Passive mine water treatment: The correct approach?

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The implementation of passive, waste water treatment technologies by the mineral sector has been delayed by many factors. These are explored in this paper. A precise understanding of the contaminant generation process, is a prerequisite to any successful remediation strategy, whether active or passive, but is often marginal at best. The effectiveness of wetlands which bio-mineralize nutrients and organics, reduce metal acidity and improve pH has been widely demonstrated but the message doesn't seem to be getting out.

Weathering on the surface of the minerals is initially a geochemical process but is then accelerated by bacteria, a biogeochemical process; this sets in motion the secondary precipitation, dissolution and hydrolysis of the weathering products, a chemical process which again is accelerated by bacterial activity, entering again the realm of bio-geochemistry and bio-mineralization. The resulting contaminant stream is generated by hydrological as well as hydro-geological processes as atmospheric precipitation transports the weathering products to ground and surface water. Once the contaminants are in the water particulate formation and surface science are dominant disciplines which need to be evoked to optimize the treatment. A review of the recent literature on passive treatment in the mining sector is utilized in this paper to highlight areas of research that could bridge the gap between disciplines and further develop the geochemical and ecological treatment for mine waste management areas.

1 Introduction

In 1953 EUGENE ODUM published the Fundamentals of Ecology which defined the new science of ecology. Eugene and his brother Howard, both of whom died in 2002, taught us that systems are unified by the energy that flows through them and can be understood only by studying them in their entirety (MITSCH 2003). The Limits to Growth, by DENNIS MEADOWS (1972) and Our Common Future by the BRUNDTLAND COMMISSION (1987), taught us about sustainability and in 1989, MITSCH & ORGENSON carried those ideas further in Ecological Engineering: An Introduction to Ecotechnology. The roots of Ecological Engineering may go back all the way to the ancient Chinese view of the earth (yin) and heaven (yang) as a system composed of and defined by a series of ecological techniques which facilitate a synchronized development of economic benefits and ecological, environmental and social advantages.

Ecological Engineering is a scientific discipline aimed at applying knowledge of natural biological systems to achieve human (industrial) objectives in a natural self-sustaining way. It encompasses such diverse activities as the revitalization of rain forests, the construction and population of artificial marine reefs, the rejuvenation of depleted farming soils, the reversal of desertification and the re-establishment of wetlands in previously drained riverbeds. A typical ecologically engineered project would be the restoration of wetlands to control eutrophication or degrade persistent organic pollutants.

Mining activities disturb the land, surface waters and ground water. The mining industry has made progress in growing vegetation on tailings deposits with a considerable investment in fertilizer and limestone, mostly to control dust. And it is beginning to learn that hardy, indigenous species can do a similar job and with this the acceptance of restoration ecology, remediation and conservation efforts grow. But the industry has never embraced the principles of Ecological Engineering or applied them to the major problem posed by mining wastes that is to the amelioration or prevention of Acid Mine Drainage.

Slow progress is also apparent in a recent issue of the journal Ecological Engineering, containing papers presented at a 1999 symposium Ecology of Post Mining Landscapes in Cottbus, Germany, (HUTTL & BRADSHAW 2001). The editors concluded in their introduction, that a narrow engineering approach to restoration is not enough. But only a single paper in the special issue dealt with the treatment of pyrite or pyritic wastes It presents water management formulas to determine the rate at which fresh water must be provided and acidified groundwater removed from flooded coal pits to keep the overall acidity within acceptable levels. The old mantra – the solution to pollution is dilution – has been soundly discredited in the rest of the world but not apparently in the management of mining waste water. Surely there has to be a better way.

In the past 50 years we have finally recognized the size of the footprint we have left on the planet. But the gap between technological implementation and scientific understanding has only widened. We are building a municipal waste treatment plant in Singapore that will contain 90 km of deep tunnels, 170 km of linking sewers, two centralized waste treatment plants and a 6 km outfall pipe into the Straits of Singapore (SUTTER 2004). But the further study on bacteria that will drive that system are largely ignored. Similarly, the mining industry is building ever-bigger and more energy-intensive treatment plants. And it too has largely ignored the alternatives offered by bacteria. This objective of this paper is to examine the reasons for this.

2 Environmental management in mining

Environmental issues associated with mining have been known since Agricola, who stated in 1556 that "... further, when the ores are washed, the water used poisons the brooks and streams, and either destroys the fish or drives them away it is clear to all that there is a greater detriment from mining than the values of the metals which are produced" (AGRICOLA 1556).

