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SUSTAINABLE FULL-SCALE REHABILITATION OF POLLUTED MINE TAILINGS AND ACID MINE DRAINAGE (AMD)

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ABSTRACT

For more than 150 years of mining in South Africa, nature has had to deal an accumulation of polluted substances. Destruction of rock by explosives exposes new surface areas with an abundance of water-soluble elements. The common remediation technique used for acid mine water is treatment with lime or with caustic soda. These techniques are not effective enough to keep the environment free of residues and don't provide a sustainable treatment of acid mine drainage (AMD). The long- term environmental result of treatment with caustic soda is saline soil and could in addition, lead to irreversible soil sterility.

A remediation technique for cleaning highly polluted AMD water should raise the pH and immobilise the heavy metals, keeping them out of the system permanently. With an organic medium – an organic material, a mixture of a specific Casuarina needle and a specific, pine bark with 2 other semi decomposed plants - it was proven that even in pH ranges of below pH 3.5, high concentrations of Mn and Fe may still be removed. Only, after immobilising and binding heavy metals and treating up to 10,000 m³ AMD per day, for at least two years, the organic medium has to be replaced. The quality of the treated AMD is confirm to the minimum guidelines for agricultural purposes and can be used for irrigation.

The used material can be deposited on certified hazardous waste dumps, or could be recovered and recycled for the elements it contains. Mixed with mine tailings the organic medium absorbs and binds metals from the tailings and detoxifies the soil by immobilisation, so that Casuarina pines - an ingredient of the organic medium – can be planted in the soil and on top of the mine tailings.

This added benefit assists in the prevention of dust storms, fertilises the tailings and closes the circle between the organic material and the rehabilitation of polluted mine tailings and AMD, thus providing a tool for sustainable remediation.

INTRODUCTION

To the present polluted acid mine drainage (AMD) – seen as one of the biggest environmental problem in the world - from South Africa's gold mines, has been treated by the precipitation of heavy metals with lime and sulphates (Barnes, 1968).

Chemical treatment with expensive and toxic caustic soda (sodium hydroxide, NaOH) is to raise the pH, in order to reduce corrosion in pipes and pumps (Maree, 2004). The use of lime (calcium carbonate, $CaCO_3$), is to lift the pH for the precipitation of metals and some accumulated residues in the cleaned water (Maree, 2004). This water is then usually dispersed into wetlands to be remediated by natural processes within the wetland system. Finally it may migrate to the ground water. This is acceptable only for low volumes of water.

After water treatment a highly polluted sludge is deposited on the mine tailing dams. This toxic sludge doesn't allow any plant growth on the mine tailings because of amongst other things the high heavy metal content.

Research relating to the sustainable full-scale rehabilitation of polluted mine tailings and AMD by an organic medium is divided into different phases. A fully closed cycle of rehabilitation is established, from AMD treatment, with a water quality within the limits of agricultural use (DWAF, 1996), to reuse of the organic medium as a fertiliser for Lucerne and *Casuarina* trees after treatment and the detoxification of hazardous mine waste by planting *Casuarina* trees on top of the tailings.

MATERIALS AND METHODS

The AMD is treated by a cascading test bed system comprising four cascades, each 8 meter by 25 meter in size (figure 1-3). The water flow was 6,000 - 9,000 m^3 per day and the water had a contact time with the medium of about 15 minutes. The organic medium was placed into shade-net bags and packed against the water flow, so that the water and the organic material have optimised contact with both turbulent and laminar flow. After treatment the quality was within the limits for agricultural use, as specified by the Department of Water Affairs and Forestry (table 2).

Figure 1: Construction of cascade system

Figure 2: Water treatment

Figure 3: Treatment with in basins loose material

When using the organic medium for remediation of AMD, most of the heavy metals and salts are bound, immobilised and precipitated on top of the bags of material. This precipitate can be easily removed or the material can be deposited on tailings storage facilities. The organic medium is usable for up to two years (test done by the Department of Geosciences in 2007), before the effectivity in binding metals and salts decreases (recommended replacement intervals depend on the quality of the water). After about 18 month the used organic medium is mixed in with the mine tailings as to constitute a 5% concentration. This organic material still has a residual cation exchange capacity, so that the metals and salts in the soil are bound and precipitated to the surface of the tailings. The immobilisation of the metals in the tailings is very important because of the potential post-mining process which may make use of the rest of the valuable minerals still available. This process is done by removing the mine tailings as a sludge. If the metals are not bound they will be mobilised immediately, and leach through to the ground water level where they then enter water which maybe used for human consumption. The organic medium prevents this potential problem by the immobilisation of metals and salts, for an estimated time of up to 7 years. The benefit of the mixing of the organic medium and tailings is that it functions as a fertiliser when planting *Casuarina* trees (figure 4+5), one of the ingredients of the organic medium, and is useful for the prevention of dust storms (figure 6).

