ScienSage

Journal of Advanced Scientific Research

Available online through http://www.sciensage.info/jasr

ISSN
0976-9595
EDITORIAL

Ecologically Engineered Strategies For The Management Of Acid Mine Drainage: An Overview

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ABSTRACT

Acid Mine Drainage (AMD) is a serious environmental pollution problem of the mining industry around the world. The treatment of AMD is one of the major concerns for the mining industry. Ironically, even under the best reclamation scenario it requires long-term collection and treatment. Active treatment systems commonly used by the Indian mining industry at active mine sites require continual addition of alkaline chemicals like lime, hydrated lime, caustic soda, soda ash, etc. these chemicals besides being very expensive, also, lead to production of voluminous low-density sludge. The disposal of this sludge is again an environmental problem to be dealt with. These active treatment processes are often expensive both in terms of capital and operating costs. For the last three decades researchers, throughout the world, have been expressing their opinion that a better solution to long-term treatment of AMD lies in the use of other technology with the application of integrated biological processes in engineered ecologies, which are passive technologies. One of the highly effective passive technologies for ecological engineering approach is construction of wetland to effectively treat AMD. The problem of AMD exists at number of sites in India. The main aim of the present manuscript is to devise a new treatment technology for AMD in India. The need for this technology is because the current approaches are too expensive and impractical at the sources of AMD at abandoned mines contaminated water continues to be discharged day after day without any treatment.

Keywords: Ecosystems, Constructed wetlands, Environmental contaminants, Biochemical processes, Substrate and Vegetation

1. INTRODUCTION

Mining like the proverbial serpent in the "Garden of Eden", has never been held in high esteem. Most people consider mining as an unmitigated evil, and some who are more realistic, concede that it is a necessary evil. The volume of non-fuel minerals consumed during the five decades since the Second World War has exceeded the total extracted from the earth during all the previous history of mankind. While the world population doubled during the period 1959-1990, the production of six major non-ferrous metals viz. zinc (Zn), copper (Cu), lead (Pb), tin (Sn), and aluminium (Al) increased eight fold. The most serious problem facing the mine industry presently is the enormous mass of mine tailings (about 18 billion m^3/y) and is expected to double in the next 20-30 years. Environmental concerns facing the world were first voiced and decisions were taken at the United Nations conference on the Human Environment held at Stockholm in June 1972, in which India participated to take appropriate steps for protection and improvement of human environment. While pollution by industries received greater and immediate attention for obvious reasons, that by mining and allied operations received attention thereafter. In developed world, there is a tendency to favour environmental protection in any argument over priorities. In developing countries, however, the perspective is often different: development is the priority, not conservation.One of the serious environmental pollution problems of mining industry is Acid Mine Drainage (AMD). That is caused by surface mines, underground mines, sub-grade ore piles, waste rock heaps, as well as seepage from the tailing dams of sulphide minerals is often highly acidic and have elevated levels of dissolved metals in toxic concentrations. It is well documented that sulphide minerals and pyrites are exposed to the atmosphere their oxidation produces sulphuric acid and releases metals and other pollutants to the drainage. This drainage is called AMD. The characteristics of AMD include low pH, a high concentration of heavy metals, sulphates and some other toxic chemicals. Mineral processing also releases acidic effluents that may contain other toxic substances, and mill tailings that typically amount to about 90% of the ore. Seepage from tailings impoundments can be a source of AMD for decades.

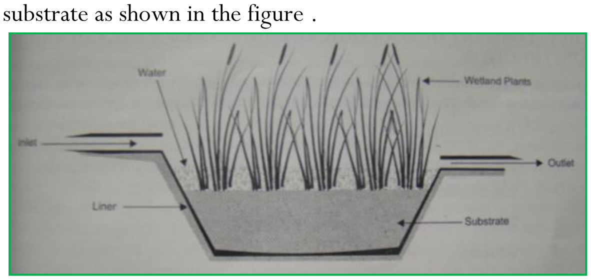
2. TREATMENT OF AMD

Today, one of the major issues being faced by the mining industry is the treatment of AMD and also continuous seepage from tailing ponds during and after closure of mining property, which even under the best reclamation scenario may require long-term collection and treatment. If left uncontrolled, it results in contamination of the surrounding land as well as water basins that is both intense in term of concentration and extensive in the area affected. Most water remediation techniques are time consuming and costly that it has become a continuing problem for Government entities, private industries and the general public. While chemical treatment or some other form of active effluent treatment has traditionally been concluded in throughout the world and there are very limited funds available for treatment of such discharges, so, greater consideration has been given recently to forms of self sustaining treatment technologies, which are attractive treatment alternatives as opposed to maintain a chemical treatment plant. An alternative approach to chemical treatment is the use of passive treatment systems, which can be long-term solution to the problems generated by AMD. Passive treatment system utilizes the chemical, biological and physical removal processes that often occur naturally in the environment to modify the influent characteristics. This expensive technology uses the natural ability of the ecosystem to heal them. This is especially needed on sites where no person or company is responsible for this AMD problem. One of such technology is using ecological engineered constructed wetland.

