Integrating the Acid Mine Drainage Value Chain – Polluted Water Abstraction to Sustainable Environmental Conformance

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Abstract

The approach presented herewith suggests that AMD is viewed as a source of scarce commodities, namely water and valuable chemicals.

A proper sustainable business would take a view on minimising the life cycle cost of such recovery. A significant cost contributor is the extraction of the AMD from the mine.

Abstraction concepts revolve around the Ritz HDM pumping system. This pump is a free-hanging, double-suction submersible pump. The pump is supported only through a revolutionary piping column, which in itself is free-hanging from the top of the shaft or well. Such pumps can be located as deep as 1 km underground, so no underground pumping stations are required. The pumps are virtually maintenance free, through the balanced axial thrust design. Potential maintenance can be effected from surface.

The treatment technology entails addition of basic barium salt (carbonate or oxide), to the water and precipitating sulphates in the form of the very low soluble barite. This process happens at distributed AMD treatment sites. The water treatment plant simply receives water from lime neutralisation plants, basic barium salt is added, treated water is dispatched and formed solid barite is transported to a centralised chemical factory. The capital investment of such a water treatment plant is significantly lower than a membrane treatment plant.

At the chemical plant, the barite is converted to the basic barium salts required by the AMD treatment plants. Sulphur presents itself in numerous chemical forms, making itself available as a raw material for a number of different chemical products. These range from elemental sulphur, sulphuric acid and other higher value sulphur based chemicals, such as sodium bisulphide.

Key words: Mine water, abstraction, barite, sulphate removal, modeling, chemical reclamation, barium sulphate precipitation, sustainability

Introduction

AMD IS NOT A NEW PHENOMENON. One of the oldest documented mining regions in the world, the Rio Tinto region in Spain, had problems associated with AMD beginning over 2000 years ago (Balkau and Parsons, 1999; Boocock, 2002). Since then, there have been thousands of documented cases of AMD and it is becoming increasingly visible as more mines approach closure around the world.

Following the discovery of diamonds and gold in Southern Africa and the subsequent development of platinum, chromium, manganese vanadium, iron ore, and coal reserves, the country was transformed from a relatively underdeveloped region to a fairly modernised nation with widespread infrastructure and an increasingly diversified economy. In 1999, mining directly contributed to approximately 6.5% of GDP and 33.5% of total export revenues. To increase profits through the removal of minerals that would otherwise remain buried deep within the Earth's crust, elaborate pumping systems were employed in the beginning of the 20th Century to remove water from mine shafts, a process which has become known as mine dewatering. Although this method was successful, there were also many unintended consequences including but not limited to the modification of the water table, creation of sinkholes, and elevated levels of aquatic, air, and soil pollution (Adler and Rascher, 2007).

In the 120 years since mining activity began to unlock significant gold reserves, the impact on the Water Table in the Witwatersrand Reef's Western Basin has been dramatic.

Mining operations, to expose and remove the gold-bearing ore, has resulted in the following:-

- Dolomite formations in the area have been disrupted and the water that naturally filtered through them (en route to the Upper Vaal River and Tweelopies Spruit catchment) has begun to subside.

- Water that drained through the dolomitic rock, into the voids caused by mining operations, has mixed with the exposed ore (Pyrite) and combined to form a Sulphuric Acid solution known as Acid Mine Drainage (AMD). This has contaminated the water, making it unsuitable for drinking and other domestic uses.

- Reservoirs of contaminated AMD have collected in the mining voids and have begun discharging into nearby rivers at a rate of 15 Mega Litres per day.

This therefore poses a significant environmental threat – not only to the surrounding residential communities who rely on the rivers for their potable water – but also to the nearby Sterkfontein Caves which could be flooded, and irreversibly damaged, if the water seepage is not effectively addressed.

The Sterkfontein Caves - which form part of the Cradle of Humankind World Heritage Site - date back some 3.5 million years. It is sobering to note that to fill the Western Basin void, which potentially threatens their continued existence, has taken just 2.5 years.

