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Treatment of Acid Mine Drainage: A General Review

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Abstract: Acid mine drainage has severe environmental effects. These environmental effects can be devastating for living organism. The acidity of acid mine drainage destroys plants, vegetations, human and animals health, corrosion of pipes, building and building materials, Increasing degradation and contamination of aquatic resources and make water quality unsuitable for human and biota utilization. Presently treatment of mine influence water has significant challenges because of its persistent nature. The generation of acid mine drainage once initiated, can continue for decades and often long after active mining operations have ceased. Traditional treatment methods are not suitable for treatment of mining effluents. Recently, passive treatment systems have been proposed and implemented as low-cost, effective, efficient and long-term management options. This review summarizes the applications of active and passive treatment system for treatment of acid mine drainages.

Keywords: Acid mine drainage, effect, active and passive treatment technology.

INTRODUCTION

The generation of Acidic wastewater is a natural process that becomes accelerated and intensified by different mining operation for coal and metals mines. When host rock was exposed to weathering, it will release minerals. Acidic mine drainage (AMD) or acid drainage (AD) also called acid rock drainage (ARD). It has high acidity, low pH, high contents of dissolved metals [1],[61],[81]-[82],[86]), iron [68] and turbidity. Different mining activities are dangerous sources of an enormous natural environmental problem. Related to air, water, soil contamination and biodiversity loss [8],[60] with severe health risk to human living surrounding mining regions [3],[88]. To maintain the environmental quality, it required efficient and continual treatment option. Treatment methods are commonly divided into either active treatment system, required alkaline chemicals to neutralize the acidity.

The passive treatment system means trust on biological, geochemical, and gravitational processes. The active treatment system of AMD to remove acidic and metals is often a costly option, long-term liability. In recent years, many passive systems have been developed for the treatment of acid mine drainage, without using hazardous chemicals and that take advantage of naturally occurring chemical and biological processes to cleanse infected mine waters. The first passive technologies included anoxic limestone drains (ALD), limestone ponds (LP), open limestone channels (OLC), successive alkalinity producing systems (SAPS) and different types of constructed wetlands (i.e. aerobic wetlands and anaerobic horizontal/ vertical flow wetlands). Passive treatment does not require regular care, chemical reagents or energy.

Sources of mine influence water

The primary sources of mine impact water during different mining operation are runoff from open pit workings, Infiltration of rainwater into waste rock dumps piles milling area, haulage roadways, and contaminated surface [46]. Infiltration of groundwater onto waste rock dumps piles, Spent ores piles from heap leach operations, Upon abandonment of mines sites, this is typically followed by flooding, Active and abandoned tailings lagoons[16].

Treatment of Acid Mine Drainage

Treatment of acid mine drainage are broadly categories, in active and passive treatment. The active treatment system is more complicated, requires more unit processes and higher operation costs compared to the easiest and simple passive treatment system. Its overall operating cost is very low as compare to other treatment process. Numerous of method have been used by different countries for acid mine drainage treatment including precipitation [11],[41],[62], electrochemical remediation[22], oxidation and hydrolysis[26] neutralization [22],ion exchange [19], titration [48], adsorption[50],[63],[73]. All these technologies are used for contaminant removal from wastewater; adsorption process offers the best advantage regarding most efficient and economical and simplicity in operation.

Active Treatments

Active treatment systems utilized for the improvement of water quality [85]. Active treatment system requires artificial energy or bio-Chemical reagents for neutralization of AMD; there are numerous studies carried out on the variations of this technique by many researchers, but the ultimate process involves the addition of base to neutralize acid [10],[59].

Many liming materials are also used in active treatment systems as neutralizing agents/chemicals. It does not only neutralize the AMD, it also serves to precipitate the metals out of the solution at different pH value. Active treatment can be the very useful option of treatment. However, it required the continuous and long-term commitment to treatment, equipment failure, different weather conditions, and reductions in the budget can result in lapses in treatment, which may have devastating consequences. Presently these chemicals are used in the active treatment of AMD; these include Ammonia (NH3), Calcium Oxide (CaO), Calcium Carbonate (CaCO3), Calcium Hydroxide (Ca (OH)2, Sodium Carbonate (Na2CO3). Sodium Hydroxide (NaOH) are used in the neutralization of AMD [6],[70], agricultural limestone and phosphate rocks have also been used to treat AMD [44].

