Removal of Heavy Metals from Acid Mine Drainage: A Review

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ABSTRACT:

Mining of coals and metals generates solid and liquid wastes that are potentially hazardous to the water resources and environment. Mine water (MW) also known as acid mine drainage (AMD) or acid rock drainage (ARD) is one of the very serious challenges of mining industries worldwide. This literature review summarises the removal of toxic metals from the mine waste water by various suitable treatment process. In order to reduce and remove the toxic heavy metals from mine waste water.

Keyword: Treatment, effects, metals, mine waste water

INTRODUCTION:

Mine water (MW) contains toxic heavy metal and strong acidity [13]. Heavy metals, including Cd, Co, Cr, Mn, Ni, Pb , Cu and Zn, have the potential to become major contamination sources that causes severe environmental pollution to human, aquatic life, food crops and soil environments[1],[21].Water pollution raises a great concern nowadays since water constitutes a basic necessity to all living things. World Population increases day by day which directly imposed pressure on natural water resources to fulfil the demands of fresh water. Mining sector requires huge amounts of water for their different activities**.** The waste generated from mining of coal, minerals and metals that are potentially hazardous to the Human health and environment [3-4], [9]. Protection of aquatic and terrestrial ecosystems from mining pollutants is a major concern of environmental protection bodies and the responsible of mining industry owner itself. During the mining operation many commercially-valuable base metals, such as copper, gold and zinc, found with sulphide minerals, and these are often associated in ore bodies with other, relatively non-valuable minerals and waste rock, such as pyrite (FeS_2), as well as other gangue minerals. The occurrence of pyrite and other sulphide minerals in tailings. Pyrite can be oxidized by oxygenated water and ferric iron. The generation of mine water is a natural phenomenon occurring in sulphide bearing rock materials and resulting in the production of acidic water in nature. Mine water have low pH (<5) seeps through waste rock piles, tailing dumps, and country rocks, dissolving metals along its typical major rock constituents (Ca, Mg, Na, K, Fe, Mn & Al) as well as trace elements such as Cu, Cd, Pb, Ni, As & Zn. These contaminated waters have a harmful impact on human health, life of aquatic organisms, animal health, plants, vegetation, engineering materials, structure, and quality, safety of the agricultural and ecological environment. The main source of mine water may be, tailings impoundment, waste rock dump, milling area, haulage roadways, and contaminated surface [19], [22].

CHEMISTRY OF MINE WATER:

Mine water generation is a self-sustaining cycle, when its generation taken off, it does not stop until one of the necessary agents, commonly sulphide materials, becomes depleted, Worldwide accepted equation as follow [33],[19).

$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$
(1)
Iron sulfide (Pyrite) + Air (Oxygen) + moisture (Water) ➔ Ferrous Iron +Sulfate + Acidity
Pyrite exposed in the presence of oxygen and water to produce iron (II), sulfate, and hydrogen ions.
$4Fe^{2+} + 7O_2 + 2H_2O \rightarrow 4Fe^{3+} + 2H_2O$
(2)
Ferrous Iron + Oxygen + Water ➔ Ferric Iron + water
Step 2 shows oxidation of Fe (II) to Fe (III)
$4Fe^{3+}\quad 12\,H_2O \rightarrow 4Fe\,(OH)_3 + 12H^+$
(3)
Ferric Iron + Water ➔ Ferric Hydroxide (yellow boy) + Acidity
Hydrolysis of Fe (III) and precipitation of iron (III) hydroxide if pH >3.5
$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$ (4)
Pyrite + Ferric Iron + Water ➔ Ferrous Iron + Sulfate + Acidity
Here iron (Fe (III)) as oxidizing agent, in place of oxygen for Oxidation of additional pyrite (from steps 1 and 2).
$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe\,(OH)_3 + 8H_2SO_4$ (5)
Pyrite + Oxygen + Water ➔Ferric Hydroxide + Sulfuric Acid
There are a variety of other metal sulphides that release these metal ions into solution [42]
Sphalerite: ZnS: $(s) + 2\,O_2\,(aq) \rightarrow Zn^{2+}\,(aq) + SO_4^{2-}\,(aq)$ (6)
Galena: PbS: $(s) + 2\,O_2\,(aq) \rightarrow Pb^{2+}\,(aq) + SO_4^{2-}\,(aq)$ (7)
Millerite: NiS: $(s) + 2\,O_2\,(aq) \rightarrow Ni^{2+}\,(aq) + SO_4^{2-}\,(aq)$ (8)
Chalcopyrite: $CuFeS_2\,(s) + 4\,O_2\,(aq) \rightarrow Cu^{2+}(aq) + Fe^{2+}(aq) + SO_4^{2-}(aq)$ (9)

METHOD OF TREATMENT OF MINE WATER:

There are a many technologies available for mine water treatment; these are categories, as Active and Passive treatment processes. In this paper comparative study of these methods for removal of heavy metals from mine water.