The AMD Value Chain

Acid Mine Drainage is one of the serious legacies of our mining history. Whilst mining occur, water is generally pumped out as it is collected. Contamination levels are therefore not as significant, given rather protracted retention times.

The major challenge usually starts after mine closure, when exposed pyrite rock formations (containing primarily iron sulphide (FeS) is dissolved in water in the presence of oxygen. This microbiologically catalyzed process converts the sulphides to sulphuric acid through oxidation, whilst dissolving iron in the water, primarily as the divalent ion.

When the mining void eventually fills, AMD decanting commences, causing pollution to the environment.

It has long since been recognized that this water needs to be treated. Treatment schemes typically entails extraction, treatment and release to the environment. The major issue with such an approach is that it is not and cannot be sustainable. This approach also advocates the premise that AMD is a problem, and that the problem can only be solved by applying huge sums of money.

The first paradigm shift required to achieve a successful solution is to target a premise of self-sustainability of any solution applied to AMD treatment.

Wikipedia defines self-sustainability as follows:

"A system is self-sustaining (or self-sufficient) if it can maintain itself by independent effort. The system self-sustainability is:

- the degree at which the system can sustain itself without external support;
- the fraction of time in which the system is self-sustaining.

In the economics literature, a system that has the quality of being self-sustaining is also referred to as an autarky.

In order to successfully deal with the challenge of AMD handling, the AMD treatment system must therefore be an autarky, or be as close to an autarky as possible.

It is evident that to be fully autarkic, the total cost required to operate a system must be less than the total income derived by a system.

The traditional approach of abstraction, treat and release entails only costs, and no income. Such a system is therefore clearly not self-sustainable.

To drive to an autarkic system, all components of such a system must be considered, separately and jointly.

Overall for the system, two objectives are targeted to enable achievement of the overall goal, namely:

- Maximise revenue;
- Minimise costs.

Maximising revenue is dependent on identifying the potential revenue generating components in such a system. AMD is practically 99,5% water, with the remaining 0,5% being contaminants. The only thing making the water unusable, is the fact that the contaminants are in the water. Separation of the water and the contaminants will provide value to the water.

The water in the AMD is therefore a potential revenue generating item.

Likewise, the contaminants in the water are worthless while they are contained in the water stream. In the event, however, that they could be separated and purified, they could earn value and so contribute to revenue.

The components of a treatment system typically also comprises its value chain. In general, the three major system components are:

1. AMD extraction;
2. Water Recovery;
3. Contaminant Recovery.

AMD in underground basins possesses no value. AMD transport to surface is therefore the first item in the value chain. This is analogous to mining, where any mineral contained underground is worthless. This component therefore adds value to the AMD by getting it to the right place for processing. Transferring AMD to surface is generally a very high cost affair, having to overcome significant heads in a rather corrosive environment.

Water recovery is the process where contaminants are separated from the water, in this process making the water usable for some defined purpose. In this process, significant value is added to the water, at certain costs.

The contaminants that were removed from the AMD is now treated to a usable form and recovered as chemical components having a value, again at a certain cost.

The remainder of this paper reports on one approach to make AMD treatment self-sustainable by consideration of the proposed value chain.

Value Chain Component 1: Towards Sustainable Extraction

Both the water and contaminants have no value being underground. In order to have any value, the first step would be to transfer the AMD to surface.

The traditional approach for mine dewatering would be to install huge pumping stations underground, and pump AMD from sealed compartments to surface through piping installed in a vertical shaft. This would require operators and maintenance personnel to enter the pump station (which could be located more than 1000 m underground). This is clearly a high cost approach. In conjunction with maintaining the pump station, and associated equipment underground, the shaft and elevation systems also need be maintained and operated.

The Ritz Pump solution provides for a submersible solution, completely installed, operated and maintained from surface.

