BAUXSOL TECHNOLOGY

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Bauxsol Technology involves environmentally advantageous treatment methodologies for intractable environmental problems such as acid, arsenic, and heavy metal contamination of water and soils. The Bauxsol products have remarkable ability to neutralise acid and to trap and bind trace metals and some other chemical substances.

Bauxsol Technology involves the use of pure Bauxsol powder or one of many possible patented blend formulations, specifically designed to treat contaminated waters with particular compositions (e.g. to enhance the removal of arsenic, manganese or phosphate).

Pure Bauxsol powder consists of dry red solid grains composed of a complex cocktail of minerals that usually include: abundant hematite, boehmite, gibbsite, sodalite, quartz and cancrinite, minor aragonite, brucite, calcite, chromite, diaspore, ferrihydrite, gypsum, hydrocalumite, hydrotalcite, ilmenite, lepidocrocite, p-aluminohydrocalcite, portlandite and whewellite, and a few very low solubility trace minerals.

Bauxsol Products have high acid neutralising capacity (2.5 - 7.5 moles of acid/kg, depending on the product) and very high trace metal trapping capacity (usually greater than 1,000 milliequivalents of metal/kg of Bauxsol Product).

Despite their high acid neutralising capacity, Bauxsol Products all have a near-neutral reaction pH (typically between 8.2 and 8.6) and TCLP (Toxicity Characteristic Leaching Procedure) values are sufficiently low that Product can be transported and used without the need to obtain transport permits.

Various forms of Bauxsol Products can be produced to suit individual applications (e.g. slurries, powders, pellets and porous blocks).

Using standard powder-handling facilities and methods, Bauxsol Products are safe for unskilled workers to handle. After use, reacted Bauxsol Products are not waste materials as they can be re-used in other applications. For example, after treatment of metal-contaminated water, the exhausted Bauxsol Product forms non-dispersive sediment that supports healthy plant growth and from which it is very difficult to leach any metals that were bound during water treatment.

Whereas most metals removed by clays and zeolites are absorbed and can be desorbed if chemical conditions change slightly, most metals bound using Bauxsol Technology are held as structural components of minerals and not on exchange sites on mineral surfaces and therefore cannot be easily removed.

Accelerated aging studies indicate that metals remain strongly bound to the Bauxsol Product sediment for long periods. There is no evidence that the Bauxsol-metal bonds weaken with time and as such it appears that metals are effectively immobilized.

For reacted Bauxsol Products, TCLP tests or leaching with acidic solutions buffered at a pH of about 3 are able to remove only a small proportion of the bound metals. Work to assess the long-term stability of reacted Bauxsol sediment stored under reducing conditions is in progress. It is unlikely however, that reducing conditions would result in any loss of trace metals because reducing conditions and the presence of sulphate in the Bauxsol Product would encourage development of sulphate reducing bacterial populations and any sulphide produced would rapidly trap any metals that were released. Consequently, it is believed that reacted Bauxsol sediment can be safely stored under oxidising or anoxic conditions without any risk of the loss of trace metals through normal leaching.

Hence, reacted Bauxsol sediment is likely to retain any metals that it has bound over time.

PRODUCTION

Virotec produces Bauxsol Products by chemically and physically modifying the caustic red mud residues generated during alumina production by the Bayer process.

Refinery residues are a highly caustic hazardous waste (pH is typically about 13). The first stage in the production of Bauxsol Products involves pH neutralisation of the red mud by creating reaction conditions that form new carbonate, hydroxide and hydroxycarbonate minerals and preserve the acid neutralising capacity of the solids. Much of the sodium originally present in the red mud is released during this treatment and stabilisation process.

The next stage in the production of Bauxsol Products involves adding selected reagents required to produce specific formulations.

The Bauxsol Product is then dried, bagged or stockpiled for bulk transport to sites where it may be required.

All Alumina refineries produce process residues with roughly one to one and a half tonnes of red mud resulting from every tonne of alumina produced. Virotec sources its raw material from Alumina refineries in several countries, including the Eurallumina Refinery on the island of Sardinia, Italy.

