POLLUTION STATE FOR ACID MINE DRAINAGE

INTRODUCTION

Mining is an anthropogenic action that can have a main influence on natural components. The most serious cases arise when sites (both active mine sites and the abandoned mine lands) can be classified as “devastated landscape.” In these cases, according to Mahr and Malgot (1985), the natural components have lost the capability to autoregenerate in a timely manner, and their rehabilitation is only possible through anthropogenic correction. For this reason, there is a general societal consensus that active mining should have minimal impact on the environment and that degraded mine sites should be rehabilitated. Otherwise, environmental balances can be irreversibly destroyed, with serious negative consequences for surrounding ecosystems, including humans.(Favas, Martino, and Prasad 2018)

Acid mine drainage (AMD) or acid metalliferous drainage is the wastewater resulting from mining activities. It has been considered as a pollutant of serious concern because of its acidic nature, high content of toxic metal ions (Fe, Zn, Cd, Al, Cu, Pb), dissolved anions (sulfates, nitrates, chlorides, arsenates, etc.), hardness, and suspended solids. The pH of AMD ranges around 2–4. The sulfate concentration ranges from 100 to 5000 mg L^{-1}. (Dhir 2018)

Metal-rich mine wastewater is generated due to accelerated oxidation of iron pyrite (FeS_2) and other sulfide minerals during mining activities. AMD exerts negative on environment by:

• adding metals to aquatic ecosystems

• altering water chemistry

• decreasing the amount of oxygen available for aquatic organisms

• precipitation of metals (ferric hydroxide, aluminum hydroxide etc.), leading to reduced availability of light to aquatic ecosystems

• changing water quality.

Acidic nature of AMD destroys vegetation, accelerates soil erosion, and increases the susceptibility of aquatic animals to disease. Because of these environmental concerns AMD needs to be treated before release in the environment. AMD treatment mainly involves chemical, physical, and biological processes. The chemical processes mainly include oxidation, reduction, coagulation, adsorption, absorption, ion exchange, complexation, chelation, hydrolysis, precipitation, sedimentation, and crystallization, while physical processes include gravity, aeration, and dilution. Biological treatment methodologies mainly include biosorption, biomineralization, bioreduction, and alkalinity generation.

COMPOSITION OF MINE WATER

Mining operations unlike other sectors are fully reliant on the location of minerals with partial possibilities to mitigate and adapt to regional water or quality impacts. Chemical characteristics generated from mine activities with natural water are termed mine water or mine waste drainage. This activity has successfully elevated mining companies across the globe to refine minerals, reduce waste, limit pollution, and drive profitability. Mine water comprises of AMD, neutral mine drainage, and alkaline scarcity mine drainage. When mine and mine waste drainage have neutral pH, with a high concentration of dissolved metals, they are called neutral (or alkaline) mine drainage. When the rocks made of sulfur are excavated from a mine surface or an underground mine, they react with water and oxygen to form sulfuric acid. This acid is carried off the mine site by rainwater or surface drainage and gets to the nearby streams, rivers, or lakes; thereby impacting negatively on the quality of this water body. Even though AMD has received greater attention than neutral or alkaline mine drainage, their environmental adverse effects can still not be neglected.

In general, mine water comprises of potentially toxic substances that can affect water quality, thus making water pollution a global concern. (Oyewo et al. 2018)

METALS OF SERIOUS CONCERN IN MINE WATER

The majority of economically mine deposits are connected with potentially hazardous trace and harmful elements. The highest threat posed to water resources arises from mine discharges that have been found to be contaminated with metals, transition metals, and inner transition metals. In the midst of the above mentioned pollutants, iron sulfate, radioactive and rare earth (REEs) metals have been a serious challenge in mine water treatment due to their chemical and physical properties. Sulfate, for instance, is very soluble and this makes its removal a very tedious task. The consumption of drinking water containing sulfate concentrations in excess of 600 mg L^{-1} commonly results in laxative effects, therefore the allowable sulfate concentration in drinking water has been reported to be between 250 and 500 mg L^{-1} due to its lower environmental risk compare to other dissolved metals. This has been under investigation and in many practices; and little or no useful information has been documented. Tolonen et al. (2016) reported the use of precipitation techniques in sulfate removal and this happens to be the only reliable technology in sulfate removal up till date, therefore more research has to be done. Iron ox hydride usually present in very high concentration in mine water regardless the type or location of mine site (Tolonen et al. 2016). Precipitation and adsorption are commonly efficiently used in Fe removal but require effective sorbent medial and they are termed low-cost technologies. Radioactive and REEs minerals are also a challenge in industrial world owing to their unavailability but can still found in mine dump; therefore more research is required in the area of their recovery for sufficient supply. Adsorption process can also be sufficiently used to remove trace of radioactive and REEs afterward, provided an efficient sorbent media is applied. Other common metals that can be found in mine effluents are Cd, V, Cu, Al, Cr, Hg, Pb, Zn, Ni, etc.; these can also pose a serious risk to human and aquatic life depending on their bioavailability.(Oyewo et al. 2018)

PROCESSES USED IN TREATMENT OF ACID MINE DRAINAGE

AMD treatment technologies are mainly categorized as passive and active. Both treatment methods are effective in lowering acidity via generating alkalinity, reducing toxic metal and sulfate concentrations.