Passive Treatments

To maintain the health and quality of the natural environment for present and future generations. Many strict rules and regulation have been taken by many national and international organizations such as the Central Pollution Control Board (CPCB), World Health Organization (WHO), Unites States Environmental Protection Agency (US EPA) to control the amount of contaminants released into the environment. Last twenty-five years, the possibility of harnessing natural ameliorative processes for mine water treatment has been investigated [84].Passive treatment systems are a method for successively removing acidity and metals from acid mine drainage in a human-made bio-system that capitalizes on biological and geochemical reactions [46]. Passive treatment systems are considered to be eco-friendly, low energy, environmentally sustainable wastewater treatment systems. Passive treatment technologies are attractive sources of mine waste water treatment in coal mines effectively, utilized since, 1970 [7].The primary passive treatment systems are limestone, anoxic limestone (ALD), open limestone channel (OLC), oxic limestone drains (OLD), reducing and alkalinity producing systems (RAPS) and successive alkalinity producing system (SAPS)[74] and limestone ponds[7], [24]-[25] [38],[43],[65], microbial reactor, reactive walls and biosorption systems; are also reviewed [65].

Passive technology is used in the United Kingdom[58] [86], since the early 1990s and also practices in other parts of the world including, North America, and Western Europe [66]. These attractive Passive technique having engineered based facilities utilized a series of treatment that requires negligible or no maintenance once constructed and operational. Truly passive treatment systems are significantly reduced treatment expenses at many mine sites [31]. Selection of suitable passive treatment system depends on many important factors likes, local topography, site characteristics, water chemistry, flow rate [45], and refinements in design are ongoing. [43]. passive treatments system offer an efficient treatment technology with a small investment, likes, minimum inputs, works without any usual information of cost-intensive resources, such as technical manpower, chemicals, and energy, no external energy required, reduce operational and maintenance cost [28]-[29].Passive treatment systems have many advantages of naturally occurring chemical and biological reactions in a controlled environment to treat mine waste water with nominal operational and maintenance cost [35],[50].Presently, Reduce, recycle, reuse and recovery are a very traditional process for the effective environmental management. Many Technologies such as precipitation, reverse osmosis, metal extraction, filtration and adsorption [5] are available for mine wastewater treatment. The selection of suitable treatment technology for mine wastewater management depends on many factors.

These factors are a degree of contamination, the level of contaminant removal, Government, rules and regulations, treatment cost, volume of mine waste water, residue generated after treatment, hence treatment technology may be used a just single method or a combination of several techniques. Passive treatment technology are mostly applied for treatment of mine-impacted water such as acid mine drainage (AMD) [58] [64] and other open systems such as constructed wetlands and lagoons. Wetlands are used to treat mine influence water / acid mine drainage (AMD) generated from different stages of coal and metals mining operations [15]. The artificially and natural wetlands are a valuable ecological system, also known as biological filters, both systems offer efficient and economical treatment facilities with minimum inputs of natural resources. It required little investment and less maintenance, low operating costs and no external energy [28]-[29],[51]. Wetlands have a possible opportunity for helping to solve a broad range of water quality and environmental associated problems [37].The performance of Passive treatment also depends on the flow rate and hydrochemistry of the mine water, geology, hydrology and topography of the mining region, land availability and Contaminated Land issues [66).The main problems related to the AMD treatment with passive systems has reviewed in details by [16],[38]. Many factors influence the design conditions, likes flow volume, the characteristic of the AMD, availability of land [89], characteristic of site and metal removal mechanisms also playing a vital role in the design, efficiency and optimal life of passive treatment system.

Natural Wetlands

Natural Wetlands have been used worldwide, for assimilating large amounts of environmental contaminants [36].Natural wetlands are characterized by water-saturated soils with supporting vegetation. It was first noted amelioration of AMD the following passage through naturally occurring Sphagnum moss bogs [76] in Ohio and West Virginia, USA. Many studies also documented similar phenomena in brief by [14] in Typha wetlands. Wetlands are suitable for low pH and high metal concentrations. Mine water eventually degrades the natural quality of wetlands. Over a thousand natural wetlands have since been constructed to receive mine water from both active and abandoned mine and provide conservative treatment of AMD [57]. Acid mine drainage contain heavy metals and suspended solids, which are easily removed and retained in wetlands system.

Aerobic wetlands

Aerobic wetlands are the simplest form of passive treatment methods. It is shallow ponds usually designed to promote precipitation of metal oxides or hydroxides by providing the aeration and suitable residence time. Aerobic wetlands are cattails, vegetated with emergent plant species and contain 15 cm to 25cm water level for maintaining the aerobic condition. The size of wetland depends on the contaminant load entering the wetland. At a site in Ohio, United state, metal sludge is accumulating at a rate of about 30-40 mm per year [23]. Many studies at some sites in Pennsylvania, USA, show the sludge accumulating rate ranges from 3.2 to 4.4cm per year [23]. These data suggest that a suitable freeboard of 91.4cm provide sufficient volume for 25-50 years of treatment. Wetland plants remove toxic metals from acidic water by adsorption [90]. The removal capacity of wetlands depends on many factors likes, concentrations of dissolved metals, Dissolved oxygen (DO), air, pH, the alkalinity of AMD, active microbial biomass, the retention time of AMD in the wetland [71]. Aerobic wetlands also create sufficient new removal sites, option for long-term treatment in low maintenance and economic cost [29], but theses wetlands required longer detention times and large surface area [71] for mine water treatment.

