The Conversion and Sustainable Use of Alumina Refinery Residues: Global Solution Examples

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Abstract

This paper introduces current industry best practice for the conversion of alumina refinery residues (or "red mud") from hazardous waste to benign, inert material. The paper will examine four neutralization methods and Basecon Technology, a sustainable conversion process. The paper will consider ways through which this converted material can be combined and processed for sustainable applications in the treatment of hazardous waste streams (such as industrial wastewater and sludges, biosolids, and CCA wastes), contaminated brownfield sites, and mine site wastes. Recent discoveries and applications, such as the successful treatment of high levels of radium in drinking water in the USA, will also be discussed. Examples of global solutions and their technical merits will be assessed.

Introduction

The alumina refining industry has for many years been seeking ways to minimise and reduce the environmental and social impacts of its caustic solid waste, a waste classified as "hazardous" in most countries. Such an initiative is imperative given the worldwide industry generates over 80 million dry metric tonnes of caustic waste tailings each year, with at least 30 million dry metric tonnes produced in Australia alone [1]. Moreover, recent reports from near Alcoa's Wagerup refinery in Western Australia maintain that "residents of the nearby south-west town of Yarloop say the emissions are making them sick, causing symptoms such as nose bleeds, sore eyes and skin ulcers...There is a very long list of known toxic or carcinogenic substances which are regularly emitted [from the refinery] and yet exactly what combination it is which is making people sick... hasn't been clearly drawn out" [2].

These concerns are even greater in less developed industrial nations, where accidental immersion in red mud has resulted in death. Alcoa has therefore recently stated: "Finding practical uses for new and stockpiled refinery residue – which has ongoing environmental and land use impacts and significant storage costs – is arguably the biggest challenge facing the global alumina industry" [3]. This paper describes some of the standard methods for neutralising caustic alumina refinery residues and considers their respective limitations. Focus will turn to the merits of Basecon Technology and its added advantage of producing a re-usable raw material which has environmental benefits. Particular attention will be given to a number of sustainable technologies which utilise this raw material in treatment solutions for industrial wastewater and solids, sewage effluent and biosolids, composting and fertiliser, and other applications. It will be shown that these applications represent a break-through in the sustainable re-classification and re-use of alumina refinery waste.

Standard Alumina Refinery Waste Neutralisation Methods

The production of alumina by the Bayer Process results in the creation of large quantities of caustic waste; typically two tones of red mud are produced for every one tones of alumina [1]. Alumina refineries face two choices: either store the mud indefinitely or re-use it. However, long-term storage costs and environmental liabilities are high but re-use requires some form of neutralization. Raw red mud is highly caustic (pH is usually >13.2) and there are substantial problems associated with its long-term storage, including:

- The cost of constructing and maintaining containment facilities is high, and the land used for red mud storage is not available for other purposes;
- Caustic red mud presents a serious threat to the health of any wildlife or humans that come in contact with it;
- Preventing the escape of caustic leachate into groundwater systems, or treating any contaminated groundwater, is difficult and expensive and may need to be continued long after red mud deposition in the storage facility has ceased; and
- The costs associated with public liability insurance, environmental protection, security bonds, and site rehabilitation and closure are high, and are likely to significantly increase in the future.

These costs and liabilities can best be reduced by not having to store some or all the red mud. However, not having to store it requires that it is re-used in some form, and both transport and re-use applications require neutralization of the caustic component of the red mud. Natural weathering processes will eventually neutralize stored red mud, but adequate neutralization takes many decades and in the interim the problems listed above will be applicable. Thus, it is desirable to neutralize red mud in such a way that it is no longer highly caustic [4]. Several methods for achieving this objective include acid neutralization and seawater neutralization, among others.