ACTIVE TREATMENT:

Generally active treatment involves many chemicals as neutralising agent to the source of acid mine drainage or directly addition to the receiving stream that has been polluted. Active treatments are very successful; following chemicals are successfully used in active treatment [6], $CaCO_3$ (Calcium Carbonate), CaO (Calcium Oxide), Ca $(OH)_2$ (Calcium Hydroxide), NH_3 (Ammonia), NaOH (Sodium Hydroxide) and Na_2CO_3 (Sodium Carbonate) etc. Active treatment is very complex, requires constant maintenance and transportation of waste away from the site [17]. This system also requires more unit processes and thus higher running costs compared to the passive treatment system not require Energy and special plant machinery or chemicals. The chemicals does not only neutralise the mine water, it also have the capacity of precipitation of heavy metals from the mine water at different pH condition.

PASSIVE TREATMENT:

Since the early 1990s, passive treatment systems have been developed to treat mine water following are the major methods of passive treatment: primary passive technologies include aerobic and anaerobic wetlands; limestone ponds, open limestone channels (OLC), vertical flow reactors, settling ponds, limestone diversion wells, anoxic drain of calcareous and sandstone, anoxic limestone drains (ALD). Passive treatment on the other hand only required natural and constructed wetlands which require very small investment and maintenance; however its initial construction costs is higher than active treatment process. Although it's overall operational and maintenances cost are relatively very less [12], [16]. This studied shows the behaviour of organic waste materials for treating mine waste water. These are oak chips, spent oak from shiitake farms, organic-rich soil, spent mushroom compost, and sludge from paper recycling plant. These waste materials were placed in column reactors, which were inoculated by anaerobic digester fluid. The number of sulphate-reducers increased in 2 weeks. The reactors were continuously fed with simulated mine waste water for 35 weeks to determine sulphate reduction and metal removal capacity of waste materials [30]. This study shows the use of 1,3-nzenediamidoethanethiol dianion (BDET, known commercially as Met X) for selectively and irreversibly bind soft heavy metals and remove>90% of several toxic or problematic metal from aqueous solution. The concentrations of metals such as iron may be effectively minimise at pH 4.5 from 194 ppm to 0.009 ppm which are below standards [25]. Bentonitic clay was used as a solid natural coagulant for treatment of the acidic and oily waste water of high molecular weight with the bentonitic clay as coagulant and constant pH of 7.5 at temperature of 25 °C [2]. Study of mine water sludge on the basis of solubility of the major dissolved metals, a two-step precipitation process was developed to uptake high purity iron and aluminium as separate hydroxide products through the manipulation of current mine water treatment process. Result shows iron precipitation at pH 3.5-4.0 with precipitate purity more than 93.4% and iron recovery more than 98.6%. Mine water also used as source water for Aluminium recovery after iron precipitant. Aluminium precipitated at pH 6.0–7.0 with aluminium recovery more than 97.2% and precipitate purity more than 92.1% [40].Shows a critical review of the heavy metal removal from acid mine drainage by wetlands techniques, in which sedimentation, settling, filtration, adsorption, precipitation, co-precipitation into insoluble compounds are takes place by physical, chemical and various biological Processes for removal of heavy metals. Wetlands absorb heavy metals and make them slowly concentrated in the sedimentary deposits to become part of the geological cycle. The result shows, wetlands have low cost treatment, producing pollution free water from mine waste water [33.The removal ability of Fe and Mn by different materials likes concrete, sand, limestone, starfish, and black shale from Wastewater impacted by acid mine drainage. The change in pH, Eh, and EC as a function of time was quantified and found high Neutralization efficiency for AMD and maintained the pH value above11[7]. The Combined passive treatment technologies are used to treat acidic rock drainage (ARD), and maintain a neutral pH and low hydraulic conductivity (less than 4.0, 10, 11 m/s) after 16 pore volumes of permeation. It is also shows that geosynthetic clay liners were able to reduce metals from lime treated ARD water showing with (>80%) removal efficiencies [25], [35].