Although the particles in dry Bauxsol Products are very fine grained, they are remarkably non-dispersive in water and readily flocculate to settle out as sediment. After Bauxsol Technology was used to treat the 1.5 billion litre, 10m deep tailings dam at Mt Carrington in Australia, the water became completely clear within 48 hours and the suspended solids load fell to below 1 mg/L.

The non-dispersive, sedimentary nature of reacted Bauxsol Product is a most desirable feature compared to the highly dispersed sludge that commonly remains after alkali treatment such as addition of lime.

Additionally, the sediment from reacted Bauxsol Product, when added to soil or waste rock, will support plant growth and hold most of the bound metals sufficiently tightly so that they cannot be taken up by the plants or released in leachate.

Table 1 summarises results of Toxicity Characteristics Leaching Procedure (TCLP) testing of Bauxsol Product and shows that no trace elements are released in potentially environmentally hazardous concentrations.

INERT POWDER

Table 1

TCLP (Toxicity Characteristic Leaching Procedure) DATA FOR FRESH BAUXSOL PRODUCT AND THRESHOLD VALUES FOR CLASSIFICATION AS AN INERT SOLID IN N.S.W. Australia

Contaminant	TCLP Value (mg/L)	NSW Regulations Threshold Value (mg/L)
Arsenic	<0.01	0.5
Beryllium	<0.01	0.1
Cadmium	<0.01	0.1
Chromium (total)	0.05	0.5
Copper	<0.01	No limit set
Lead	<0.01	0.5
Mercury	<0.01	0.02
Molybdenum	<0.01	0.5
Nickel	0.02	0.2
Selenium	<0.04	0.1
Silver	<0.01	0.5
Vanadium	0.06	No limit set
Zinc	<0.01	No limit set

ENVIRONMENTAL GEOCHEMISTY

Geo-technically, solid Bauxsol powder has a plastic limit at 33% moisture and a liquid limit at 53% moisture (i.e. the plasticity index is 20%); the linear drying shrinkage is 7.5%. Particles in dry Bauxsol powder are very fine grained with about 80% of the total mass having a particle size of less than 10 microns.

When the fine-grained Bauxsol Products are added to metal-laden water or soil a chemical reaction is initiated with the heavy metal contaminants and they are sequestered within the fine grains as insoluble minerals. At the same time, the Bauxsol Products neutralise any acid in the soil or water.

In soil, Bauxsol grains simply remain in situ. After reaction, the grains are inert and pose no environmental hazard.

The mixture of carbonate, hydroxide and hydroxycarbonate minerals in the Bauxsol Products largely provide the acid neutralising capacity, but some of these react slowly. Hence, almost 48 hours are required for the reactions to go to completion.

Tests involving the addition of standardised sulphuric acid to powdered Bauxsol Product show that about 40% of the acid neutralising capacity is used in 5 minutes, about 70% is used in 4 hrs and about 95% is used in 24 hrs.

As with acid neutralisation, the ability of Bauxsol Product to strip trace metals from water increases over time, and over about 240 hrs, 1 kg of Bauxsol Product has the ability to strip more than 1,000 milliequivalents of metals from water in contact with it. It is considered that most trace metals are initially trapped by adsorption, which is particularly efficient because the Bauxsol Products are dominated by particles with a high surface area/volume ratio and a high charge/mass ratio. However, adsorption alone cannot explain the ability of the Bauxsol Products to strongly bind trace metals because when desorption tests (using compulsive exchange reagents) are carried out on Bauxsol Products that have been fully loaded with metals and aged for 7 days, less than 20% of the bound metals can be recovered (less than 5% for As, Cd, Cr, Cu & Zn).

If the Bauxsol sediment is left to age after use, it develops a renewed capacity to trap trace metals even if its metal trapping capacity was saturated before it was left to age. Numerous studies show that Bauxsol sediment can continue to extract trace metals from water in contact with it for many years.