All of these strategies can be used with varying degrees of efficiency to neutralize caustic red mud and thereby wholly or partly resolve some of the storage and management problems listed above. However (with the exception of reprocessing the red mud to recover other elements, such as titanium and residual alumina and magnesium, which does not consider re-use after element recovery [5]), most re-use options that try to address red mud storage and management problems do not make use of the inherent acid neutralizing, metal binding, PO_4 binding, and other unique properties of neutralized red mud. This requirement when re-using refinery residue imposes serious constraints on the selection of neutralization options. Below are five neutralization options along with their treatment limitations.

Acid Neutralization

Adding acids (usually waste sulfuric acid or acidic water produced when scrubbers are used to remove acid forming gasses from industrial emissions such as those resulting from coal combustion) to reduce red mud pH for safer storage has been attempted. However, large volumes of acid are required. This method may be reasonably cheap provided sufficiently large quantities of waste acid are available and need to be disposed of, and is particularly applicable where contaminated waste acids are produced during scrubbing of acid forming gasses (primarily sulfur dioxide) during coal combustion or other industrial processes, such as sulfide mineral roasting. However, sufficient quantities of acid to neutralize all the red mud waste are seldom available near a refinery and, more critically, the resultant waste material has almost no value for commercial re-use value. Thus, unless a new use for this material is identified, refinery waste neutralized through acid addition must be stored indefinitely and the storage area must ultimately be rehabilitated.

Seawater Neutralization

The addition of seawater can be very effective in neutralizing red mud for refineries that are near the sea [6, 7]. However, large amounts of seawater are required (typically 12-18 times the volume of red mud to be neutralized) if the discharge water is to meet environmental standards and large ponds are required to allow the solids to settle before the calcium and magnesium depleted seawater used in this process can be returned to the sea. These limitations add substantially to the cost of processing.

Reverse Scrubbing Neutralization

Red mud in suspension can be used as a scrubbing agent to counter acid forming gasses produced during coal combustion or sulfide mineral roasting. The technique of using these suspended wastes as a scrubbing agent can be effective, but its primary purpose is in neutralizing the gas emissions not neutralizing the caustic mud. Neutralizing the red mud is an incidental benefit, and the resultant waste solids have no commercial or technical value. Thus, unless a new use for this material is identified, refinery waste neutralized through acid scrubbing must be stored indefinitely and the storage area must ultimately be rehabilitated.

Gypsum and CO_2 Neutralization

Adding gypsum to, or bubbling carbon dioxide (an unwanted gas) through, caustic red mud can produce a waste that is relatively safe to store [2]. However, these procedures can be extremely costly and the resultant semi-neutralized waste solids have little or no commercial or technical value.

As described above, there are several neutralization techniques that can be employed by refineries, but the only available conversion strategy that will facilitate both the sustainable treatment and conversion of red mud from "hazard" to "inert" and the re-use of large volumes of neutralized red mud is Basecon Technology, because it: a) simultaneously converts red mud at an economical rate; b) preserves and enhances its chemical and physical properties; and c) thereby imbues it with commercial value. Such a conversion method foreshadows a sustainable future for the alumina industry.

Basecon Technology

Basecon Technology was developed by Virotec International plc. The Technology economically converts caustic red mud into an inert and safe raw material called Bauxsol Raw Material (BRM), which has remarkable environmental and industrial re-use characteristics. There are five basic steps in the design process of Basecon Technology:

Step #1. Add a mixed-element treatment solution to the red mud until the liquid phase has a pH of 9.0-9.5 and an alkalinity of <300mg/L.

Step #2. Separate the solid and liquid fractions by settling and decanting the liquid fraction.

Step #3. Depending on discharge requirements, add acid (waste acid or acidic water from scrubbers) to the liquid fraction until pH is less than 9.0 and alkalinity is <200mg/L.

Step #4. Discharge the liquid fraction to the sea, transfer to evaporating ponds for salt recovery, or store as required.

Step #5. Wholly or partly dry the solid fraction or retain in slurry form for environmental re-use, or store as required.