Ecological engineering is a new sector of environmental engineering, which seeks to bridge engineering and ecology. Ecological engineering can be defined as the development of sustainable ecosystem that integrates human society with its natural environment for the benefit of both. It is concerned with natural and artificial ecosystems, which are, have been or may be stressed by human activities. This branch of engineering focuses on the design monitoring, manipulation, remediation, restoration and even creation of such ecosystems. Apart from engineering it also includes logistical risk managements, project management and field construction matters relating to stress ecosystems then with researching human impacts on the natural environments. Ecological engineering is basically involved with building artificial ecosystems i. e. constructed wetlands and lagoons for wastewater treatments. The main goal of ecological engineering research is the development of methods, which harness the nature to serve as self-maintaining ecological systems capable of treating AMD. Wetlands are such self-sustaining ecosystems, which can remediate contaminated mine drainage. The system needs to be properly planned, designed, constructed and monitored by applying integrated ecological engineering approach to get long-term benefit at the different conditions encountered at acid generating sites. During the last three decades, passive treatment of AMD using technologies such as constructed wetlands has developed as an alternative to conventional treatment. Natural wetlands have been used for centuries as a sink for waste, being capable of assimilating large amounts of environmental contaminants. They act as biological filters and are a viable option for helping to solve a wide range of environmental and water quality problems. Research proceeds on utilization of natural wetlands and wetlands constructed especially to remove contaminants from a variety of wastewaters. Constructed wetland systems emulate the assimilative properties of natural wetlands in an environment that can be controlled and manipulated. Such systems have been used to treat AMD from metal and coal mining operations.

3. COMPONENTS OF CONSTRUCTED WETLAND

A constructed wetland is a shallow basin filled with substrate and planted with vegetation tolerant of saturated condition. Water is introduced at one end and flows on the substrate and discharged at the other end though a weir or other structure, which controls the depth of water. So wetland is a complex assemblage of Water, Basin, Substrate and Plants. Sometimes a liner is also included beneath the substrate as shown in the figure .



4. POLUTANTS REMOVAL MECHANISM IN CONSTRUCTED WETLAND

Wetlands have several functions that aid in the removal of metals in drainage and ameliorate AMD. These characteristics are required for certain processes to occur: adsorption and ion exchange, bioaccumulation, bacterial and abiotic oxidation, sedimentation, neutralization, reduction, and dissolution of carbonate minerals. The contaminants caused by AMD of concern are sulphate, manganese (Mn), iron (Fe), and some other heavy metal concentrations. Wetland processes, reduces concentrations of these pollutants. Processes within natural wetlands have been found to remediate contaminants within AMD: imitation of these processes can work similarly in constructed wetlands. Wetlands have organic –rich substrates which exchange dissolved metals. This exchange occurs between the dissolved metals and abundant humic and fulvic acids contained within the substrate. Wetland sediments are generally anaerobic below a thin oxidized surface layer and contain organic carbon for microbial growth. The anoxic zone of the sediments provides conditions which favour microbial and chemical reducing processes, transforming iron and sulphates to hydrogen and sulphides. Soluble metals are converted to insoluble forms by the anoxic conditions of wetland sediments. Settling of suspended solids occurs from water velocity control of the wetland vegetation. It has been verified Typha wetlands as effective removers of iron and manganese. It has be recorded that iron concentrations dropped from 20-25mg/L (ppm) to 1ppm, manganese concentrations dropped from 30-40ppm to 2ppm in a Typha wetland. Sphagnum sp. has also known significant effect on concentrations of iron, managenese, sulphate, and other mineral concentrations. Plants roots will retain arsenic metalloid and other metals. Plants also generate microenvironments that assist in the reduction and oxidation processes. Certain bacteria, such as those in the generas Desulphovibrio and Desulphotomaculuum, employ sulphate in anaerobic respiration. These are but a few of the many examples of how a wetland can treat AMD, and therefore by employing our knowledge in wetland construction, simulate these processes for AMD remediation.

5. DEVELOPMENT OF ECOLOGICAL ENGINEERED WETLAND AND CONSTRUCTION

The design of a constructed wetland for the treatment of AMD varies upon site characteristic. The most important design considerations are: Biochemical processes

- Loading rate
- Retention time
- Slope
- Substrate
- Vegetation
- Sediment control
- Morphology
- Seasonality
- Regulatory issues

Biochemical Processes have to be carefully considered when planning a construction of a wetland to treat AMD, conditions which are favourable to chemical and microbial reducing, adsorption, neutralization and precipitation need to be incorporated into the soil, hydrology, vegetation, and site development plan.

