds have been equipped with rodding access points to allow for annual rodding through to remove any accumulated bio-fouling precipitates. Based on post-mortem results obtained from field-scale pilot plant units operated for 10 years at VCC (Molwantwa et al. 2010), the reactor is expected to contain sufficient volume to allow for retention of all iron and aluminium precipitates.

7 Critical plant features

Based on 21 years of experience in the research and operation of passive sulphate reduction technology generally and 12 years of experience in the research and operation of passive bio-neutralisation technology in particular, a number of key statements can be made with regard to critical features and expectations for the VCC plant.

The plant meets the requirements of passive treatment technology and does not include any mechanical, electrical or process control equipment other than a control valve for dosing of molasses to accommodate planned evaluation of different molasses dosing rates. The molasses being dosed has been diluted by a factor of 20 to reduce its value as a feedstock in order to prevent theft and all molasses dosing equipment is contained within a fortified brick and concrete building to reduce theft. The dilute molasses also allows for a higher molasses flow rate, making for easier control.

Prior unpublished research undertaken for mining clients to assess the application of the technology to highly acidic pit decants has shown that the bio-neutralisation technology will continue to operate in the absence of molasses dosing, albeit at a reduced efficiency and the planned two-week maintenance and molasses replenishment interval is therefore not considered to pose a significant risk to the operation of the plant.

All the research work that has been undertaken to date and which is covered in the numerous references that incorporate the primary author have also shown that the bio-neutralisation technology can be operated on a stop-start basis with no effect on performance and columns have been easily restarted after as long as a year of zero flow, provided that the reactors have not been allowed to dry out. The bio-neutralisation reactor is fitted with a U-tube outlet structure with a siphon break to prevent the reactor from ever running dry.

The VCC bio-neutralisation reactor will serve as a reservoir for the acidophilic culture for use in future applications. During the 12 years of research into this technology, more than 100 new reactors have been successfully seeded from other columns and the knowledge on how to do this has been established.

During the development of the bio-neutralisation technology, the reactors have been subjected to various process shocks, including excessively high flow rates, termination of flow, extreme pH fluctuations, extreme metal acidity fluctuations and temperatures encountered in typical South African winters and, in all cases, the technology has proved to be capable of rapidly recovering from such process upsets. Ten years of data collected at the VCC site (Molwantwa et al. 2010) has shown that even in sub-zero winter temperatures, the temperature of the water in the reactors does not drop to below 12°C, at which point the bio-neutralisation process slows down but still continues. Due to summer rainfall conditions, flow rates of decants to be treated also drop in winter to accommodate the reduced kinetics of the sulphate reduction process.

The two-year commissioning and operational phase that will be implemented at VCC will generate the data that will allow extrapolations of long-term performance, when coupled with the extensive research experience underpinning this technology.

8 Conclusion

The South African passive treatment research programme that commenced in 1994 has led to the successful development of a high rate sulphate reducing reactor and a high-rate bio-neutralisation reactor. The research programme has also lead to the finalisation of research into the development of a passive sulphide oxidation technology that still requires a final step of field-scale trials.

This paper presents the scientific basis for the bio-neutralisation technology and describes the process design and physical construction of a full-scale passive treatment plant to treat the West Adit decant at the Vryheid Coronation Colliery in northern KwaZulu Natal, South Africa. The construction has been successfully completed and the plant is currently in the final commissioning phase.

While there is not yet any operational water quality data for the plant, site data is being collected on a daily basis and monthly detailed water quality sampling has commenced. The presentation at the conference will include the full set of operational and water quality data collected up to and including February 2016. Operational experience in terms of capital and operating cost estimates will also be included in the conference presentation.

Based on 12 years of operational experience with laboratory-scale reactors (Figure 1) it is expected that the VCC plant will have an effective operational life of at least 25 years. Early passive sulphate reduction technology suffered from gradual loss of efficiency over time, but this problem has been overcome with the patented technology being used in the VCC plant.

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