TAILINGS DAM ‘clean and release’ treatment

At sites where annual evaporation exceeds annual precipitation, management of ponded AMD/ARD has often relied on evaporation of the water, but this approach requires a dam large enough to hold all the water that could be accumulated during a series of high rainfall events. Consequently, there is a permanent risk of dam failure or overtopping, and as water evaporates, the concentration of contaminants in the remaining water progressively increases.

Ponded AMD/ARD water can be treated *in situ* or by pumping it to a chemical processing facility for treatment prior to discharge, but this involves a substantial capital investment in constructing the facility and ongoing expenditure for reagents, operation of the facility, and disposal of the contaminated sludge produced.

Conventional treatment by lime addition does not reduce the concentrations of all metals to the low levels required for the protection of aquatic ecosystems and the treatment results in the formation of large volumes of unstable sludge that constitute an environmental hazard.

Bauxsol Technology provides a cost-effective new alternative to existing methods for treating ponded AMD/ARD water to the high standards required for the protection of aquatic ecosystems or to the less stringent drinking water, stock watering or irrigation water standards as required. It will both neutralise acid in the water and strip metals from the water so that treated water can be discharged safely and does not require indefinite storage. The effectiveness of Bauxsol Technology at stripping trace metals from contaminated water is not affected by the salinity of the water.

The volume of water to be treated does not limit the use of Bauxsol Technology to treat ponded AMD/ARD and the results of treating large water bodies are consistently similar to the results obtained in laboratory studies of samples of water from the large body. In field applications, however, as opposed to laboratory tests, some additional Bauxsol Product is usually needed to treat stored acidity in near-surface sediment in the dam and any additional water that flows in while the treatment is in progress.

When used to treat acid mine waters by direct addition, Bauxsol Products do not produce a sludge but settle through about 10m of water within 48 hours to form a thin layer of sediment typically less than 5mm thick.

Trace metals bound to the Bauxsol sediment in a treated dam cannot be readily liberated. In August 2000 Virotec treated AMD water in a 1.5 billion-litre Tailings Dam at Mt Carrington, Australia to stringent aquatic ecosystem discharge standards and the water was then released into the environment. Evidence indicates that the Bauxsol sediment was still extracting trace metals from the treated water over 200 days after treatment was completed; for example, the zinc concentration in the water had progressively dropped from 39.1 µg/L to a value of 16.8 µg/L with no further addition of Bauxsol Product.

The Bauxsol sediment remaining after treated water has been discharged can be easily revegetated and will support healthy plant growth.

The Bauxsol Technology required and the application strategy will depend on the initial composition of water to be treated and the treatment targets adopted.

EFFECT OF TREATING AMD WATER IN A 2ML TOE DAM BY DIRECT ADDITION BAUXSOL TECHNOLOGY

Component	Before treatment	After treatment
pH	3.6	8.3
Aluminium (µg/L)	60,710	31
Arsenic (µg/L)	5.3	3
Cadmium (µg/L)	1,660	0.2
Copper (µg/L)	42,560	4
Iron (µg/L)	7,050	34
Lead (µg/L)	70	<0.1
Nickel (µg/L)	145	12
Zinc (µg/L)	64,850	19

EFFECT OF TREATING AMD WATER IN THE 1,500 ML TAILINGS DAM AT MT. CARRINGTON, NEW SOUTH WALES, BY DIRECT ADDITION BAUXSOL TECHNOLOGY

Component	Before treatment	After treatment
pH	5.2	7.3
Aluminium (µg/L)	1,060	13
Cadmium µg/L)	310	<1
Copper (µg/L)	1,510	3
Iron (µg/L)	230	29
Lead (µg/L)	16	<0.1
Nickel (µg/L)	145	12
Zinc (µg/L)	11,570	39

ACID MINE DRAINAGE

The continual discharge of Acid Mine Drainage (AMD) or Acid Rock Drainage (ARD) water can have a cumulative or chronic environmental impact.

