

Heavy Metal Sources Impacts & Removal Technologies

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Abstract—The heavy metals like copper (Cu), zinc (Zn), lead (Pb), mercury (Hg), nickel (Ni), cobalt creates pollution and has become one of the most serious environmental problems today. The treatment of heavy metals is of special concern due to their bigotry and persistence in the environment. In recent years, various methods for heavy metal removal from wastewater have been extensively studied. This paper reviews the methods which have been used to treat heavy metal wastewater and compare these technologies. These technologies include chemical precipitation, ion-exchange, and low-cost adsorbents and their comparison and plant wastes as adsorbents including rice husks, spent grain, sawdust, sugarcane bagasse, fruit wastes, and weeds for heavy metal removal, membrane filtration, coagulation flocculation, flotation and electrochemical methods.

Keywords—(Heavy metals, Chemical Precipitation, Coagulation, Flocculation)

I. INTRODUCTION

Heavy metals refer to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. Heavy metals are natural components of the Earth's crust, which cannot be degraded or destroyed. Small quantity of heavy metals which are enter in our bodies via food, drinking water and air, are very harmful for us. Some heavy metals (e.g. Copper, selenium, zinc) are essential to maintain the metabolism of the human body, but at higher concentrations they can lead to poisoning (Sorme & Lagerkvist, 2002).

The source of heavy metals are industries such as metal plating facilities, mining operations, fertilizer industries, tanneries, batteries, paper industries and pesticides, etc. Heavy metals wastewaters are directly or indirectly discharged into the environment have increased tremendously, especially in developing countries. Unlike organic contaminants, heavy metals are not biodegradable and tend to accumulate in living organisms and many heavy metal ions are known to be toxic or carcinogenic. Toxic heavy metals of particular concern in the treatment of industrial wastewaters include zinc, copper, nickel, mercury, cadmium, lead and chromium. For removing these metals many technologies are being used viz. Chemical precipitation, ion-exchange, adsorption, membrane filtration, electro-chemical treatment technologies, etc. The present review article deals with the current techniques for the removal of heavy metal ions from wastewater (Fenglian & Wang, 2011).

Adsorption has become one of the alternative treatments, in recent years; the search for low-cost adsorbents that have metal-binding capacities have intensified. The adsorbents may be of mineral, organic or biological origin, zeolites, industrial by-products, agricultural wastes, biomass, and polymeric materials. Membrane separation has been increasingly used recently for the treatment of inorganic effluent due to its convenient operation. There are different types of membrane filtration such as ultrafiltration (UF), Nano filtration (NF) and reverse osmosis (RO). Electro treatments such as electro dialysis have also contributed to environmental protection (Barakat *et al.*, 2004).

II. HEAVY METALS AND THEIR EFFECTS

Eco-toxicological effects of heavy metals are well understood and have been a global concern for environmentalists. Water pollution by heavy metal ions has become a serious environmental issue, especially due to their toxicity and tendency to bioaccumulation. Zinc is a trace element that is essential for human health. It is important for the physiological functions of living tissue and regulates many biochemical processes. However, too much zinc can cause eminent health problems, such as stomach cramps, skin irritations, vomiting, nausea and anemia (Wingenfelder, 2005).

Copper does essential work in animal metabolism. But the excessive amount of copper brings about serious toxicological concerns, such as vomiting, cramps, convulsions, or even death (Babel *et al.*, 2006).

Arsenic is the most common cause of acute heavy metal poisoning in adults. Arsenic is released into the environment by the smelting process of copper, zinc, and lead, as well as by the manufacturing of chemicals and glasses. Arsine gas is a common by product produced by the manufacturing of pesticides that contain arsenic. Arsenic may also be found in water supplies worldwide, leading to exposure of shellfish, cod, and haddock. Other sources are paints, rat poisoning, fungicides, and wood preservatives. Target organs are the blood, kidneys, and central nervous, digestive, and skin systems (Razo *et al.*, 2004).

Cadmium is a byproduct of the mining and smelting of lead and zinc. It is used in nickel-cadmium batteries, PVC plastics, and paint pigments. It occurs mostly in association with zinc and gets into water from corrosion of zinc-coated ("galvanized") pipes and fittings. Effects of cadmium are in the liver, placenta, kidneys, lungs, brain and bones.

Iron is a heavy metal of great concern, particularly because ingesting dietary iron supplements may acutely poison young children. The iron is absorbed rapidly in the gastrointestinal tract causes of that its work as a toxic metal. The corrosive nature of iron seems to further increase the absorption. It can cause a rusty red or brown stain on fixtures or laundry and cause water to develop a metallic taste. The effects are on the liver, cardiovascular system, and kidneys (Martins *et al.*, 2004).

