© 2016 IJSRSET | Volume 2 | Issue 2 | Print ISSN : 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

ACID Mine Drainage : A Case Study of An Indian Coal Mine

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ABSTRACT

Water is essential to life on our planet. A prerequisite of sustainable development must be to ensure uncontaminated streams, rivers, lakes and oceans. We often take the presence of clean water for granted, forgetting its importance and assuming that it is always available. Unfortunately, the law and technology to protect this vital resource remains far from perfect. Increasingly, human activities threaten the water sources on which we all depend. Mining is one such activity. In fact, water has been called "mining's most common casualty."

This paper discusses one of the major negative impacts that the mining industry has on water i.e. Acid Mine Drainage (AMD), the chemistry of AMD, its environmental effects and impacts and a brief discussion about various treatment methods. Further a case study from India of an Effluent Treatment Plant (ETP) has been used to describe three of the treatment methods in details and the results of this ETP. Finally concluding with suggestions to improve the existing plant and overall AMD Treatment in Indian Mines.

Keywords: Acid Mine Drainage, Coal Mines, Effluent Treatment Plant.

I. INTRODUCTION

Coal mining has severe impacts on the environment that go well beyond the problem of production of CO_2 generally associated with the use of coal. Mining deeply affects air, water and land resources. Due to mining, dust and methane, sulphur dioxide (SO_2), oxides of nitrogen, CO and other gases are spread in the air, thus affecting water and land resources, as well as human health. These are consequences of underground mining and, even more, of opencast operations. Another source of damage related to mining is fires in the mines, which are frequent and have severe consequences not only for the environment and the safety of the workers, but also for the production itself. The impact of mining and associated activities on water resources is also difficult. Mining requires large amounts of water, diminishing the quantity available for other purposes. Furthermore, both underground and opencast mining disturbs aquifers and water table.

The main pollutants associated with mining are suspended solids, dissolved salts, acidity and iron compounds. One of the major problems related to coal mining and water pollution is Acid Mine Drainage (AMD), the outflow of acidic water from coal mines.

Overburden is rocks that must be removed, so the ore can be mined and processed to obtain the metal for commercial purposes. Many metals occur in nature in the sulfide minerals form. When the ore mined and rock covers that contain sulfides are exposed to the open air, then water, oxygen and bacteria reacts to produce solution of sulfuric acid. The acidic water can dissolve metals contained in the cover rocks and cause adverse environmental impacts to the water bodies if not managed properly. This process is known as acid mine drainage. Acid mine drainage is formed from rocks that contain minerals mine sulfide and oxygen through contact with air and water. Acid mine drainage are characterized by lower pH, increasing levels of sulphate, shed and bring the heavy metal content. Indications of acid mine drainage in coal mining area is the appearance of the precipitate or yellow-orange in mine water flow, the sulfur odor, and acidity of the soil.

II. METHODS AND MATERIAL

Chemistry of AMD

Acid Generation and Metals Leaching

Acid generation and metals dissolution are the primary problems associated with pollution from mining activities. The chemistry of these processes appears fairly straightforward, but becomes complicated quickly as geochemistry and physical characteristics can vary greatly from site to site. This paper will not describe these variables and their affects on chemistry; it will give an overview of the most common scenario found at coal and hard-rock sites with environmental concerns.

Pyrite (FeS_2) is responsible for starting acid generation and metals dissolution in coal and hard rock sites alike. When pyrite is exposed to oxygen and water it will be oxidized, resulting in hydrogen ion release - acidity, sulfate ions, and soluble metal cations, equation 1. This oxidation process occurs in undisturbed rock but at a slow rate and the water is able to buffer the acid generated. Mining increases the exposed surface area of these sulfur-bearing rocks allowing for excess acid generation beyond the water's natural buffering capabilities.

$$2FeS_2\,(s) + 7O_2\,(aq) + 2H_2O \rightarrow 2Fe^{+2} + 4SO_4^{-2} + 4H^+ \qquad (1)$$