.The treatment behaviour of fly ash (FA) study for the active treatment of mine water from a coal mine. It efficiency depends on the ratio of the FA used in mine water. Mine water with FA was successfully converted to zeolite-P. This Zeolite-P was used for polish the primary active FA process water It was observed higher removal of major AMD contaminants Fe, Al, Mg, Mn and sulphate was achieved with the fly ash treatment and trace elements such as Zn, Ni, Cu and Pb from the process water[38]. The study of vermiculture biotechnology by using Canna plants in continuous flows at room temperature for removal of copper, BOD, COD and Suspended Solids from aqueous solution by with variation in flow rates and initial concentrations. The experimental results confirmed that vermiculture biotechnology could be efficiently used for the removal of copper (II) ions from aqueous medium; the main disadvantage is that it needs regular maintenance, certain life span and its construction cost. They must be effectively managed if they are to continue to improve water quality [16].Characteristics of bacterial community for using both classical culturing and modern direct sequencing techniques and found culture independent methods are more suitable than the culture dependant methods. They compared culture-based characterization with direct sequencing of the 16 SrRNA gene and find that the two methods produced very similar results. The Acidithiobacillus and Acidiphilium genera, although estimates of relative species abundance were only obtained from direct sequencing. Interestingly, their culture-based methods recovered four species that had been overlooked from sequencing results [2].Magnetite nanoparticles (γFe2O3) was used for removal of selective heavy metals Cu, Ni, Mn, Cd(II), and Cr(VI) from mine waste water by adsorption process. It was found to highly pH dependent, and the results indicates the best chromium (Cr (VI)) adsorption at an initial concentration of 50 mg/L, 0.1 g doses of nanoparticles, a temperature of 70 °C, and pH 2.6. The best nickel (Ni (II)), cadmium (Cd (II)), manganese (Mn (II)), and copper (Cu (II)) adsorption occurred at different pH 8.5, 10, 8.5, and 6.5, respectively. This study also indicates that removal of these five metals by maghemite reached equilibrium after only 10 min [29]. Three-stage batch reactor system for treatment of mine water and municipal waste water and examine the viability of Zn-rich acid mine water (MW) and raw municipal wastewater (MWW) in ratio of 5:1 and Compared to the influent mix to account for dilution, dissolved Fe ,Al, Mn and Zn removed up to 99.9%,99.7%, 4.5% and 33.9%, respectively. Significant and substantial metals (Al, Fe, Mn, Zn) removal, alkalinity generation, nitrification, and phosphate removal was also shows without use of energy and refined materials, results were found similar to the previous synthetic mine water and grit-screened MWW passive co-treatment experiment. In this studies nitrification occurred despite inhibitory Zn concentrations and pH increased to 7.06 and Phosphate reduced to below detection limits. The study revealed the feasibility of non-synthetic mine water and raw unscreened MWW passive co-treatment in relatively low ambient temperatures at range of 8.2 to 10.3°C[39].Limestone used for neutralization of mine waste water and found more suitable with many advantages of active treatment, high removal efficiency can treat AMD with different characteristics and with high flow, they can be controlled automatically, they occupy small space, but they have high capital costs and they generate more sludge. The advantages of passive treatment are low costs, they last for many years and they don’t use power, but they need large areas and high retention time to operate efficiently. In general it is possible to conclude that active treatments are more suitable for mines [10].The role of bacterial biomass for removal of the heavy metals from aqueous solutions by Bio sorption has emerged as a low-cost technological option for removal and recovery of base metals from aqueous wastes water, capacity of Bacillus licheniformis was evaluated for bio sorption ability for iron and copper at different temperatures and pH values respectively (30ºC, 35ºC, 40ºC, 45ºC, 50ºC and 55ºC) and (3, 4, 5, 6, 7 and 8) ,result show more removal efficiency of the of Fe and Cu ions at pH 8 with 92% and 93% respectively, for Fe ions 92% removal was found at 30ºC and for Cu ions 94% of removal was seen at 45ºC, With various advantageous recover important heavy metals in low cost [28].Study shows the concentrations of some of the toxic metals like Cu, Ni, and Zn etc are higher than permissible limits. Therefore, it is necessary to remove these heavy metals from the wastewater. The selection of treatment methods depends on some basic parameters of waste water such as pH, initial metal concentration, contact time; amount of adsorbent and capital investment. Adsorption process is very effective to use low-cost materials for removal of heavy metals from aqueous solutions [28].Studied the use of fly ash with alkaline hydrothermal treatment at 90°C.In the form of zeolite for removal of heavy metal from aqueous mine water and also used as fertilizer for agricultural sector. These zeolite products were suitable for removing Cr, Cu and Pb from aqueous solutions. Result shows the removal capacity of Ni, Zn and Cd in 1hr, found much lower in both cases, although MG-Z found more efficient than MT-Z in up taking Zn and Cd after 2 hr [15]. Experimentally examine, CFA and MCFA were as a reaction medium of PRB for treatment of mine water at a starting pH of 4.0 based on the results, CFA have good adjustment effect for the pH of mine water, which enables the adjustment of pH from 4.0 to 7.0 or above, and can be maintained for a long time, in which coal fly ash (CFA) was used as the reaction medium. Result show the removal of COD, sulphate in 12 hr with 53.4% and60.4%, and heavy metal ions (Cu^{2+},Cd^{2+}, and Zn^{2+}) were 74.8% , 42.9%, and 26.7%.acid treated CFA was found more effective for removal of heavy metal ions (Cu^{2+},Cd^{2+}, and Zn^{2+}), the removal rate of Cu^{2+}even reached