Since then, metal values have become even more integral to society while larger rock volumes are mined and moved. As in other industries, the mining sector has largely ignored the economic consequences of clean air, water and soil. Consequently, the scale of mining increases exponentially, as do its detrimental effects

Typically, the mining industry seeks engineered solutions to its environmental problems. It looks for ways to confine wastes, retain the run-off, and isolate the waste from oxygen and water; no easy task given the million of tonnes of waste generated by even a small mine. The logic is that if less water gets to the surface of minerals, less oxidation occurs, less AMD is generated, fewer or smaller treatment plants are required and less disposal space is needed for the contaminated sludge that such plants generate. It is assumed such plants will operate for 100 to 1000 years, in the case of uranium mines (WITTROP, pers comm), or 10 to 15 years for base metal mines; for the purposes of shareholders this means 'in perpetuity', a concept that no-one in the mining industry seems to think is unreasonable.

Meanwhile, scientists have begun to better understand the role of bacteria in the process of oxidation; the timetable by which mineral surfaces weather, the limitations imposed on contaminant generation by the transport of oxygen by advection, convection or diffusion and the movement of weathering products in surface run-off and groundwater (BARKER et al. 1997). Like the workings of a fantastically complex watch, each of these interlocking cycles rotates at a speed of its own, turning in seconds, decades or centuries. It follows that any effort to interrupt those cycles, must work on the same time scale. And more importantly; remediation efforts must be given appropriate time spans in which to prove themselves.

Typically when the mining industry wants a solution, it wants it yesterday. So for the past many decades it has lurched from one quick fix to the next. Mine managers used to dump mine wastes into any available water body, mostly on the theory that out of sight was out of mind. Then regulators decreed that acid generating wastes must be kept out of the water. Now we're back to subaqueous storage. Similarly, elements of the industry have embraced passive water treatment systems as a panacea, and have struggled to incorporate them into conventionally-engineered systems.

WIEDER & LANG (1982) were among the first to notice that acid mine drainage flowing through a bog was much improved. Soon, more than 100 constructed wetlands were being planned or built (BRODIE & WILDEMAN 1993). Microbial sulphate reduction was identified and acclaimed. The following years produced a flood of conferences on constructed wetlands (e.g. HAMMER 1989; COOPER & FINDLATER 1990). More recently, WILLSCHER (2001), to quote a European review, has compiled a list of reduction procedures used to reduce acid generation, including the exclusion of water and air, inhibition of microbial oxidation, and the promotion of sulphate reducing bacteria, to mention the most common practices worldwide. BROWN et al. (2002) produced a comprehensive compendium on mine water treatment including passive approaches. The literature on these topics is vast. In 2003, WILLSCHER elegantly summarized at least seven different ways to utilize limestone in combination with wetlands. She concludes that passive and semi-passive treatment methods need to be improved and that we should adopt an interdisciplinary approach. In the same year, a similarly eloquent review of the natural alkalinity generating processes for extremely acidic mining lakes was compiled by TOTSCHE & STEINBERG (2003) who concluded, sadly, that, there simply is no economic, practical way that those lakes can be saved.

In spite of the extensive resources expended by government, industry and academe, the short time horizon available for research, development and implementation is leading us to false conclusions. The best available economically achievable technologies are changing too fast and the not unexpected failures could have been avoided by bridging the gulf between scientific knowledge and its application. Ecological Engineering has been left off the technology treatment train. This is especially unfortunate because, after two decades of research and field testing, it is just now beginning to prove itself (FYSON et al. 1998; KALIN 1997, 1999, 2001a, b, c, 2003). This author contends that we are still not addressing the origins of the problem; that is reaction rates and the contaminant generating processes. Treatment approaches must be assessed for their effectiveness on appropriate time scales if we are to find truly sustainable solutions.

There is no doubt that passive treatment systems and/or constructed wetlands effectively reduce organic water pollution. But when the run-off from mining wastes flow through wetlands, the deposition of metals onto adsorption sites can overload them leading to system failure and wetland destruction (KALIN et al. 1995).

In a narrow sense, constructed aerobic and anaerobic cells as well as reactive walls, which establish ecological communities and for some limited time achieve specific objectives, can be considered Ecological Engineering. Those techniques have certainly advanced our understanding of the potential of natural systems. But they are not self-sustaining. Given their limited, functional life span, they are not true applications of Ecological Engineering.

To ensure that a wetland treatment system is self-sustaining, and long lasting, it must be protected from the metals and/or inorganic pollutants in mine waste run-off. This can be done in two natural treatment steps. First the metals must be adsorbed onto particulates, either inorganic (e.g. clays) or organic (e.g. humic substances, living cells) forming organic metal complexes or colloids. This particulate matter then settles to the sediment where microbial mediated bio-mineralization takes place, supported by organic matter input. In the deeper portions of the sediments, the organically bound metals are mineralized into stable compounds. This approach can retain the metals within the mine management area but does not solve the problem of contaminant generation.