Further oxidation of Fe^{+2} (ferrous iron) to Fe^{+3} (ferric iron) occurs when sufficient oxygen is dissolved in the water or when the water is exposed to sufficient atmospheric oxygen.

$$2Fe^{+2} + \tfrac{1}{2}\,O_2 + 2H^+ \rightarrow 2Fe^{+3} + H_2O \qquad (2)$$

Some acidity is consumed in this process; however, the stage is set for further hydrogen ion release that will surpass these benefits. Ferric iron can either precipitate as ochre ($Fe(OH)_3$ the red-orange precipitate seen in waters affected by acid mine drainage) or it can react directly with pyrite to produce more ferrous iron and acidity.

$$2Fe^{+3} + 6H_2O \rightarrow 2Fe(OH)_3\,(s) + 6H^+ \qquad (3)$$

$$14Fe^{+3} + FeS_2\,(s) + 8H_2O \rightarrow 2SO_4^{-2} + 15Fe^{+2} + 16H^+ \qquad (4)$$

When ferrous iron is produced as a result of equation 4 and sufficient dissolved oxygen is present the cycle of equations 2 & 3 is perpetuated (Younger, et al, 2002). Without dissolved oxygen equation 4 will continue to completion and water will show elevated levels of ferrous iron.

Once the waters are sufficiently acidic, acidophilic bacteria - bacteria that thrive in low pH - are able to establish themselves. Microorganisms can play a significant role in accelerating the chemical reactions taking place in mine drainage situations. Thiobacillus Ferroxidans, a bacteria, is commonly referenced in this case. These bacteria catalyze the oxidation of ferrous iron, further perpetuating equations 2 through 4. Another microbe belonging to the Archaea kingdom, named Ferroplasma Acidarmanus, has recently been discovered to also play a significant role in the production of acidity in mine waters.

Environmental Effects of AMD

AMD introduces sulfuric acid and heavy metals into the environment. The environment can naturally assimilate some AMD through dilution, biological activity, and neutralization, although its capacity to treat AMD may be limited. When this treatment capacity is exceeded, drainage and surface water flowing out of mining areas can be very acidic and contain elevated concentrations of metals. The metal-laden acidic drainage and surface water can lead to ground water contamination. The ability of the receiving environment to assimilate AMD will depend on site specific conditions such as drainage patterns and dilution, biological activity, and neutralizing capacity of the ore, waste material, tailings, and/or surrounding soils. Drainage patterns and dilution depend largely on the climate and topography of a site. Naturally occurring biological activity can attenuate the metals concentration by adsorption and precipitation of some metal species such as sulphates. Neutralization is the consumption of acidity in which hydrogen ions are consumed according to the following reactions:

$$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3$$
$$HCO^{3-} + H^+ \rightarrow H_2O + CO_2$$

The neutralization capacity of a soil depends largely on the presence of naturally occurring, acid consuming minerals. The most common mineral is calcite ($CaCO_3$), a major constitute of limestone, and dolomite ($CaMg(CO_3)_2$). Other neutralizing minerals include other carbonates of iron and magnesium and aluminum and iron hydroxides. As neutralization occurs, metals precipitate because of decreased solubility at higher pH.

The impact of AMD can increase over time if the neutralizing capacities of the soil are depleted. This may occur if the neutralizing minerals have a tendency to from crusts of precipitated salts or gypsum which inhibits further reaction, or if the neutralizing minerals are depleted through numerous reactions with AMD. The impact of AMD can also change if the rates of AMD formation change due to the alteration of site conditions. For these reasons, there is often a time lag after mining activities begin until AMD is detected. The times can range from 1 to 10 or more years; AMD may not be detected until after surface reclamation occurs. Acid generation, once it begins, is difficult to control, often accelerates, and can persist for centuries.