Basecon Technology is founded on a patented computer model that calculates the exact amount and type of mixed-element treatment solution to be applied in Step #1, and the exact amount of acid to be added in Step #3. Computerised alkalinity and pH neutralization curves show that up to 10-12 parts of seawater are required to treat caustic red mud with a pH of 13.5 and alkalinity of 15,000mg/L to pH of 8.5 and alkalinity of <300mg/L but only one to four parts of the Basecon Technology mixed-element treatment solution are required to achieve the same goal.

The converted red mud produced by the technology typically consists of a cocktail of fine-grained minerals that includes hematite, boehmite, gibbsite, sodalite, quartz and cancrinite, minor aragonite, brucite, calcite, diaspore, ferrihydrite, gypsum, hydrocalumite, hydrotalcite, lepidocrocite, p-aluminohydrocalcite, portlandite, titanium oxides, and other low solubility trace minerals.

This solid material is BRM, and its use in an extensive range of environmental reagents and applications, has been fully documented [8]. The exact composition of BRM depends on the composition of the feed bauxite used, operational procedures at the refinery, and exactly how the caustic red mud is neutralized, but none of the minerals in BRM is known to be environmentally hazardous. Irrespective of its exact composition, BRM has a significant acid neutralizing capacity (up to 9.0 moles of acid/kg depending mainly on operational procedures at the refinery and the quality of the bauxite feed) and a high trace metal binding capacity (usually ±1,000 milliequivalents of metal/kg). BRM also has a high capacity to trap and bind phosphate and other chemical species, and is a flocculent under certain conditions.

The metal binding properties of BRM are particularly exciting. For example, it has been shown that the longer metal-laden BRM is left to age after use, the more tightly metals are held into the solid matrix, and as the residue ages new metal trapping capacities develop. If the residue is left in a tailings dam or pit lake after the completion of treatment, metal concentrations in the water will continue to decrease for at least 12 months without further treatment.

Most trace metals are trapped by adsorption, which is particularly efficient because the reagents are dominated by particles with a high surface area/volume ratio and a high charge/mass ratio. However, over time, mechanism such as precipitation and isomorphous substitution also come into play as metals are redistributed within the solid BRM matrix.

As a result, the proportion of metals that can be recovered decreases as time increases. The soil reaction pH of BRM is sufficiently close to neutral and the TCLP (Toxicity Characteristic Leaching Procedure) values for the mineral mixture are sufficiently low that it can be transported and re-used without the need for permits that would be required for the transport of hazardous materials. Similarly, BRM is safe for unskilled workers to handle.

Basecon Technology thereby provides the knowledge of how to optimize the volumes and methods of the mixed-element treatment solution and how to limit operating costs and reduce liabilities in order to produce near-neutral BRM with extremely low levels of alkalinity. Basecon Technology also provides the knowledge of how to conserve water and produce marketable salts from red mud. In these ways, Basecon Technology represents the most cost-effective, optimized, and long-term solution to the treatment and re-use of alumina refinery residues.

BRM Additives and Know How

When blended with other natural additives and with its modified chemistry and new physical properties, BRM has several unique characteristics, including:

- Acid neutralizing capacity (up to 15.0 moles of acid/kg);
- Metals, radium and arsenic binding capacity (>1,000 milliequivalents of metals/kg);
- Phosphorous and phosphate binding capacity;
- Odour abatement properties;
- Soil amendment properties;
- Oil and grease sequestration properties and hydrocarbon destruction properties; and
- Sludge consolidation and dewatering capabilities.

In order to capitalize on these chemical and physical properties, Virotec has developed a range of 19 blended reagents for the remediation and long-term benefit of the environment and society [9]. Each of these reagents are derived from the combination of BRM and other natural additives, and when added to metal-laden water, sludges or soil, trigger a chemical reaction with acid forming minerals, heavy metals and other contaminants, with metals becoming sequestered within the fine particles of the reagents as insoluble minerals and any actual acid (TAA) or potential acid (TPA) in the water, sludge or soil being neutralized.