In order to apply centrifugal pump solutions to mine dewatering, multiple pumping stages are required to overcome the high pumping head requirements. Progressing beyond four pumping stages has traditionally disqualified the use of submersible pumping solutions, as the axial thrust became intolerable leading to frequent pump failures.

The Ritz solution provides for a fully submersible pump (see **Figure 1**) providing for two suction points (top and bottom), with the pumping stages so arranged to cancel the axial thrust. It also provides for 50% lower flow velocity. With this innovation, suddenly there is no limit on the number of stages that can be employed in a single submersible pump.

The resultant economic benefits are operational reliability, low wear, and a long service life (exceeding 20 years). These pumps can provide heads up to 1500 m and flow rates up to 6,000 m^3/h.

Figure 1*: A Ritz HMD pump being placed in the test bay. Note the two suctions to combat axial thrust.*

Two such pumps were installed in Germiston, South Africa, each capable of pumping 1500 m3/h of water at a head of 450 m. The pumps each contains 15 stages.

Another novelty of these pumping systems is the manner in which they are installed. They are free-hanging on a vertical piping system. Piping sections are typically about 6m each. Each section is connected to each other with a novel ZSM™ coupling, depicted in the following figure. The couplings (see **Figure 2**) provide a leak tight seal and a tin chain is used to lock the two pipe sections onto each other.

The pump hangs at the bottom of this piping column in a protective shroud. Installations in excess of one km (1000 m) deep are possible.

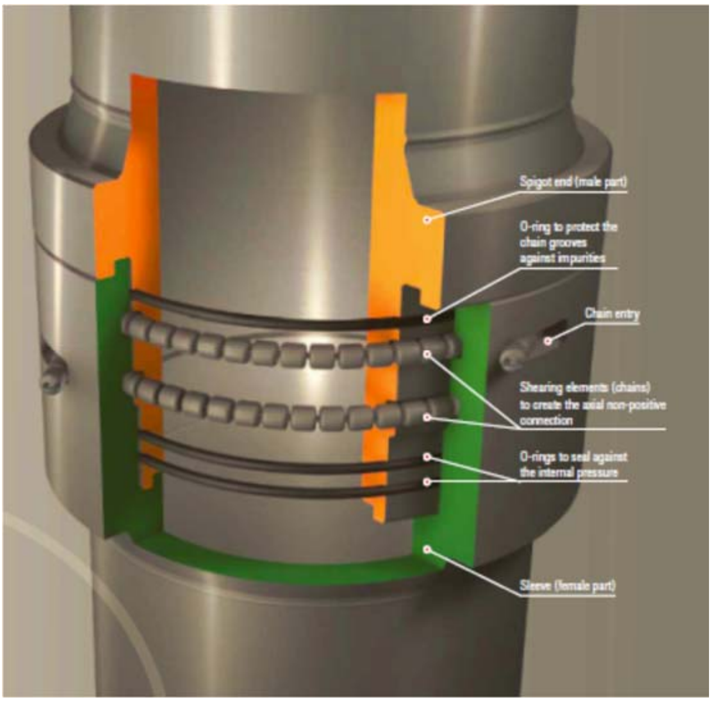

Figure 2 *ZSM Coupling for vertical free-hanging piping columns*

Value Chain Component 2: Water Recovery from AMD

The AMD has to be converted to a standard suitable for consumption, being potable or otherwise.

In general, AMD has three quality issues, namely pH (low and acidic), dissolved metals (primarily ferrous iron) and high levels of sulphate. The Alkali-Barium-Carbonate (ABC) process was developed to take care precisely of these three issues.