Anaerobic wetlands

Anaerobic wetlands are modifications of natural wetlands with cattails and other typical vegetation above the water, but anaerobic wetland contains 0.30-0.60 m layer of organic matter over 0.15-0.30 m bed [90] of limestone, or placing a layer of a mixture of organic matter and limestone to a depth of 0.50-1.0 m. [43],[90].Wetland, chemical and microbial processes which decrease pH value [90]. The AMD slowly flows down through the organic material. Which can be composted municipal waste materials [84], cow/horse manure with straw [84], paper recycling sludge [21], hay and softwood sawdust [50], spent mushroom compost and wood chips [21]? Micro-organisms in the organic layer reduce sulphate, and the substrate promotes chemical and micro- organism actions that generate alkalinity and increase pH value. Anaerobic wetlands neutralize AMD by encouraging the generation of bicarbonate alkalinity ($HCO^{3-)}$ by both anaerobic microbial sulphate reduction. However, efficiency and mechanism of mine waste water treatment vary seasonally and with wetland age [77].

Anoxic limestone drains

Anoxic limestone drains (ALDS) have been developed by Tennessee Valley Authority in the early nineties, and utilized many parts of the US, where water conditions allow ALD treatment [70]. ALDs are limestone-filled trenches of typically Dimensions may be, 1.0 m thick, 1.0-7.0 m wide, and 25-100 m long[74]. It can rapidly produce bicarbonate alkalinity via limestone dissolution and reduce the size of wetland. They are installed at the point of discharge to capture the AMD subterraneous.

ALDs are capped with clay or compacted soil to prevent AMD contact with oxygen [43]. The acidic water flowing through the trench dissolves the limestone and releases bicarbonate alkalinity. ALD treatment mine waste water increased the efficiency of the treatment plant and reduced the size of treatment units due to the decreased metal loadings and increased alkalinity of the ALD effluent discharged into them. The ALDS effluent pH typically ranges between 6.0 to7.5 [71].This systems required 14-15hours retention time [34] to maintain the efficiency and construction cost of alkalinity generation with more removal capacity of heavy metals than the natural wetlands.

Open limestone channels (OLCs)

Open Limestone Channels (OLCs) are very similar to rock lined ditches, suitable for treatment of mine drainage (Skousen, Rose et al. 1998), contains low alkalinity and high acidity with dissolved heavy metals. Open lime stone channels have been a more efficient treatment option, have been reviewed by any researchers [25] [38] [65].Where AMD must be transported over some distance during treatment. Use of open channels lined with limestone has been shown to be an effective option for removing iron and generating small amounts of alkalinity [87].During AMD treatment such channels become armoured and clogging with iron, research indicates that the armoured limestone retains some treatment effectiveness. In order to improve the life of system and reduce the risk of system failure, high flow velocities (above 0.1 m/s) are provided by providing the sufficient channel slope 20 % [71], for getting best performance of the OLC, these flow velocities keep hydroxide flocs in suspension and to clean precipitates from limestone surfaces [84], and the abrasive action of fast-moving water tends to dislodge the armouring iron. Open limestone channels can be successful as one element of a passive treatment system, but this system individually not suitable for proper treatment of acid mine drainage (AMD) [90]. OLD can be more efficient and effective when mine water fails to be treatable with ALDs and construction of a compost wetland, or RAPS is technically and economically not possible [23].

Vertical flow systems

Vertical flow passive treatment systems are a combination of ALDs and anaerobic wetlands, it also compensates the limitation of both systems, in vertical flow systems layer of an organic and limestone is the main constitute elements. This method is also known as Successive Alkalinity Producing Systems (SAPS) [52] and (RAPS),[74] reducing and alkalinity producing systems, consist of suitable layers, that includes standing water,

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organic matter and gravel of limestone [52]. In SAPS, 100cm to 300cm acid water is filled over 20 to 30 cm of organic compost, and it first flows down through organic layer, which is underlain by 50 to 100 cm of limestone. Vertical flow systems are similar to the anaerobic wetland; the only difference is AMD is forced over the limestone layer. Which provide direct contact with both the limestone and the organic materials. The vertical flow systems are constructed within a water-tight basin, and having a standpipe to regulate required water depths to maintain the organic and limestone layers remain in underwater position. To avoid clogging of the limestone layer with iron and other metal precipitates, a flushing pipe is provided in the drainage system [52]. For severe AMD discharges, numerous vertical-flow systems can be used in series to generate alkalinity successively for suitable treatment.