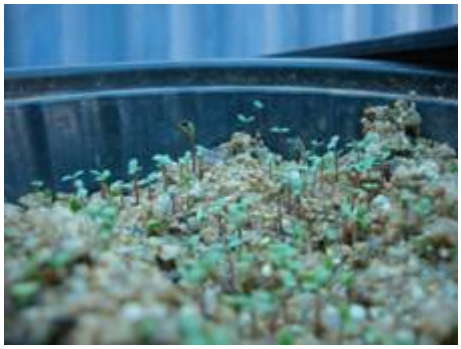

Figure 4: *Casuarina* tree at seedling stadium

Figure 5: *Casuarina* tree planted on mine tailings

Figure 6: Sand storm on tailings storage facility

After three years of growth the needles of the *Casuarina* trees can be harvested every 9 months, mixed with pine-bark and two other semi decomposed plant-products to again produce the organic medium. This will ensure continuous production of material for water purification (AMD) and mine tailings rehabilitation.

The harvesting of the *Casuarina* needles and the cultivation of Lucerne provide opportunities for job creation after mine closure. Former employees of a mine may have the opportunity to keep on working for the same company and supporting these companies in fulfilling the responsibility of rehabilitating the complete mine site in an environmentally friendly manner.

TECHNICAL AND SCIENTIFIC BACKGROUND

Heavy metal immobilisation

The organic material has the ability to exchange both, positive and negative ions between the organic material and a fluid (figure 7). The different strength of charges is because of the different semi-decomposed organic material such as pine needles and bark. When the process of de-composition starts, the charge of the organic medium changes to low and high negative because of the higher amount of H^+-ions from the de-composing processes of the different organic materials. Thus cation and anion exchange can occur in the organic medium at the same time.

The pine-bark in the organic medium contains lignin and tannin, which raises the pH from 3.0 to > 5.0, so that all heavy metals in the AMD are immobilised. In this pH range the organic medium binds all heavy metals and salts strongly, even when the contact time is only about 15 minutes (more contact time will remove more metals, sulphates and silica).

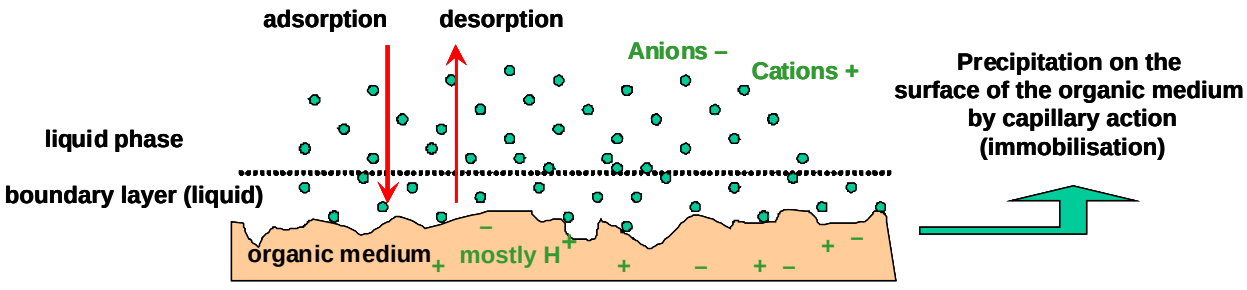

Figure 7: Immobilisation of heavy metals by ion-exchange

After the metals and salts are bound and immobilised, they are precipitated on the surface of the organic medium at temperatures over 15°C. This is a result of the temperature gradient between the surface of the medium and the internal temperature of the medium itself. The precipitation of metals and salts can be seen on the surface of the bags (figure 8) or by microscopic examination (figure 9+10).

Figure 8: Precipitation on the surface of the bags filled with the organic medium

Figure 9: Microscope picture of precipitation of metal sulphide (1:500)

Figure 10: Microscope picture of precipitation of salt (1:500)

Agricultural use of treated AMD

The treated AMD, with a pH of about pH 5.0 and from which more than 80% of the heavy metals have been removed can be used for irrigation of a specific cultivar of Lucerne. Because of the low pH (free acid) of the AMD, the water must come into contact with the soil in order to remove free oxygen and to ensure a neutral pH that will not damage the natural plant oils and cells epidermis.

Plants use traces of metals and salts as nutrients for growth. These metals and salts are bound by ion exchange from the soil. Ions bound by the roots of plants are HCO_3^- and H^+. These ions are changed to bindings with better strength and energy-potential ($Al^{3+} > Ca^{2+} > Mg^{2+} > K^+ = H^+ > Na^+$) (Scheffer, 2002).