AMD/ARD is widely acknowledged as the greatest environmental problem facing the mining industry with serious impacts from both the acid and released metal ions.

Preventing the formation and escape of these acidic metal-rich leachates from mineral recovery operations is a management problem for modern mining operations, and a major remediation problem for wastes associated with abandoned mine sites, some of which are hundreds of years old.

Adverse environmental impacts can be avoided either by treating the AMD/ARD water in collection dams or by preventing the formation of the acidic metal-rich leachates.

Once the AMD/ARD has formed there are few treatment options available and all alternatives to Bauxsol Technology involve some form of chemical treatment.

SULPHIDIC SOILS and MINE WASTES

Acid sulphate soils exist in coastal lowlands in many parts of the world, particularly in tropical and sub-tropical regions, where they are linked to the degradation of subaerial (e.g. scalding of vegetation) and aquatic (e.g. fish kills) ecosystems. In many parts of the world, acid sulphate soils cause serious problems for agricultural productivity, the protection of fisheries resources, land development, and the protection of building foundations and underground infrastructure (e.g. cable networks and pipe lines).

Current management strategies for developments in acid sulphate soil areas include leaving the affected area completely undisturbed, preventing work that may lower the water table or removing the sulphidic material for burial below the water table. These options are either costly, or impose major constraints on land use. Lime is sometimes used to neutralise the acid that may form but there are several problems associated with its use, including:

1) Lime is slightly soluble in rainwater and most groundwater. If a series of wet seasons precede a drought, much of the lime may have been leached from the soil before the acid that it was supposed to neutralise is produced,
2) In some coastal settings, particularly near mangroves, adding too much lime may cause more environmental problems than it solves due to localized high pH,
3) Bicarbonate ions that form when some of the lime dissolves, may accelerate the decomposition of sulphides, and
4) The formation of gypsum, when calcium in the lime reacts with sulphate produced during sulphide mineral oxidation, may adversely affect soil drainage.

Sulphidic mine tailings and sulphidic waste rock usually provide a greater environmental threat than acid sulphate soils because when they oxidise they usually release much greater quantities of metals that have a high eco-toxicity (e.g. arsenic, cadmium, copper, mercury, etc.).

Oxidation of the sulphides in these materials usually begins slowly, but once the pH of the pore water falls to about 3, ferric iron can catalyse the breakdown of sulphides and the process can accelerate rapidly. Oxidation of the sulphides can also be accelerated significantly by sulphur and iron oxidising bacteria that commonly colonise the sulphidic material.

The most widely used strategy to manage sulphidic mine tailings and sulphidic waste rock is to isolate it from atmospheric oxygen by placing it in lined and capped impoundments. However, there are many major problems with using lined and capped impoundments, which can be described as a 'cover up' rather than a 'clean up' strategy. These problems include:
1) An impoundment does not provide a permanent solution because at some stage it will inevitably fail and create a future remediation problem (no engineered structure will last forever),
2) Because very large quantities of sulphidic material are often involved, confinement is not always practical,
3) Although caps and linings can prevent the production of acid leachate by infiltrating rainwater, they seldom completely prevent the escape of leachates with groundwater, and
4) Capped impoundments can only be revegetated with small plants because the roots of large trees can puncture previously impermeable caps.

Sulphidic waste rock and mine tailings have sometimes been managed in the past by blending with acid neutralizing chemicals such as lime, however the difficulties associated with this approach (as described above) have shown that this approach is of limited long-term value.

The ideal solution is to permanently treat the sulphidic soils by applying Bauxsol Technology at the source of the problem.

SULPHIDIC SOIL TREATMENT

Bauxsol Technology can be used to prevent acid and trace metal release from sulphidic mine tailings, sulphidic waste rock and acid sulphate soils and it overcomes problems associated with the use of lime.

Bauxsol Technology has several advantages over alternative chemical treatments because:

1) Bauxsol Product cannot be leached from the soil by rainwater or groundwater before acid that needs to be neutralised has formed,
2) Bauxsol Product will enhance the nutrient retention capacity of the soil or mine site wastes thereby improving its suitability for plant growth, and
3) Bauxsol Product cannot accelerate sulphide decomposition even if insufficient Bauxsol Technology is applied.