Environmental Impacts of AMD

AMD is a unique pollutant because acid generation and discharge continue to occur even after the mining is ceased. As a result of this acidity it is unsuitable for the use of animals, plants, mankind and aquatic life. The problem of AMD is not restricted to the local area at the source, but may extend to distances if the affected water is allowed to get discharged into the main water stream. AMD impacts more frequently on the quality of ground water than that of surface water. If acid producing mines are located in permeable formation, water with low pH percolates into the aquifers and gets spread over a wide area through ground water movement which is ultimately consumed in different ways by human beings through wells and bore wells. The acidic water is not only responsible for the corrosion of mine plant and equipment and formation of scales in the delivery pipe range, but also pollution of the mine surface environment, thus affecting the surface ecology.

AMD causes serious threat to human health and ecological systems because it contains heavy metal contaminant which I not biodegradable and thus tend to accumulate in living organisms causing various diseases and disorders. Low pH of mine discharge results in solubility of heavy metals in water and its high concentration causes toxicological effects on aquatic ecosystems. Acute exposure of high concentration of metals can kill organisms directly, while long term exposure to lower pH can cause mortality or other effects, such as stunted growth, lower reproduction rates, deformities and lesions.

AMD also has direct effects on fish by causing various physiological disturbances. High acidity may adversely affect fish growth rates and reproduction. The primary cause of fish death in acid water is loss of sodium ions from the blood. Less availability of oxygen to the cells and tissue leas to anoxia and death as acid water increases the permeability of fish gills to water, adversely affecting the gills function. Besides chemical effects of mine drainage, physical effects, such as increased turbidity from soil erosion, accumulation of coal fines and smothering of the stream substrate from precipitated metal compounds may also occur. Precipitation of ferric hydroxide may result in a complete layering of stream bottom, filling in crevices in rocks and making the substrate unstable and unfit for habitation by benthic organisms.

Treatment of Acid Mine Drainage

Over the past two decades a variety of treatment systems have been developed. There are two broad classes of methodologies used to treat Acid Mine Drainage:

- **Passive Treatment:** The concept behind passive treatments is to allow the naturally occurring chemical and biological reactions that id in AMD treatment to occur in the controlled environment of the treatment system, and not in the receiving body.
- **Active Treatment:** Active treatment technologies involve treating mine drainage with alkaline chemical to raise water pH, neutralize acidity and precipitate metals.

Passive treatments conceptually offer many advantages over conventional active treatment systems. The use of chemical addition and energy consuming treatment processes are virtually eliminate with passive treatment systems. Also, the operation and maintenance requirements of passive systems are considerably less than active treatment systems. Effective active treatment is expensive when the cost of equipment, chemicals and manpower are considered.

Table 1: Technologies available for AMD Treatment

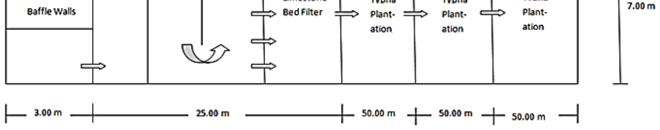
S.No.	Passive Treatment	Active Treatment
1.	Aerobic Wetlands	Precipitation
2.	Compost/ Anaerobic Wetlands	Oxidation
3.	Open Limestone Channels	Dosing with alkali
4.	Diversion Wells	Sedimentation
5.	Anoxic Limestone Drains (ALD)	Reverse Osmosis
6.	Successive Alkalinity-Producing Systems (SAPS)	Sulfidization
7.	Vertical Flow Reactors (VFR)	Ion Exchange
8.	Pyrolusite Process	

Case Study

AMD at Durgapur mines of Chandrapur Area, WCL , Maharashtra, Coal India Ltd.