In liquids, the reagent grains quickly drop out of solution and settle to form a thin layer of sediment. Independent data collected by the U.S. EPA shows that the products continue to extract metals up to five years after treatment was completed. In soil, the grains of the products remain where they are.

Even after the treatment of elements such as As, Cd, Hg and Pb, applications have clearly demonstrated the grains are inert and pose no environmental risk or human hazard.

Worldwide Sustainable Industry Applications

The 19 reagents contribute to four different technology groups designed to cover a broad range of industry applications: ViroSoil Technology for the treatment of contaminated soil and site remediation; ViroFlow Technology for the treatment of industrial wastewater and sludges, and contaminated drinking water; ViroSewage Technology for the treatment of municipal effluent and biosolids; and ViroMine Technology for the treatment of liquid and solid mining waste. Each technology is described below with an example of a sustainable application in the treatment of hazardous waste streams or drinking water.

<u>Soil Remediation</u>

Contaminated soils have been identified by most regulatory authorities as the single highest priority of the three main waste types. The technology offers a unique approach to treating contaminated soil and promoting vegetation, with results providing clean, nutrient-rich soil which can be used in agriculture, horticulture and aquaculture [10].

<u>Contaminated Site Remediation</u>. WestRock Developments of Townsville, Queensland, sought to find an economic solution to the remediation of an abandoned industrial site. The site had been previously occupied by a cannery, and as a result of over 20 years of operation there was substantial soil contamination, including high concentrations of copper, lead and zinc. Due to the highly desirable location of the site on the Ross River, there were substantial financial drivers for WestRock to re-develop the site.

The contaminated site could not simply be excavated and transferred directly to landfill due to high leachable metal loads, predominantly lead. Accordingly, a suitable fixation method was required for the treatment and disposal of about 3,000 cubic metres of soil to Townsville City Council's landfill. As a result of applying the technology, the results in Table I show that treated soil was well below the limits set for landfill acceptance. The results shown are averages for approximately 54 separate tests performed on the treated soil. Soil was sampled and analysed for each 50 cubic metre treated by the technology.

Table I – Contaminated Soil Before and After Treatment

Parameter	Metals Contaminated Soil (TCLP Metals in mg/L)	Treated Soil After ViroSoil Technology (TCLP Metals in mg/L)	Limit for Landfill Acceptance (TCLP Metals in mg/L
pH	5.9	9.0	6.0-10
Copper	0.24	0.01	100
Lead	10	0.04	5.0
Zinc	18	0.02	500

<u>Hydrocarbon Destruction</u>. One of the most urgent worldwide environmental problems is the contamination of soil and water due to petro-chemical industrial pollution. Hydrocarbons such as fuels, oil, grease, solvents, lubricants and coolants are among the most common types of contaminants. When coupled with heavy metals sequestration, ViroSoil Technology is a powerful method for combating this significant environmental threat.

Hydrocarbon destruction using the technology is a safe, cost-effective and environmentally responsible method for dealing with and eliminating hydrocarbon contamination. To assist and enhance natural hydrocarbon breakdown and increase the rate of degradation of the contaminant, an inoculum of naturally occurring petrophillic microbes is required to rapidly proliferate and reach a fully established working population.

In soil remediation technology, hydrocarbon contaminants are absorbed into the matrix of the reagent, with indigenous microbes consuming and transforming hydrocarbons into simpler compounds. This process continues until eventually the hazardous hydrocarbon is degraded to carbon dioxide, water, and benign organic elements. Table II shows the results of the treatment of hydraulic sump oil contaminated soil at a mine site in New South Wales, Australia. Disposal criteria required a Total Petroleum Hydrocarbon (TPH) of <10,000mg/kg. The parameters are petroleum hydrocarbon categories, for example, C10-C14 = aliphatic hydro-carbons + decahydro naphthalenes, methyl decahydro-naphthalenes, dimethyl decahydronaphthalenes.