Loading Rate determines the maximum ability of a constructed wetland to treat AMD.

The Retention Time is determined by the volume and concentration of AMD, existing effluent standards and the rate of treatment, precipitation, run-off, infiltration, evapotranspiration, etc. all these variables have to be considered when determining the maximum contaminant reduction.

Slope is an important factor to consider in wetland design. Slope of < 5% maximizes contact by wetland vegetation and substrate, therefore influencing iron and manganese removal. The US Environmental Agency (EPA) recommends a slope of less than 1% will optimize efficiency of wastewater remediation.

Substrate & Vegetation are closely linked, in that the substrate used is dependent upon the desired vegetation. For example, design of Typha wetlands often use composted hay and manure on top of a layer of limestone ($CaCO_3$). Increased organic matter content of wetland sediments has been shown to influence increased metal adsorption. Lime stone and sewage sludge are considered important additives for soil condition manipulation.
Vegetation is an important developmental characteristic for wetland construction due to its important role in AMD remediation, and its influence on other wetland characteristics. Perennial vegetation can be established by placing rhizomes directly into a saturated subsurface zone. The use of local stock is favoured because their local adaptability. Two main species used in constructed wetlands are Typha sp. and Sphagnum sp. Typha sp. are characteristic of being acid tolerant and thriving under a variety of environmental conditions. This versatility and hardiness, along with Typha sp. ability to adsorb iron and manganese, make it and excellent vegetative choice for wetlands constructed to remediate mine draiage. Studies on Sphagnum sp. show significant influence in reducing sulphates, iron, and manganese concentrations found difficulty in establishing Sphagnum sp. due to its sensitivity to the stresses associated with transplanting, abrupt changes in water chemistry, and excessive or insufficient water depth. This establishment problem, along with its having slow generating ability, makes its use in a constructed wetland less viable than Typha sp. this does not preclude its consideration, however, because of Sphagnum sp. excellent ability to aid in AMD remediation. Future research and development techniques allowing Sphagnum sp. use in constructed wetlands could prove critical in this remediation technology.

High Sediments loads in AMD make sediment accumulation an important consideration in wetland design and construction. Ponds designed to accumulate sediment can be constructed into the wetland treatment system. These sediments ponds would be constructed prior to the treatment wetland. Sediments then can be dredged from the pond without disturbing the wetland habitat. It has been found that seasonal harvesting of plant biomass reduce sediment accumulation, although this does raise a concern of affecting levels of important organic matter accumulation in sediments.

Morphometry, or the geometric configuration, can be extremely influential in a constructed wetlands ability to perform AMD remediation. Designs, which imitate natural wetlands, such as varied shape and slope, are more aesthetically pleasing, provides better wildlife habitat, and enhances macrophyte establishment. Placement of islands within the wetland system increases habitat diversity and act as natural water flow breaks and diversions. A more serpentine shape outperformed a rectangular shape in reducing contaminants of AMD has been determined.

Seasonality of the locale in which the wetland is to be constructed is an important factor in wetland design, in particular areas where climate fluctuations are great. The bacteria catalyzing AMD creation is as active during cold seasons as does in warmer seasons. The dormant season and its effect on the vegetation's ability to remediate AMD is therefore important to consider. Typha sp. are subject to a efficiency decline at locale with colder temperatures regime, whereas Sphagnum sp. does not face these same restrictions.

Regulatory issues can hinder the use of constructed wetlands to remediate AMD due to uncertainty of the ability of wetlands to remediate effluent to meet standards on a consistent basis, or whether they can be maintained to retain biological control.

6. ADVANTAGE OF CONSTRUCTED WETLANDS

Constructed wetland treatment technology have emerged as a viable option for addressing a wide range of water quality problems specially in treating AMD and effluents loaded with metals. Such high tech treatment systems are quite efficientin raising pH, reducing the other toxic components. The treatment are often more economic than energy intensive engineered treatment plants. The constructed wetland treatment technology has the following advantages over the conventional treatment (Chemical or Active treatment plants).

Provides a High Level of Treatment: Properly designed, constructed, maintained and managed wetlands can provide very efficient treatment of acid mine water. Laboratory and field test results show that pollutants were reduced to very acceptable levels. High metal removal rates have been observed in both the constructed wetland and natural wetland.

Relatively Inexpensive to Construct: Each constructed wetland's design is site specific, taking into consideration such variables as topography, water supply, soil types, etc. selection of a site with accomplishing specifications keeps establishment costs low.