The changed ions can be separated into groups of major nutrients like nitrogen (N), phosphorus (P), sulphur (S), potassium (K), calcium (Ca) and magnesium (Mg), and the group of trace elements, such as boron (B), molybdenum (Mo), chlorine (Cl), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu), which are only needed in a small amounts (Gisi, 1997).

Lucerne absorbs and removes the available macro- and micro elements via the root system and uses them for growth. Because of the high growth potential the Lucerne, it can be harvested every forth or fifth week. With this high growth potential, a large amount of heavy metals and salts can be removed from the soil and may detoxify the soil over a long period of cultivation.

Used organic medium as fertilizer

The semi-decomposed organic material with the immobilised heavy metals is a good growth medium and serves as a fertilizer for different nitrogen fixing or heavy metal adapted plants. The used organic medium mixed with natural or contaminated soil (5%) and gives the plants enough nutrients to grow well in soils with the ideal pH. In addition it may replace micro organism's destroyed by fertilisers.

The semi-decomposed bark functions as mulch, it loosens the soil and buffers the pH and keeps moisture in the soil. During decomposition the bark and needles provide a growth medium for bacteria, yeast and fungi, which in turn make nutrients available for plant growth.

Casuarina trees as detoxifier and wind breaker on mine tailings

The *Casuarina* tree is suitable for growing on mine tailings. The tree has the ability to grow on soils highly contaminated soils, and this species can survive in highly polluted sludge produced in the mining process.

When at a height of about 50 – 70 cm, young *Casuarina* trees are strong enough to be planted on tailings. Before planting 0.5 m³ of soil is mixed with 5% of used organic medium, so that the young seedling has fertiliser to grow in. In addition the medium raises pH (soil/buffering). Average irrigation should be higher than 200 mm rain per year – even with high rainfalls the plant is able to grow well on the tailings. After a growth period of three years the needles of the *Casuarina* trees can be harvested every nine months. These needles are one ingredient of the organic medium.

The loose fallen needles begin to decompose while lying on the ground and a huge variety of fungi, yeasts and bacteria start to grow in the semi de-composed organic material. This process aids the growth of the plant by detoxifying the surrounding soils by binding and metabolising the heavy metals in the tailings.

As an additional advantage, the trees photosynthesize and contribute to the reduction of CO_2 levels. Without establishment of vegetation the severe sandstorms on mine tailings carry high-polluted sand away and cover cities and buildings kilometres away. During this transportation the different elements and heavy metals fall out, because of their specific weight and produce highly concentrated toxins for flora and fauna as well potentially contamination the ground water.

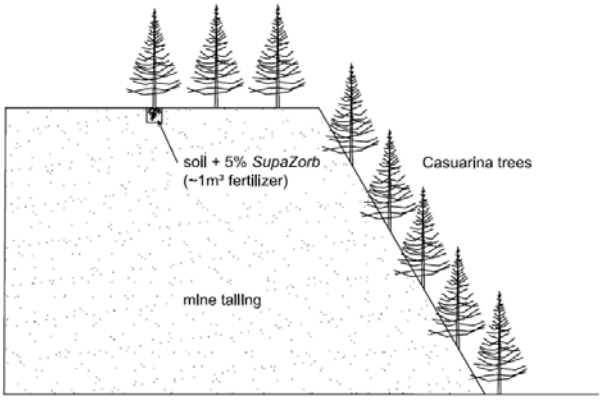

Figure 11: Planting *Casuarina* trees on the mine tailings

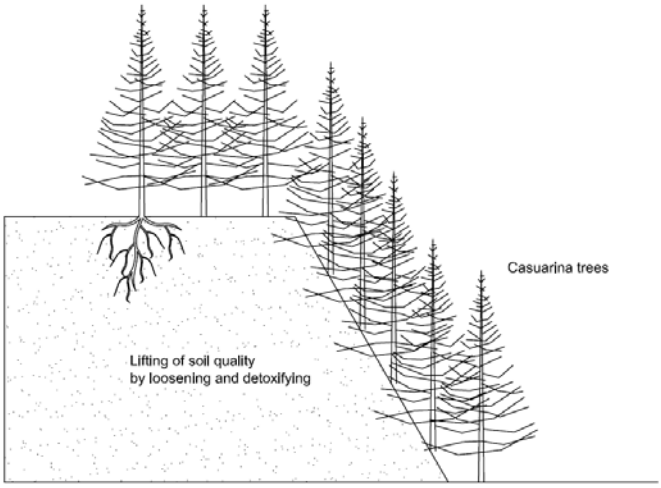

Figure 12: Growing *Casuarina* trees on the mine tailings

RESULTS

The main difficulty in disposing of polluted acid mine drainage (AMD) is the large amount of macro-elements and heavy metals including calcium, magnesium, potassium, sodium, phosphate, sulphate, ammonium, chlorine, bicarbonate, iron, manganese, copper, zinc, beryllium as well as having a pH of less than pH 3.0. This low pH is caused by the release of hydroxide, which causes free acidity (Neculita, 2007). A solution for improving the water quality is to raise the pH and immobilise the heavy metals and remove them from the AMD in a sustainable manner (table 1).