ACTIVE SYSTEMS

This method involves addition of neutralizing chemicals such lime (calcium oxide), calcium carbonate, sodium carbonate, sodium hydroxide, and magnesium oxide. Addition of alkaline material raises pH of AMD, accelerates chemical oxidation of ferrous iron, and facilitates precipitation of metals as hydroxides and carbonates. Active treatment methods are costly because they require regular maintenance (chemical reagents, mechanical systems, labor input) for their continuous operation. In most of the cases, iron-rich sludge is produced as a byproduct. (Dhir 2018)

PASSIVE SYSTEMS

These treatment systems involve chemical, biological, and physical methods to treat wastewater. This treatment results in lowering of acidity, reducing sulfate, metal concentrations, and controlling salinity. Microbes form an important component of these treatment systems. Alkaline materials used in the process neutralize acidity, while organic substrates create reducing environments required to precipitate metal as sulfides. Organic substrates provide support for microbial attachment. These treatment methods are best suited to treat mine effluents with low acidity (<800 mg $CaCO_3$ L^{-1}) and low flow rates (<50 L s^{-1}).(Dhir 2018)

This treatment system offers advantages such as high rate of metal removal with low operation costs and minimal energy consumption. Passive bioremediation systems mainly include:

- limestone ponds
- open limestone channels
- anoxic limestone drains (ALD)
- successive alkalinity-producing systems (SAPS)
- permeable reactive barriers (PRB)
- packed bed iron-oxidation bioreactors
- aerobic wetlands
- anaerobic wetlands/compost reactors
- bioreactors

Passive bioremediation processes are further categorized as abiotic and biological depending on the mechanism.(Dhir 2018)

CHEMICAL PRECIPITATION TECHNIQUES IN METALS REMOVAL FROM MINE WATER

This process is a conventional technology used in treating mining-influenced water, effluent water, and industrial wastewater. Chemical precipitation processes involve the addition of chemical reagents, followed by the separation of the precipitated solids from the cleaned water. Typically, the separation occurs in a clarifier, although separation by filtration or with ceramic or other membranes is also possible.

In an initial screening procedure, ferrous sulfate, ferric chloride, alum, and lime, are chemicals commonly used in the wastewater treatment industry, were tested individually and in combination. This was probably a result of the inability to find the exact precipitation pH and perhaps the difficulty in detecting a colloidal precipitate in a dark solution by visual means. Amaral et al. (2016) reported the use of this technology in sulfate-bearing AMD (coal and metal sulfides) and the separation was done via floatation(Amaral Filho et al. 2016). The result revealed the maximum removal percentage (80%–82% of the feed content) appears to be limited by the efficiency of the dissolved air flotation process and the chemical equilibrium of the precipitates, which leaves some soluble sulfate in solution. Bubbles readily attach to the flocs and become entrained and/or entrapped in the flocs, creating aerated flocs. Because all of these mechanisms operate simultaneously, the flotation of the flocs is very rapid, as indicated by the high kinetics rate constant.

AMD that contains various toxic heavy metals as well as dissolved iron and aluminum that contaminate downstream areas was also treated using this technology and the limitation was also discussed. Riodan et al. (1997), combined precipitation and biosorption methods using residua brewery yeast as biosorbent media and reported 360 mg g^{-1} biosorption capacity, this confirms the efficiency of these methods but not environmentally friendly due to the requirement of large settling tanks for the precipitation of voluminous alkaline sludge therefore, a subsequent treatment is needed.(Oyewo et al. 2018)

ADSORPTION TECHNIQUES IN METAL REMOVAL FROM MINE WATER

Adsorption is mainly surface process, which occurs when a gas or liquid solute gathered on the surface of adsorbent media, forming a molecular or atomic film, while desorption is the opposite of this process. The term sorption comprehends adsorption and absorption processes but they are totally different mechanisms. On the other hand, absorption is a process where by a substance diffuses in to a liquid or solid to form a solution.

This advanced technique can be applied for different purposes but quite robust in terms of wastewater treatment effectiveness. It is highly economical, mostly depending on the choice or type of adsorbent used. Adsorbents are usually in the form of moldings, spherical pellets, or rods. Adsorbent must possess high abrasion resistance, to enhance surface capacity for adsorption as a result of higher exposed surface area. They should also possess a distinctive pore structure and diameter, which allows fast transportation of the vapors. This process can be used in mine water treatment for the removal of metals even at trace level; it is highly efficient in very low metals concentration. As mentioned above, the performance of any adsorption process depends on the choice of sorbent media and the most commonly efficiently used is activated carbon. Other adsorbents such as polymer-based, zeolite-based, clay-based, and agricultural waste have also been investigated in metals removal from mine water but their limitation is either cost-effectiveness or limited performance, therefore more research is required in the area of effective and efficient sorbent media development.

Kefeni et al. (2017) reported the research article from 1980 to 2016, but lay more emphasis on the latest papers published in between 2010 and 2016 to address up-to-date AMD treatment options. Kefeni and his coworkers revealed that about 200 references are included in the current paper and 79% are those published since 2010. Moreover, each author extensively discussed their prevention and remediation options based on their experience and observation in real AMD issue. The authors believe that their review is very important to design and look for an alternative best technology for prevention of AMD generation including continuous metals removal in the future.(Kefeni, Msagati, and Mamba 2017)

CONCLUSIONS

Active (addition of lime or other alkaline chemical) and passive (constructed wetlands and compost bioreactors) treatment technologies have been applied to treat acidic mine waters.

The remediation of AMD is a demanding concept that solely relies on several factors such as the day to day AMD load, net acidity, metal concentration, and flow rate. The outcome and limitation of emerging treatment technologies in mining applications was reviewed and reported. These include biological systems for anion removal, alterative chemicals for metal precipitation, investigations into physical separation technologies for concentrating and recovery process streams, adsorption process, and ion exchange systems used for recovery and metals removal.

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