91.85%,due to low cost and high removal efficiency MCFA shows the promising potential for controlling mine water in mine [39].The impact of mine waste water on World Heritage listed upland river. Below the mine, macro invertebrate family richness decreased by 65% and abundance by 90%. Upstream of the waste discharge had very low electrical conductivity (EC) of 30.0μS/cm and pH was acidic (5.6) in contrast to that below the mine which showed EC 11 times higher (342 μS/cm) and a shift in pH to 7.2.The concentration of zinc below the mine was 101.5 μg/L and while below the permitted discharge level of 2500 μg/L as set in the environmental protection license (EPL),was found 10 times more than the recommended ANZECC guidelines for the protection of natural ecosystems[5]. Study of bone char behaviour for the removal of manganese from acid mine drainage (AMD) as an adsorbent in batch process. Bone char found more suitable material for the removal of manganese from mine water. The removal efficiency of Manganese mainly influenced by the pH of the aqueous and ratio of solid/liquid phase Metal removal found nearly neutral pH values. The effect of particle size and temperature proved to be insignificant for the investigated operating range[31].The analysis of the current state-of-the-art of AMD and its work performed in recent years on its occurrence, effects (on human health, plant life and aquatic species), and summarizes the remediation approaches taken far reduction and prediction of mine water problems[31].This review shows the recent advances in biotechnologies that have been proposed for secure reactive mine tailings and to remediate mine waters. Management of tailings ponds to promote the growth of micro-algae that sustain populations of bacteria that reduced the production of acid mine drainage. Elsewhere, targeted bio mineralization has been demonstrated to produce solid products that allow metals recovery and recycle from mine waters. It is also reduced the slug generation and increase the capacity and life of land fill [20]. Electro coagulation (EC) process was used for remove of heavy metals, silica, and a wide range of the other contaminants from aqueous solutions from mine water in different operating condition. Mine waste water passed through bottom of the EC chamber and is distributed evenly as it moves upward direction through the blades. Direct current (DC) is used for first and last blade. It is economical and efficient method for removal of heavy metal from mine wastewater. EC can be utilized effectively for economically treating a wide variety of challenging mine waste water [34]. Studied shows the removal of copper (Cu), cadmium (Cd), and nickel (Ni) from a simulated wastewater by electro coagulation (EC) method using batch cylindrical iron reactor. The influences of various operational parameters such as initial pH (3, 5, 7), current density (30, 40, 50 mA/cm^2) and initial heavy metal concentration (10, 20, 30 ppm) on removal efficiency were investigated. Its results show the removal efficiencies affected by current density and pH value. The experimental results also indicated that electro coagulation the highest removal capacity of Cd, Ni, Cu respectively 99.78%, 99.98%, 98.90% [36].

CONCLUSION:

Contamination of water resources due to mining of coal, minerals and metals ores have sever impacts on water environment, metal mining are the most important sources of the toxic metals pollution in surface and groundwater.

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Biography

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