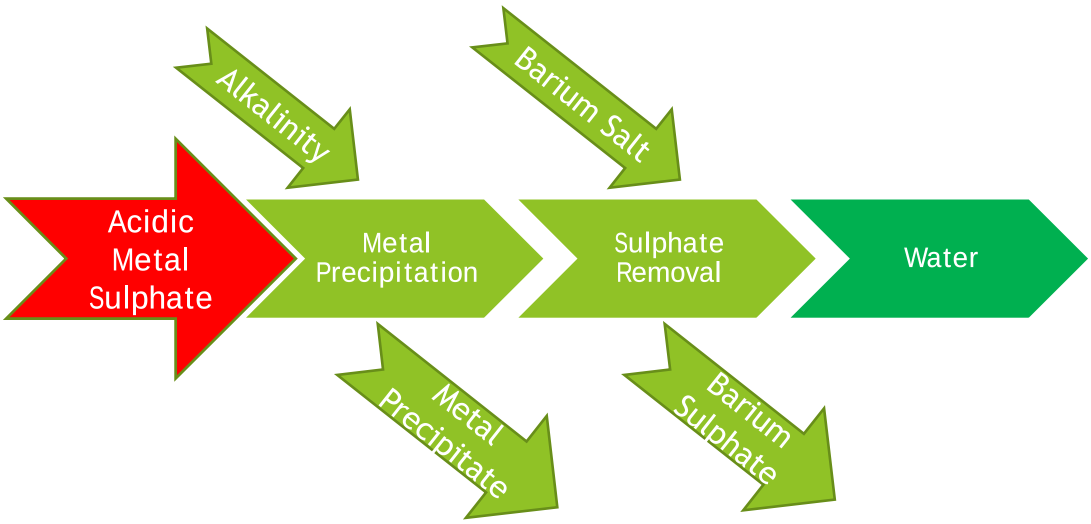

Figure 3 *The ABC water treatment process concept*

The first step is to add alkalinity to neutralize the acidity, comprising both the free acidity characterized by the pH and also the acidity associated with iron. The pH is controlled at a point where the solubility of the metal hydroxide is at a minimum.

Depending on the amount of free acidity in the water, neutralisation could be a two stage process. In the first stage, calcium carbonate could be used and hydrated lime could be used in the second step. In the second step, aeration is also provided to assist in oxidation of ferrous iron to ferric iron.

The net result is the precipitation of metal hydroxides and gypsum (depending on the sulphate levels in the feed).

The steps described thus far comprises the well-established High Density Sludge (HDS) process.

Further addition of lime to pH of about 11,5 results in the precipitation of magnesium hydroxide and more gypsum. The solid precipitates formed thus far in the process reports as a waste.

The second major process step entails removal of sulphate to a desired and acceptable concentration in the treated water.

The solution at this point in the process is saturated with respect to calcium sulphate. Sulphate can be removed to low concentrations making use of the very low solubility of barium sulphate in water. One way of achieving the precipitation of barium sulphate is through the addition of barium carbonate to a typical continuously stirred tank reactor (CSTR).

The sulphate removal reaction that takes place within the reactor is shown in the following equation:

$$Ca^{2+} + SO_4^{2-} + BaCO_3 \rightarrow BaSO_4(s) + CaCO_3(s)$$

Conductivity data is used to track the sulphate removal in the reactor. Based on the reaction equation, feed water is characterized by high conductivity due to the presence Ca^{2+} ions and free SO_4^{2-}. The treatment using $BaCO_3$ results in removal of these two species from solution, replacing them with insoluble $BaSO_4$ and $CaCO_3$. Carbon dioxide can be used to adjust the pH to desired values.

Through the different treatment stages proposed above, water suitable for reuse is produced, as indicated in **Table 1**.

Table 1 *Removal of contaminants through ABC treatment process*

Component	Unit	Feed	Treated
pH		3.3	7.9
Sulphate	mg/l	1910	90
Chloride	mg/l	44.5	49.5
Fluoride	mg/l	5.4	0.7
Sodium	mg/l	46.5	53.3
Magnesium	mg/l	124.6	0.98
Calcium	mg/l	205	75
Iron (II)	mg/l	180	0.3
Iron (III)	mg/l	2	0
Copper	mg/l	21	0.02
Nickel	mg/l	5.6	0.01

From the above, it is clear that the major operating cost of water treatment lie in the chemicals applied to the process, namely lime and barium carbonate.