Table II – Contaminated Soil Before and After Treatment

Parameter	Hydrocarbon Contaminated Soil (mg/kg)	Treated Soil After Five Weeks of ViroSoil Technology (mg/kg)	Treated Soil After Eight Weeks of ViroSoil Technology (mg/kg)
C10-C14	2,855	893	322
C15-28	15,051	7,811	4,161
C29-36	13,265	8,713	4,823
TPH	31,171	17,416	9,306

The technology uniquely combines several strengths. First, it targets a variety of different hydrocarbon contaminants simultaneously. Second, it preferentially absorbs hydrocarbons in the presence of water and contains nutrients which are beneficial to the indigenous aerobic and anaerobic micro-organisms present in the reagent matrix. Third, it supports the propagation of naturally occurring hydrocarbon-reducing microbes, which rapidly degrade the sorbed hydrocarbons into simpler compounds. Fourth, leachate problems can be reduced or eliminated, thereby protecting ground waters and adjacent waterways, and effectively suppresses volatilization of flammable vapors. Finally, there are no adverse health or safety concerns in handling the product, and is thereby quick and easy to apply.

The sorption properties of the technology reagents are based on their ability to draw targeted contaminants into its structure. It is the capillary action of the matrix which encapsulates the liquid in such a way that leaching is prevented. Once the hydrocarbon is encapsulated within the reagent matrix, it will remain in place within the matrix during the degradation process.

This is an advantage over liquid and gel applied systems, which in many instances can percolate through the soil profile and into groundwater, never having come into contact with the hydrocarbon and thus not achieving their objective.

From this it can be seen that the technology offers a wide range of different treatment and disposal options for contaminated soils across a wide range of different hydrocarbon types.

In summary, the technology absorbs and destroys hydrocarbons, utilizes a natural product derived from a totally renewable source, is completely safe to handle and apply, leaves surfaces dry and residue free, reduces the amount and hazardous nature of waste, does not release hydrocarbons under compaction and does not cause leachate, and offers multiple treatment and disposal options.

Soil Conditioning. Action Sands operates a sand quarrying and processing facility on the east coast of Australia in north-eastern New South Wales and is responsible for supplying large volumes of sand to the construction industry. Action Sands had accumulated 30,000m^3 of unusable dredge spoil that was mildly acidic and had a low nutrient value. The company wished to convert this waste material into a saleable soil product. The goal of the application was to produce a "conditioned" soil mix that would enable different species of flora to grow and thrive. The dredge spoil was characterized by:

- A high sulfide-sulfur content with a correspondingly high Total Potential Acidity (TPA);
- High levels of calcium, primarily due to the large quantities of shell grit (calcium carbonate) in the material, which contributed to a low Cation Exchange Capacity (CEC);
- A substantial nutrient deficiency, with low levels of potassium, nitrogen and phosphorus; and,
- Significant permeability due to high sand content.

The application of the technology proved to be successful in providing the chemical and physical soil conditions required for sustainable flora growth. The benefits of using the technology to remediate dredge spoils and convert them into saleable soil are summarised below:

- Increased soil moisture retention;
- Creation of a healthy, sustainable soil horizon which allowed revegetation by controlling trace element availability in a way that promotes plant growth and soil microbiota;
- Provision of adequate nitrogen, phosphorus and potassium for healthy plant growth;
- Provision of adequate organic carbon to sustain soil microbiota populations needed for healthy plant growth;
- Neutralisation of soil acidity and increased pH buffering capacity;
- Immobilisation of inorganic metal contaminants (such as Al and Fe) as non-bioavailable environmentally inert forms;
- Retention of phosphate, ammonium, calcium, magnesium, potassium and other essential macro- and micro-nutrients in plant available forms; and
- Improving the mechanical properties of soil.