Table 1: Summary of results before and after treatment with the organic medium

Description	Ca [mg/l]	Mg [mg/l]	K [mg/l]	Na [mg/l]	PO_4 [mg/l]	SO_4 [mg/l]	NO_3 [mg/l]	NH_4 [mg/l]	Cl [mg/l]	HCO_3 [mg/l]
AMD before treatment	297.78	178.88	14.86	116.10	< 0.01	2,897.23	11.14	5.72	45.81	0.00
AMD after treatment	317.82	89.20	64.90	82.30	< 0.01	815.57	2.39	0.88	49.13	613.21

Description	Fe [mg/l]	Mn [mg/l]	Cu [mg/l]	Zn [mg/l]	B [mg/l]	pH [--]	EC [mS/cm]
AMD before treatment	12.57	7.07	0.05	1.08	0.15	3.01	6.18
AMD after treatment	0.34	7.03	0.02	0.06	0.63	8.04	2.87

With the use of the organic medium it was shown that by ionic exchange extraction and adsorption, even in pH ranges of below pH 3.5, high concentrations of manganese and iron were removed. The organic material carries different charges and thus it is possible to exchange all ions, positive and negative at the same time.

This treated AMD was tested for irrigation of a special cultivar of Lucerne (SA Standard), which can be harvested every 5 to 6 weeks. This plant is able to absorb small amounts of heavy metals from soil, bind and immobilise them. Lucerne also uses macro-elements like potassium, phosphate, nitrate, ammonia as nutrients for growth. Over a period of 3 to 5 years this plant species detoxifies the soil and maybe used as a protein food supplement for animals.

Table 2: Quality limitations for irrigation (DWAF, 1996) and of AMD treated by the organic medium

Parameter	Units	Irrigation (by DWAF) max. limit	Treated AMD by organic medium
pH	-log10[H+]	6.50 - 8.40	8.04
Sulphate	[mg/l]	200.00	118.00
Aluminium	[mg/l]	5.00	1.90
Arsenic	[mg/l]	0.10	0.066
Cadmium	[mg/l]	0.01	0.0033
Chromium	[mg/l]	0.10	0.026
Copper	[mg/l]	0.20	0.061
Iron	[mg/l]	20.00	8.00
Lead	[mg/l]	0.20	0.0046
Nickel	[mg/l]	0.20	0.15
Zinc	[mg/l]	1.00	0.053
Uranium	[mg/l]	0.01	0.00023

CONCLUSIONS

The project was initiated and implemented to reduce environmental damage arising from the use of chemicals during the process of remediating acid mine drainage (AMD) and to attempt to keep the environment free from toxic and soil sterilising chemicals.

In the past in South Africa chemicals like caustic soda and lime were used to raise the pH and remove heavy metals from the process water of the mines. Treatment with an organic medium is the only non-chemical method of cleaning AMD without causing long-term problems after treatment.

The use of organic material, harvested from nature is far cheaper than the use of chemicals. The fact that *Casuarina* trees are planted on the tailings as a detoxifier and nitrogen fixer, enables mining companies to develop new job opportunities with the cultivation and harvesting of the *Casuarina* trees. Additional benefits are: a wood product, energy source with higher BTU (British thermal unit) output and less toxic fumes as well as the possibility of manufacturing a very high quality activated carbon for used in water purification and gold recovery, even after mine closure. The claims from Carbon Credits can over a period pay for the forestation and the by-products sustain job creation.

Casuarina seedlings require care until they are 50 cm high. After this stage they will grow almost anywhere on polluted soils. The organic medium can be used for almost every type of water treatment where there is high pollution of metals. Planting trees and crops on a large scale assists with the reduction of CO_2 emissions.

The project integrate sustainable acid mine drainage (AMD) treatment and hazardous soil detoxification, by the use of the organic medium. Needles and bark from a pine species - the ingredients of the organic medium – bind and

immobilises heavy metals from the polluted AMD and precipitate them onto the surface of the material, so they may be removed easily.

The quality of treated AMD is within the limits for agricultural use and can be used for the irrigation of different plant species. The used but still biologically active organic medium can be deposited on mine tailings and acts as a detoxifier for the soil and as a fertiliser for *Casuarina* trees from which the needles and bark are harvested for the production of the organic medium.

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