Value Chain Component 3: Contaminant Recovery

The major portion of sulphate reports as $BaSO_4$ from the water treatment stage. This has been co-precipitated with calcium carbonate.

In the precipitated form as is, the contaminants are basically worthless. However, the collection of these precipitated compounds from various mine water treatment facilities is proposed for treatment in a centralised chemical recovery facility, as depicted in **Figure 4**.

The aim of this central facility is to produce lime and barium carbonate for use as chemical feed at the water treatment facilities, and also to produce Sulphur (or sulphuric acid) for sale in the chemical market.

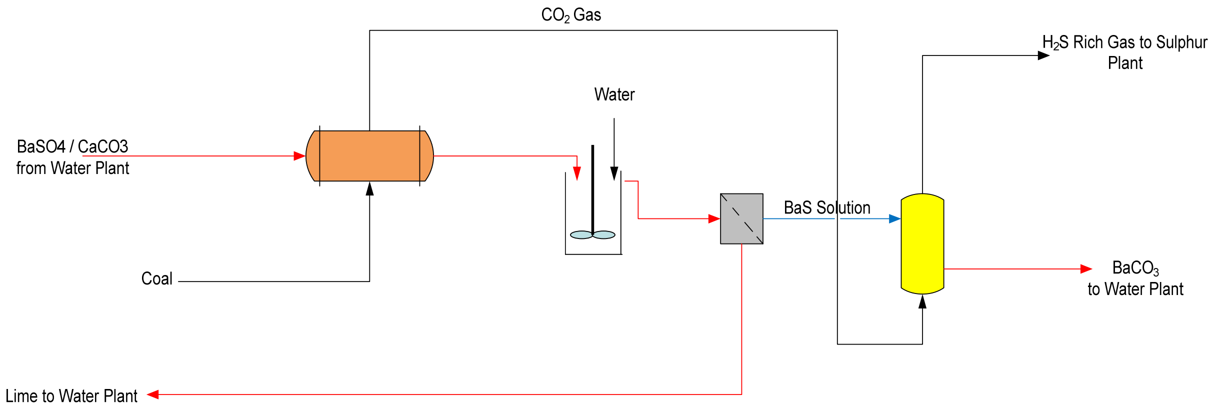

Figure 4 *The chemical recovery process*

Excess moisture is removed in a filter press. The precipitate is fed into a thermal reduction unit. Carbon or methane could be used as a reducing agent. The unit is typically operated at a temperature of 1100°C.

The following reactions occur:

$BaSO_4(s) + 2C \rightarrow BaS + 2CO_2$

$CaCO3(s) + heat \rightarrow CaO + CO2$

The carbon dioxide offgas is captured and compressed for use in the downstream carbonation stage.

The solid product (BaS and CaO) is mixed with water. The lime is hydrated to form Ca(OH)2 and filtered for reuse in the water treatment plants. The highly soluble BaS has reacted in the water as follows:

$$BaS + 2H_2O \rightarrow Ba(SH)(OH) + H_2O \leftrightarrow Ba(HS)_2 + Ba(OH)_2$$

This aqueous solution is characterized by high pH in excess of 12.

Compressed carbon dioxide (ex thermal reduction) is blown through this solution to produce barium carbonate, according to the following reactions:

$$Ba(HS)_2 + Ba(OH)_2 + 2CO_2 \rightarrow 2BaCO_3 + 2H_2S$$

The hydrogen sulphide gas can then be separately converted to either sulphur or sulphuric acid.

The barium carbonate is recycled to the water treatment plants as reagent.

Integrating the Scheme

The water treatment plants are clearly simple in concept and in design. They are significantly less capital intensive than alternative membrane treatment technologies. They also consume significantly less electricity. The only waste is in solid form, i.e. no brine to contend with. The downstream cost impacts are therefore significantly less.