Action Sands benefited from a sustainable environmental solution after altering the chemical and physical composition of the dredge spoil by applying the technology. This enabled the company to produce a conditioned soil mix for sale to residential and commercial traders, whilst also re-establishing previously unavailable land area.

In summary, it has been shown that the technology has the ability to dramatically reduce leachable metal concentrations in the soil allowing for acceptance into landfill, can destroy hydrocarbon contamination in soils, and can re-condition marine dredge spoils and turn them into commercially saleable products.

Industrial Waste Treatment

The technology treats all forms of industrial wastewater and solids [9], and drinking water. The technology can reduce heavy metals, such as Cd, Cr, Cu, Fe, Hg, Pb and Zn, by up to 99.99% in discharge water [11, 12]. The implementation of the technology has prevented major capital upgrades by increasing effluent throughput for wastewater treatment plants (WWTPs). The use of the technology also allows the re-classification of industrial sludge from "hazardous" to "inert", and has high pH buffering capabilities, typically around 8.0-8.5.

Radium in Drinking Water. In the southern states of the United States more than a 1,000 drinking water wells are currently affected by high levels of naturally occurring Ra contamination. A new generation of reagents has been developed for the removal of this radioactive element in drinking water.

Customers of the Gilbert-Summit Rural Water District (GSRWD) in South Carolina were recently introduced to the technology as the solution to their problem of naturally occurring radium in their ground water. The GSRWD is the first community in South Carolina to have an effective means of removing Ra contamination in drinking water with background levels being reduced through a filter system from 11.0 picocuries to 0.5 picocuries, with 4.0 picocuries being the allowable EPA limit.

Industrial Solids Treatment. When a worldwide wood products company decommissioned operations at a site in the Australian Capital Territory (ACT), a solution was needed to immobilise solid waste containing copper, chrome and arsenate (CCA). The solid waste needed to be treated in order to be approved for safe transport and disposal to landfill.

The technology was used as a treatment solution in order to meet regulatory limits with final testing results enabling the waste to be classified as a "solid" rather than "hazardous" waste, thereby meeting disposal criteria for the ACT EPA. Table III shows the results of the treatment.

Table III – Contaminated Solids Before and After Treatment

Parameter	Total Metals (mg/kg)	Leachable Metals After ViroFlow Technology (mg/L)	Allowable Leachable Metals as Solid Waste (mg/L)
Copper	1,075	0.99	NA
Chromium	3,455	3.0	5.0
Arsenate	3,030	0.41	5.0

Industrial Wastewater Treatment. Similarly, a large-scale CCA treatment plant in Tasmania, Australia found it difficult to comply with discharge limits. As part of their environmental licence, discharge limits imposed by the EPA were to be met before any water can be released from the site. In line with corporate environmental objectives, there was an immediate need for corrective action, continual improvement and long-term management of the CCA leachate ponds.

The key objective was to treat the water in the leachate ponds to immediately reduce CCA concentrations to below discharge limits and to improve overall water clarity. Table IV shows the results of the treatment.

Table IV: Contaminated Pond Before and After Treatment

Parameter	Before Treatment	After ViroFlow Technology Treatment	Discharge Limit
pH	6.8	7.9	6.5-8.5
Copper (mg/L)	0.14	0.01	1.0
Chromium (mg/L)	0.50	0.06	0.50
Arsenic (mg/L)	0.12	0.009	0.05
Objectionable Odour	High	Low	-

Industrial waste solid and liquid treatment using the technology successfully reduced copper, chrome and arsenate concentrations to well below discharge requirements and substantially improved general water quality and odour in the leachate pond.

Municipal Waste Treatment

Increased urbanisation and industrialisation have resulted in a dramatic surge in the volume of municipal wastewater produced around the world. They have also created significant challenges. Both sewage sludge disposal and odour pollution are worldwide problems. The capacities of sewage treatment plants (STPs) are constantly being stretched, and regulators are striving to protect the environment and minimize health risks with more stringent treatment and discharge requirements. The technology addresses municipal waste treatment and results in safe, clean water and odourless biosolids, which can be re-used as an integral part of a disease-free composting system [13].