Limestone Ponds

Limestone ponds are a effective and new passive treatment system [7],[24],[43],[87] and constructed on the upwelling of an AMD, underground water discharge or seep point. A layer of limestone is placed on the lower part of the pond, and the water flows upward direction through the limestone [31].

The efficiency of lime stone ponds depends on many factors like, topography of area, size of Ponds, and the geometry of the discharge zone, the water can be from 100cm to 300cm deep, the design sandstone pond containing 30 to 100cm of limestone directly overlying the seep for 1 or 2 days to retain the water for dissolution and to keep the seep and limestone under water. These treatment systems are suitable for low DO to contain water, no containing Fe^{3+} and Al^{3+}. After treatment the lime is exhausted by dissolution and acid neutralization, another limestone can be added to the pond over the seep. However, the advantage of this system is that the operator can observe if the lime coating is taking place because the system is not hidden. These required periodically maintenance for maintaining the treatment efficiency.

Diversion Wells

The diversion well is a simple cylinder or vertical tank made of metal, concrete or other materials 1.5-1.8m in diameter and 2-2.5 m in depth, filled with sand-sized (crushed) limestone aggregate, erected in or beside a stream or may be sunk into the ground by a stream and connected vertically down the centre of the well, by a large pipe, 0.20-0.30 m diameter enters vertically down the middle of the well and ends shortly above the bottom.

Theses device was initially developed for the treatment of stream acidity caused by acid rain in Norway and Sweden [4]. It has been adopted in the eastern part of the USA and the Appalachian region since the early 1990's [4] for acid mine drainage (AMD) treatment. The wall needs to be placed so that, acidic water pass through the diversion well, the pH value increased in very less retention time, but for achieving required degree of treatment and maintain water quality, diversion wells needed regularly clean limestone in diversion wells.

Reverse Osmosis

The semi-permeable membrane is used in this process to treat AMD. In this system, Pressure is applied on AMD and forced through the membrane into a more dilute solution. This semi - permeable membrane only allows the passage of solvent and not solute. This leaves a more concentrated brine solution on the AMD side of the membrane. This system is more efficient for heavy metal removal at a wide pH range of 3-11, from inorganic solution with a metals concentration rejection percentage of over 97% with a metal concentration Range from 21 to 200 mg/L.

These systems also use full for elimination of metals from different industries likes, electroplating, metal finishing, paper and pulp industries, municipal wastewater, coal and metal mining, petrochemical, textile, food processing industries, radioactive wastewater and contaminated groundwater [20],[79] with recovery of aluminium, acid copper, copper cyanide, chromium, gold, nickel, zinc,[20]. RO system has many drawbacks, including treatment cost of AMD, which are the high cost of purchasing and operating the membrane, high pressures are required for effective separation through RO system.

Ion exchange

Ion exchange process is firmly established as a treatment operation in the mining industry and is a valuable option for to the other procedures such as filtration, distillation, and adsorption. It is used for the recovery of metals from industrial wastewater, separation of gas mixtures, and catalysis of organic from cooling water of nuclear reactors. However, ion exchange plays a major role in the purification and demineralization of water. Ion exchange material is capable of adsorbing H^+ ions, increase the pH level and also removing base metals from AMD like zinc and copper.

Electrochemical technology

This process involves the use of electrical energy to drive unfavourable chemical reactions. This technology required regular supply of electrical energy.

CONCLUSION

Mine influence water had many severe effects on many mining sites and required proper treatment and management. The generation of mine impact water depends on many environmental conditions. It is tough to solve acid mine water problems. The choice of suitable treatment option depends on numerous environmental factors. Sometimes the actual environmental cost of a remediation system is not instantaneously apparent. One such cost is the amount of fossil fuel energy needed to transport liming materials, often very long distances from source to mine sites. Traditionally, large discharge volume mine waters have been treated by active treatment system when the mine waters in are the acidic state. The land areas required for passive could be made significantly smaller by focusing on optimizing biological treatment system for example packed bed bioreactors for removing iron from acidic mine waters, which are far more efficient than aerobic wetlands. Passive treatment systems can be a useful part of an AMD treatment system. They can play the important role as either stand-alone treatment strategies or as pre-treatment to reduce the treatment cost and increase the efficiency of the active treatment system. Passive treatment systems are capable at renovating waters with low pH, high acidity, and elevated levels of heavy metals.

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