The Bauxsol Product can either be physically mixed with the sulphidic mine wastes and the acid sulphate soil material or it can be placed in layers within the column of sulphidic material.

Bauxsol Product application rates required for each site can be calculated to ensure that no acidic or metal-rich water can escape from the site.
Both laboratory and field trials show that the effectiveness of Bauxsol Technology is greater than theoretically expected (Figure 1).

In large scale field applications of Bauxsol Technology to acid sulphate soil material or sulphidic mine wastes, both the soil reaction pH and the groundwater pH were near neutral within 48 hours of completion of the treatment work. After treatment, surface of any Bauxsol™ Technology treated acid sulphate soil or sulphidic mine waste material can be immediately planted as part of a revegetation programme.

In all field applications so far completed, the material treated with Bauxsol Product supports excellent plant growth, even at sites where no plant growth has been possible for several decades. Ongoing field trials show that all leachates from sulphidic mine wastes treated with Bauxsol Product are of acceptable quality and that the growth of grasses, shrubs and trees is excellent. Tree growth on the treated mine wastes is more rapid than on a nearby farm used as a reference site.

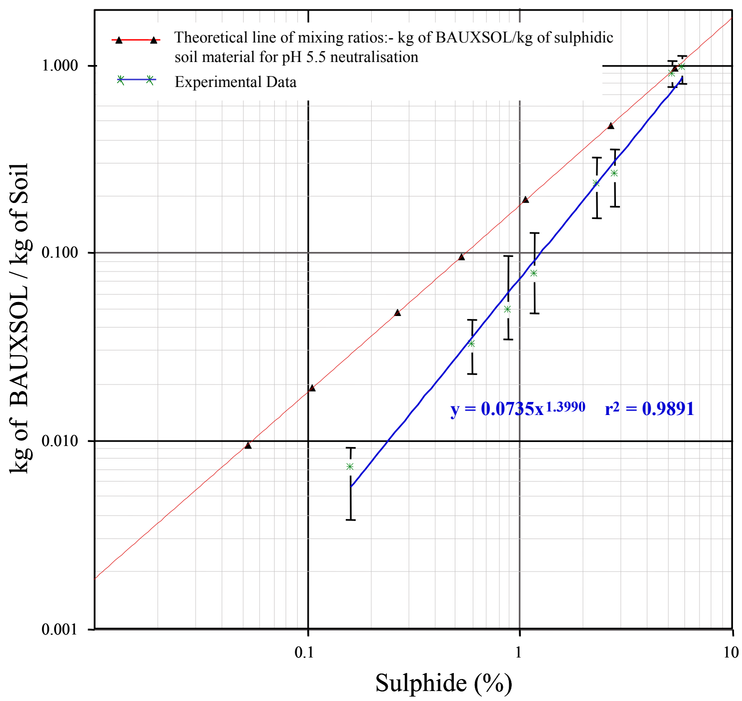

Figure 1: Plot showing the Bauxsol Product soil/sediment mixing ratios required to prevent acid release from sulphidic soils or wastes with specific sulphide mineral contents. Note that the amount of Bauxsol Product required is consistently less than that predicted from theoretical data.

OTHER APPLICATIONS

Treating Sulphidic Marine Sediments Used as Landfill

Sulphidic marine sediments are often dredged from estuaries and other near-shore environments as part of the development or maintenance of harbours and navigation channels. In many countries there are restrictions on dumping this dredge spoil in marine environments so it is often used as landfill in coastal land reclamation programmes.

When exposed to the atmosphere, this sulphidic marine sediment becomes a potential acid sulphate soil and requires management in the same way as an acid sulphate soil does.

Bauxsol Technology can be used in the management of sulphidic dredge spoil in the same way as it is used in the management of acid sulphate soils; the alternative of using lime suffers from the same problems that affect its use in the management of acid sulphate soils.