Biosolids Treatment and Composting. An inherent problem with composting is the ability to obtain a chemically and physically stable end product. For Pine Rivers Shire Council in Queensland, Australia several commercial advantages could be achieved by decreasing composting time, reducing the quantity of green waste required by the composting process, and minimising a plant's impact on the environment. As a result of these commercial drivers, the technology was introduced so that organic biosolids could be stabilised through composting and thereby reduce their impact on the environment.

Several improvements were achieved using the technology in biosolids treatment and composting, such as the bulk density and filterability of the sludge component of the biosolids and the amount of carbonaceous matter required to produce suitable compost was reduced. Other benefits of the technology for composting biosolids include:

- Odour from, and the development of odours in, biosolids and compost were eliminated.
- The rate of composting the biomass was accelerated and the temperature of the composting mass was increased such that the pathogen content of composted mass was substantially reduced.
- Water retention of the composted mass was increased; and
- Metal ions in the composted mass were immobilized in a non-leachable form.

The biosolids produced from the Pine Rivers STP are composted with green waste obtained from kerbside collection and other sources at a dedicated composting facility. The resulting composted mix is distributed on various Council parks and gardens throughout the Shire, yet another example of sustainable business practice.

Sewage Effluent Treatment. The Kilcoy Shire Council STP in Queensland, Australia, had been experiencing water quality problems due to hydraulic capacity limitations within the plant. The STP had exceeded its design capacity and Council was faced with a significant capital investment upgrade. The STP was regularly exceeding license conditions for biochemical oxygen demand (BOD) and total suspended solids (TSS), and was experiencing odour problems. The plant was also discharging too much phosphorus (in the form of PO_4) into receiving waters.

While current sewage effluent technologies can reduce BOD and TSS loads, they do not reduce phosphorus concentrations sufficiently, leaving high nutrient loads in discharged water. Studies have shown that phosphorus availability is the governing factor for algal blooms and excessive plant growth, which pollute valuable waterways.

After implementation of technology, a comprehensive monitoring program was undertaken for a period of two months to validate the system's performance. This program ensured that all flow regimes and raw sewage characteristics were considered. The technology is a simple add-on to the existing treatment plant and does not require significant capital investment; the dosing plant is linked to the STP's flow meter to ensure correct dosing of reagents during variable input flows.

The technology consisted of dosing the outflow from the trickling filter prior to input to the secondary clarifier with reagents, and monitoring the resultant outflow. The sewage effluent treatment technology showed a marked improvement of the visual clarity of water in both the secondary clarifier and the V-notch chlorination tank. Visual clarity improved from an initial 200mm depth to over 2,200mm depth after only 14 hours of operation. It was also found that phosphorus concentrations were reduced from 14.0mg/L to 0.05mg/L.

Colour and turbidity were reduced from 35 PCU and 16 NTU to 10 PCU and 1 NTU respectively. As a result of the reduction in available PO_4, algae from the sides of the tanks and pipes began to recede. The pH range at outflow from the secondary clarifier was 7.0-7.2. The significant reduction in settling time of the secondary clarifier proved that the technology had increased the hydraulic capacity of the plant without costly improvements and upgrades. The magnitude of the increased capacity was approximately 40%.

Mine Site Remediation

The technology is applied to economically treat all forms of mining waste, including acid mine drainage (AMD), tailings dam water, sulfidic mine tailings, acid sulfate soils (ASS), and waste rock dumps [14]. In particular, acid is permanently neutralized and trace and heavy metals are permanently trapped in a non-leachable form.