Inexpensive to Operate and Maintain: A constructed wetland requires little, if any, energy use and equipment needs are minimal. A well-designed wetland transfers water by gravity through the system. If topography limits the use of gravity, pumps will be necessary which increases the cost of operation. Once established, properly designed and constructed wetlands are largely self-maintaining. Operational and maintenance expenses are low (Energy & Supplies are low). Operational and maintenance require only periodic, rather continuous on site labour. The goal of this AMD treatment by constructed wetlands into provide a long term, zero or low-maintenance method of abating AMD. Although some human intervention may be required.

Able to Handle Variable AMD Water Loadings: properly-designed wetlands have shown great tolerance for varying amount of wastewater loading. This is important because varying production
Reduces, if not Completely Eliminates Odor:
Can be Aesthetically Pleasing:
Provide Wildlife Habitat:
They Facilitates Water Reuse, Recycling and are Environmentally Sensitive: These approaches are viewed with the favour by the public. They can be built harmoniously into the landscape.

Reliability: The technology offers the added advantage of operational reliability while requiring minimal operational control.

7. LIMITATIONS OF CONSTRUCTED WETLANDS

Even with the best design, there are some limitations associated with the use of constructed wetlands.

They Generally Require Larger Land Area: The constructed wetlands require larger land area depending upon the influent load than do conventional (Active) treatment systems. Wetland treatment system may be economical relative to other options only where land is available and affordable.

Requires a Continuous Supply of Water: One of the most important factors of the success of a constructed wetland is the supply of water. In addition to the AMD to be treated, supplemental water will have to be added if the acid mine water supply is not sufficient to sustain plant population during dry periods. They require a minimum amount of water of water it they are to survive.

Can be Relatively Expensive to Contrast: Just as a desirable topography and other natural factors such as soil type can make a constructed wetland inexpensive to build; undesirable land features increase construction costs. Changing the lay of the land, adding soil amendments, and/or liners, incorporating pumps, etc, increases the cost of building a wetland significantly. The efficiency of constructed wetland is affected by seasonal weather conditions, which may reduce treatment reliability. Seasonal weather conditions, such as cold and drought, reduce the efficacy of the system. Consider fluctuations in weather when designing and operating the wetland. Due to warmer climate conditions in India this parameter is not going to affect the constructed wetland treatment technology.

Can be Destroyed by an Overload of Solids: A wetland can fill in with solids or flow pattern can be seriously disrupted when the design does not allow for the removal of solids before the acid mine water enters the constructed wetland.

8. CONCLUSION

Metal contamination of soils and waters reported around the world has severe impacts on environment and human health. AMD is one of the most important sources of heavy metal environmental pollution. The target of ecological engineering research is the development of methods facilitating the establishment of self-maintaining vegetation covers for the different conditions encountered at acid-generating waste management areas, these methodologies can be applied to promote vegetation covers and wetland communities, which would function as biofiltratiion systems. Thus an effective mechanism for treating AMD from mine sites is to filter it through a biological polishing pond before release. The water flows through a swamp of marsh. The plants adsorb any heavy metals in the water. With the unwanted material thus removed, clean water can be released into the environment. This method is virtually self-sustaining and can operate unattended for many years. However, the efficiency of engineered wetland is limited in northern countries such as Canada because harsh winters prevent the use of engineered wetland during winter months. But in countries like in India the efficiency is activated because of the favourable climatic conditions.

The goal of this manuscript is to introduce a new treatment technology for AMD in India. The need for this new technology exists because current approaches are too expensive to be used at the source of AMD and practically cannot be used at abandoned mine sites. The use of constructed wetlands to control water pollution due to AMD is considered to be technologically, economically and environmentally acceptable; the retention of heavy metals in the natural wetlands accumulates problems for the future. Metal release through decomposition of wetland plant issue is undetermined. Furthermore, mining industry partnerships need to be formed with the governments and academic research institutions too implement these self-sustainable technologies although environmentally benign biotechnologies in AMD control. This work seeks to elucidate ways and means of managing the environmental impact due to AMD. Ecological engineering knowledge in the field of mine effluent treatment is in its infancy. Further work is bound to prove rewarding. Industry and academic organisations are to be encouraged to devote additional resources to work in this direction. As is usual in emerging technology, practical result may not be immediate and industry should not underestimate the time and effort needed to develop useful and reliable system. (Courtesy: Sheoran, A. S., Choudhary, R. P. and Sheoran, V. 2006. "Treatment of Acid Mine Drainage by An Ecological Engineering Approach", *Proceedings of National Seminar on Mining and Environmental Issues*, Udaipur, Rajasthan)