2.1 Knowledge Increases Complexity

Bacterial activity on minerals, which was recognized with the role of Thiobacillus ferrooxidans in copper bioleaching, has since been described for many minerals. The chemistry of weathering is better understood and so are the reactions of weathering products in water. Geomicrobiology and biogeochemistry have begun to study acid mine drainage on the micro-scale, looking at the corrosion pits on pyritic surfaces where it originates and the bio-films that prevent it. New concepts of dissolved and particulate matter have been defined and surface science has been advanced with newer microscopic techniques to advance our understanding. Academics have been thrilled to discover that bacteria are everywhere.

But, as the problem has become more multidisciplinary and more complex, a practicable solution is retreating over the horizon. Engineering solutions tend to break down problems into their component parts, so that each facet can be solved in isolation. Bacteria don't lend themselves well to such treatment and the industry has been slow to embrace them. Moreover, the inevitable conclusion of scientists to any investigation… that more study is needed… is not warmly received by the mining industry or the engineering fraternity. It is therefore useful to quote Prigogine (TIEZZI 2003): “I believe the days of the scientist in his ivory tower and of flights into pure reason are over. Today is a time of complete reimmersion in life, nature,….”. And this quote only reminds us of what Pasteur proclaimed in 1871 (KARAVEIKO 1985): “No, thousand times no, there is no category of science which could be named applied science. There are science and application of science related to it as the fruit to the fruit-bearing trees.” Ponder these statements, as they are borne out of a 25-year struggle to establish Ecological Engineering to the management of mine wastes.

2.2 Mineral Surfaces: The Site of the Problem and the Solution

The oxidation of sulphide particles in tailings, waste-rock piles, underground workings of mines and open pit walls is limited by the transport of oxygen which in turn is determined by convection, advection or diffusion to the mineral surface where bacterial biofilms display various degrees of activity. Microbes are quick to respond to changes in the environment; and nothing changes the environment more than mining followed by changes due to “restoration”.

Microorganisms populate the near earth surface, where mining takes place, at a rate greater than 108 cells per gram of soil or sediment. Densities are lower on rock surfaces but even there one cell is present per μm^2 of mineral surface or 106 per mm^2 (NORDSTROM & SOUTHAM 1997). Given those numbers it is no surprise that microbes accelerate the oxidation rates of pyrite change by orders of magnitude. Such densities speak to the importance of biofilms in the contaminant generation process and hence they should be realized as part of the solution: the arresting of the process. Microbial communities do not die. They merely become inactive when they deplete the available food source. Mining wastes should not be viewed as de facto toxic to microbes, but conditions should be created which keep them inactive, by physical and biological interference on the mineral surface which will reduce their access to the mineral. Since microbes are dependent on the oxygen transported to the mineral surface, coatings of biofilms with organic and or inorganic metal precipitates in the corrosion pit can lead to inactivity and dormancy.

It is here, at the mineral surface, where metals deteriorate and acid is generated, that the solution has to be found. Corrosion of metals is a surface deterioration phenomenon, very similar to that which takes place on the mineral surfaces in mining wastes. The formation of rust is inhibited with phosphate. And we know that phosphate is nature’s control on iron availability in the environment. So why then have we not applied phosphate as a likely inhibitor of mineral weathering?

Phosphate dispersed by the same rainwater that stimulates the production of acidity, will produce a precipitate on mine wastes that physically obstructs both oxygen transport and bacterial activity. Phosphate minerals placed on tailings or waste rock so that it can be weathered by rainwater, have produced promising results in field and laboratory experiments (FYSON et. al 1995; KALIN et al. 1997, 1998, 2003, 2004). Work is in progress to define the microbial and mineralogical composition and stability of the precipitate layer formed on the mineral surface (UESHIMA et al. 2002, 2004)

3 Conclusion

It has been said before; it merits saying again; the solution to acid mine drainage will be found only when geo-microbiology has been fully integrated into waste treatment strategies Active/chemical treatment simply does not offer an economically or environmentally acceptable solution.

A substantial expansion of the field of ecological engineering is expected in the next quarter of the century. It will be the accepted and critical driver in the improvement of terrestrial and marine environments. Mature Ecological Engineering projects will demonstrate the power of this new field.

Wetlands, or passive treatments systems used appropriately, will become an essential component of ecological restoration because of their sediment generating capacity, rather than their treatment capacity, i.e. bio-mineralization. They generate TSS for metal binding in open ponds within the wetland and they provide the carbon source for the microbial ecology of the sediments to support bio-mineralization.

More work needs to be done, of course, with an emphasis on in-situ treatment and biological polishing. But we now know that ecosystems and their resources can be managed or modified to control biogeochemical cycles and so immobilize contaminants. All stakeholders need to take a fresh look at an old problem. Nature's repair mechanisms may be slow but they're thorough. We must find ways to assist and expedite them.

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