In this paper we will discuss more explicitly two of the passive treatment methods mentioned above, namely Aerobic Wetlands and Open Limestone Channels, and one active method: Dosing with alkali. These three treatment processes were combined to treat the AMD problem at the Durgapur Opencast Mines, under WCL, Coal India Ltd., which is located in Chandrapur area of Maharashtra. In these mines a total of 7500 Gallons per minute (GPM) of acid water is discharged for 15 to 18 hours daily in the rainy season and 5000 GPM for the same time in other seasons. The average pH of this discharge was found out to be as low as 2 to 2.5 by the Maharashtra Pollution Control Board. This is the most major concern in the area as the pH is very low as compared to the permissible limits. Therefore an Effluent Treatment Plant (ETP) has been constructed to treat this acid water discharge before releasing it in the natural water bodies and increasing its pH value.

- **Plan of ETP (Not to Scale):**



The depth of this plant Is 1.2m, thus the capacity of 1495.20 Cubic Meter only; which gives the discharge a retention time of Approximately 45 minutes in rainy season and 68 minutes in other seasons.

This plant consists of a combination of the following three AMD Treatment methods in the following order:

- **Dosing with Alkali:** It is used to raise pH of acidic waters & counteract acidification by metal hydrolysis e.g., $Fe^{+3} + 3OH^{-} \rightarrow Fe(OH)_3$ (s)

It involves addition of lime to increase the alkalinity by producing hydroxide ions through a fast kinetic reaction as follows:

$$2H^{+} + Ca(OH)_2\ (s) \rightarrow Ca_2^{+} + 2OH^{-}$$

- **Open Limestone Channels (OLCs):** OLCs introduce alkalinity to acid water in open channels or ditches lined with limestone. OLCs may be the simplest passive treatment method. Dissolution of the limestone adds alkalinity to the water and raises the pH. Armoring or coating the limestone by $Fe(CO)_3$ and $Fe(OH)_3$ produced by neutralization reduces the generation of alkalinity, so large quantities of limestone are needed to ensure long-term success. High flow velocity and turbulence enhance performance by keeping precipitates in suspension, and introduction of minerals like sand stone or fly-ash along with limestone can also enhance the performance by attracting some of the precipitates thereby reducing the armoring of the limestone.
- **Aerobic Wetlands:** An aerobic wetland consists of a large surface area pond with horizontal surface flow. The pond may be planted with Typha and other wetland species. Aerobic wetlands can only effectively treat water that is net alkaline. In aerobic wetland systems, metals are precipitated through oxidation reactions to form oxides and hydroxides. This process is more efficient when the influent H is greater than 5.5. Aeration prior to the wetland, via riffles and falls, increases the efficiency of the oxidation process and therefore the precipitation process. Iron concentrations are efficiently reduced in this system but the pH is further lowered by the oxidation reactions. Therefore, a lime dozing tank and limestone filter are installed before this so as to

increase the pH to a desired level for the typha to be effective.

III. RESULTS AND DISCUSSION

Although the plant includes three processes of AMD Treatment it did not turn out to be a complete success, as the retention time was too short and the discharge was too high. Therefore the pH could be raised only to around 4, which is still very much out of the permissible limits.

IV. CONCLUSION

Given the seriousness and scale of mine drainage it is important to continue to work towards affordable and effective treatment options. The treatments discussed in this paper are exhibiting mixed success, results are encouraging but not the “walk-away,” cheap solution that they are sometimes described to be. While there are drawbacks to traditional treatments, there are some benefits that make them widespread and in some case the preferred alternative. Still the other treatments mentioned here are showing progress and with further research and performance analysis these technologies may become more widely used in the future. As in this case affordability came in way of effective treatment, it is required to encourage the government to invest more on the Research and Development of better AMD treatments as and when required, so as to move ahead of the cheap traditional methods and adopt more innovative techniques like Reverse Osmosis, Ion Exchange etc. for effective treatment of acidic mine discharge. It is also required to focus not just on “Production” and “Profit” but also towards making amends to the environment for all the negative impact that the mining industry is and has been creating on the environment.

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