Acid Mine Drainage Treatment. The Gilt Edge Mine in South Dakota, USA is an open pit, cyanide heap leach gold mine, developed in both oxidised and highly sulfidic ore bodies. The mine was developed in sulfidic (acid-generating) rock at the headwaters of coldwater fisheries and local water supplies. After the operator went out of business, 150 million gallons of acidic, heavy metal-laden wastewater in three open cut pits and millions of cubic yards of acid-generating waste rock required treatment.

About a century ago, a series of small mines began dumping metal-laden mill tailings into local catchments. In addition, sulfidic waste rock and exposed ore zones (which generate leachates to surface and ground water) contain heavy metals. Elevated concentrations of nitrates and sulphates are present in heap leach residues, and copper, cadmium, zinc and acidity provide the major risks to habitats in the receiving water catchment.

The mine was experiencing severe AMD troubles. There was a net positive water balance on the site and evaporation alone could not manage the site's contaminated water problems. Leachate generated from the sulfidic waste rock dumps was contributing to off-site acid and heavy metal migration. Of additional concern was the aesthetic appearance of the site. The site covers an area of 242 acres and there are about 12.0 million cubic yards of overburden stored in waste rock dumps, a large quantity of heap leach tailings stored with the overburden, and about 2.0 million tons of heap leach ore remaining on the heap leach pad.

The effectiveness of the technology in treating waste rock was achieved by using a lined trench containing sulfidic waste rock mixed with a tailored reagent to a final concentration of 10% (weight). The leachate was sampled monthly to determine water quality and ongoing sampling assessed the neutralizing and immobilization capacity of the technology. Ongoing four-year results demonstrated the leachate pH being neutralised from 1.93 to 7.9; other highlights include:

- The concentration of the hazardous element arsenic (As) was reduced from 35,000 to less than 4.0 parts per billion (well below the U.S. drinking water standard of 10 ppb);
- The extremely high concentrations of iron (21,000,000 ppb) and aluminium (1,200,000 ppb) were reduced to less than 50 ppb and have remained at very low concentrations ever since;
- The concentrations of many other trace metals, including Sb, Cd, Co, Cu, Cr, Pb, Mn, Ni, V and Zn, were reduced from potentially hazardous concentrations to levels that were near or below analytical detection limits and well below discharge water quality standards;
- Total dissolved solids (TDS) concentrations (i.e., salinity) were substantially reduced immediately after treatment and decreased further the longer the treatment continued; and
- The concentrations of many ions, such as Na and SO_4 which are difficult to remove, have continued to decrease substantially the longer the treatment has continued.

Pit Lake Treatment. To treat ponded waste mine water at Gilt Edge, 17,000 litre batches were treated using tailored reagents. The tank was sampled six, nine, and 42 days after the last addition. Highlights of the treatment, wherein leachate pH was neutralised from 2.59 to 7.09, include:

- Concentrations of trace metals, including Al, Cr and Pb, were reduced from potentially hazardous concentrations to concentrations that were near or below the analytical detection limits and well below discharge water quality standards;
- TDS concentrations were reduced; and

- Concentrations of SO_4, which are difficult to reduce, were decreased.

The technology has proven to be applicable for the treatment of heavy metal and acidity problems associated with AMD from waste rock dumps and water accumulated in pit lakes. Acid rock drainage water and contaminated tailings dams can now be economically treated to strict environmental standards.

Conclusion

It has been shown that Basecon Technology offers the most viable, cost-effective method currently known for converting caustic red mud residues from alumina refineries, such that the treated liquids can be safely discharged, evaporated or stored, and residues are environmentally safe to store, transport or re-use in the manufacture of reagents which have broad application in environmental remediation and waste treatment programs.

The process of converting hazardous alumina refinery waste into a benign and stable raw material, and then modifying and applying it in such a way that it can be used in these industrial applications demonstrates the power of sustainable development.

Such an approach can minimize some of the major environmental impacts and economic and health liabilities of the alumina refining industry, particularly as they relate to the costs of building and maintaining tailings impoundments, the escape of caustic residue, environmental and social health concerns, and the contamination of groundwater.

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