The unit cost of water purification needs to be less than the price achieved for the selling of the treated water. This is achieved by limiting the cost of the chemicals used in the process. The chemicals will be obtained from a centralised chemical treatment facility, which receives its feed from multiple AMD treatment plants and supplies these same treatment plants with reagents.

The income for such a chemical plant is from the sales of the treatment chemicals to the AMD treatment plants (prices to be such as to make the treatment plants self-sustainable). Costs in the chemical plant is offset by the sale of Sulphur and high purity excess carbon dioxide.

The income of such a chemical plant can be further improved (and therefore the prices of reagent chemicals further reduced) by production of high value niche Sulphur containing chemicals. Within this chemical plant, Sulphur presents itself in all its possible valence states (-2 to +6).

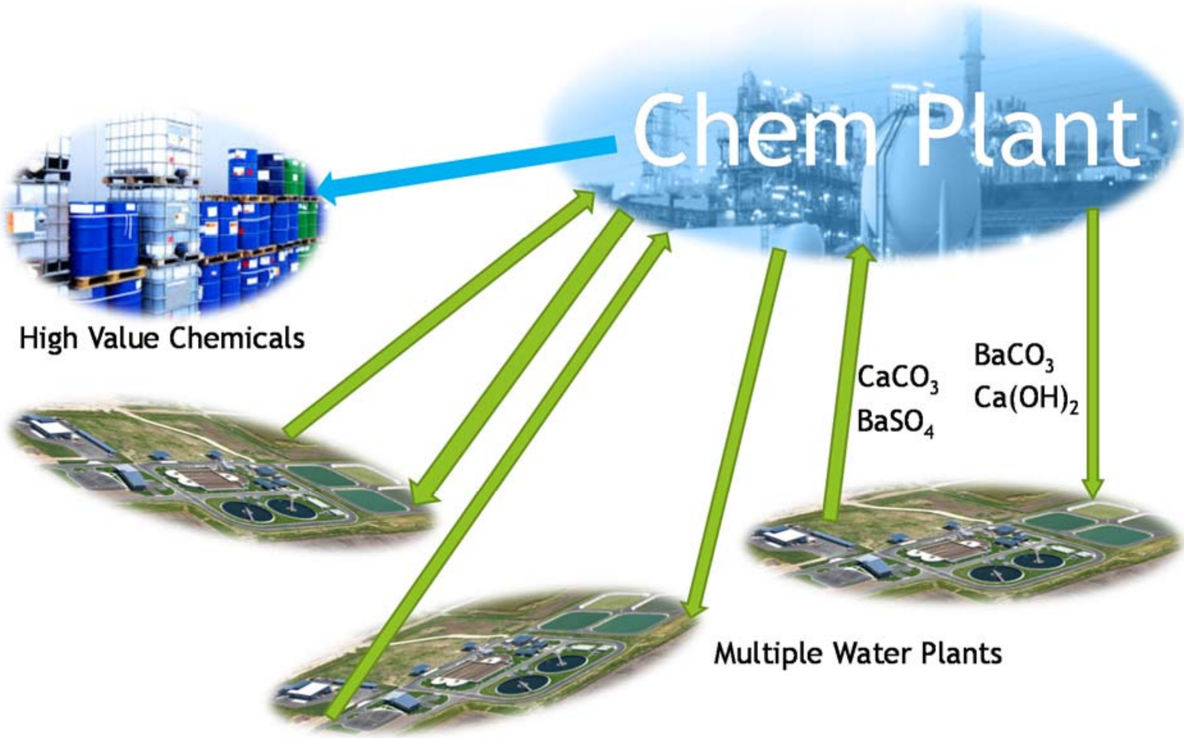

Figure 5 *Integrated AMD treatment and recovery scheme*

Conclusions

It is certainly possible through paradigm shifting to devise AMD Treatment schemes that are less costly and potentially even be financially self-sustaining. For this to occur, it is imperative that contaminants are viewed as valuable products for reclamation.

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