When Bauxsol Technology is used in this way, it improves the geotechnical properties of the dredge spoil used in the reclamation work (particularly the rate of consolidation and the shear strength of the compacted material) and it ensures that the foundations of any structures built on the reclaimed land are protected from possible acid corrosion.

Phosphates in Water & Wastewater

In addition to the ability to neutralise acid and trap trace metals, a special form of Bauxsol Technology is in development to provide excellent ability to bind with phosphate. The product from this reaction is under study as a slow-release fertilizer material.

Consequently, Bauxsol Technology has potential uses in stripping phosphate from effluent water prior to discharge to natural environments where increased phosphate loadings can promote nuisance algal growth and eutrophication, particularly the growth of potentially toxic cyanobacteria. The phosphate binding capacity of Bauxsol Technology has numerous potential applications, some of which are listed as follows:

Bauxsol Technology can be used in tertiary stage sewage treatment where it will have the added advantage of reducing the trace metal load in the treated effluent. Its use eliminates the potential hazard associated with using alum in acid coastal lowlands where free aluminium can adversely affect fish.

Bauxsol Technology can be used to reduce the high phosphate concentrations in many industrial effluents (e.g. effluents from abattoirs and plant nurseries). Tests carried out at a chicken processing facility showed that Bauxsol Technology was able to remove over 98% of the phosphate in digester effluent that had an initial phosphate content averaging 30 mg of phosphorus/L.

ARSENIC IN WATER

Groundwater in parts of many countries is unsafe for human consumption due to its high arsenic content (frequently over 50 µg/L compared to the World Health Organisation drinking water limit of 10 µg/L) and in some places, such as Bangladesh, where most surface water is heavily contaminated with microbial pathogens, many people have no alternative to drinking the groundwater extracted from wells.

As a result, several thousand people die in Bangladesh every year from arsenic poisoning and tens of thousands of others develop symptoms of chronic arsenic poisoning. Similar problems exist on a lesser scale elsewhere.

The problem is compounded in Bangladesh and some other third world countries because water treatment technologies, such as reverse osmosis, that could be used to produce safe drinking water are beyond the means of local communities to operate and maintain even if the equipment is supplied as part of foreign aid programmes.
Other chemical treatment procedures are also impractical for remote village communities.

Bauxsol Technology has been applied in an inexpensive but efficient manner to remove arsenic from groundwater. Initial trials indicate that at least 70% of the arsenic can be removed by passing water through a simple Bauxsol Technology column. Further developments aimed at increasing removal efficiencies and column capacities are expected to be successful.

Other drinking water resources have unacceptably high concentrations of trace metals such as iron, manganese and copper and the concentrations of these metals can also be reduced by treatment with similar Bauxsol Technology.

INDUSTRIAL APPLICATIONS

Treatment of Chromium-Rich Acidic Tannery Effluent

A Bauxsol Technology has been successfully used to treat acidic chromium-rich tannery wastes. The application of Bauxsol Technology raised the pH of the effluent from 3.6 to 8.5 and reduced the total chromium concentration from 1,875 mg/L to 1.9 mg/L (about 99.9% of the chromium is removed from the effluent). As an additional benefit, treatment of the tannery wastes with Bauxsol Technology reduced the organic matter content of the effluent and substantially increased the settling of suspended particles that have to be removed before the effluent can be discharged.

Treatment of the tannery effluent was particularly successful, demonstrating that the use of Bauxsol Technology for this purpose can provide better outcomes than the use of conventional alternatives.

Permeable Reactive Barriers

Virotec is currently testing the use of Permeable Reactive Barriers (PRB) to neutralise acid and strip trace metals from acidic metal-rich leachates.

The design and dimensions of each PRB and the form of Bauxsol Technology required, or the amount of Bauxsol Technology in a mixture, needs to be set to provide a balance between detention time (i.e. reaction time) in the barrier and the barrier permeability required to handle the flow rate and volume of water to be treated.