Lead can cause damage in the central nervous system. Lead can also damage the kidney, liver and reproductive system, basic cellular processes and brain functions. The toxic symptoms are anemia, insomnia, headache, dizziness, and irritability, weakness of muscles, hallucination and renal damages (Chen *et al.*, 2009).

Mercury is generated naturally in the environment from the degassing of the earth's crust, from volcanic emissions. It exists in three forms: elemental mercury, organic and inorganic mercury. Atmospheric mercury is dispersed across the globe by winds and returns to the earth in rainfall, accumulating in aquatic food chains and fish in lakes. Mercury continues to be used in thermometers, thermostats, and dental amalgam. Certain bacteria are able to transform it into methyl mercury, which is concentrated in the food chain and can cause malformations. The effects of mercury are on the brain and kidneys.

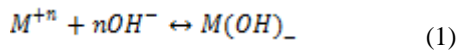
III. HEAVY METAL WASTEWATER TREATMENT TECHNIQUES

3.1 Chemical Precipitation

Chemical precipitation is effective and most common process in industry because it is relatively simple and inexpensive to operate. In precipitation processes, the chemicals react with heavy metal ions to form insoluble precipitates. The forming precipitates can be separated from the water by sedimentation or filtration. And the treated water is then decanted and appropriately discharged or reused. The conventional chemical precipitation processes include hydroxide precipitation and sulfide precipitation (Fenglian & Wang, 2011).

3.1.1. Hydroxide Precipitation

Precipitation by hydroxide formation is the most common heavy metal precipitation method. The precipitation typically follows reaction



Many heavy metals are amphoteric therefore, their solubility reaches a minimum at a specific pH (different for each metal) (Babel & Kurniawan, 2003).

The most widely used chemical precipitation technique is hydroxide precipitation due to its relative simplicity, low cost and ease to pH control. The solubility of the various metal hydroxides is minimized in the pH range of 8.0-11.0. The metal hydroxides can be removed by flocculation and sedimentation. Many hydroxides has been used to precipitate metals from wastewater, based on the low cost and ease of handling from which lime is the preferred one for use in hydroxide precipitation at industrial setting (Fenglian &

Wang 2011). Metal precipitate during flocculation with iron or aluminum salts is possible for some metals (e.g., arsenic).The addition of caustic materials is used to raise the pH level. The most common caustics are sodium hydroxide (NaOH), calcium hydroxide Ca(OH)₂ lime. Sodium hydroxide is more expensive than lime. Lime has the advantage of acting as a coagulant during the precipitation/settling process, whereas NaOH does not. Hydroxide precipitation process using Ca(OH)₂ and NaOH in removing Cu(II) and Cr(VI) ions from wastewater was evaluated by (Mirbagheri & Hosseini 2005). The Cr(VI) was converted to Cr(III) using ferrous sulfate. Maximum precipitation of Cr(III) occurred at pH 8.7 with the addition of Ca(OH)₂ and the concentration of chromate was reduced from 30 mg/L to 0.01 mg/L. The cupro-ammonia was reduced by aeration and the optimum pH for maximum copper precipitation was about 12.0 for both Ca(OH)₂ and NaOH and the concentration of copper was reduced from 48.51 mg/L to 0.694 mg/L. To enhance lime precipitation, fly ash can be used as a seed material. The fly ashes lime-carbonation treatment increased the particle size of the precipitate and significantly improved the efficiency of heavy metal removal (Pang *et al.*, 2009). The concentrations of chromium, copper, lead and zinc in effluents can be reduced from initial concentration of 100.0 mg/L to 0.08, 0.14, 0.03 and 0.45 mg/L, respectively. In hydroxide precipitation process, the addition of coagulants such as alum, iron salts, and organic polymers can enhance the removal of heavy metals from wastewater. Employed chemical coagulation and precipitation by lime to treat synthetic wastewater consists of Zn, Cd, Mn and Mg at the concentration of 450, 150, 1085 and 3154 mg/L (Chareerntanyarak, 1999).

Limitation of hydroxide precipitation generates large volumes of relatively low density sludge, which can cause dewatering and disposal problems. Secondly, some metal hydroxides are amphoteric, and the mixed metals create a problem using hydroxide precipitation since the ideal pH for one metal may put another metal back into solution (Peters, & Shem, 1993).

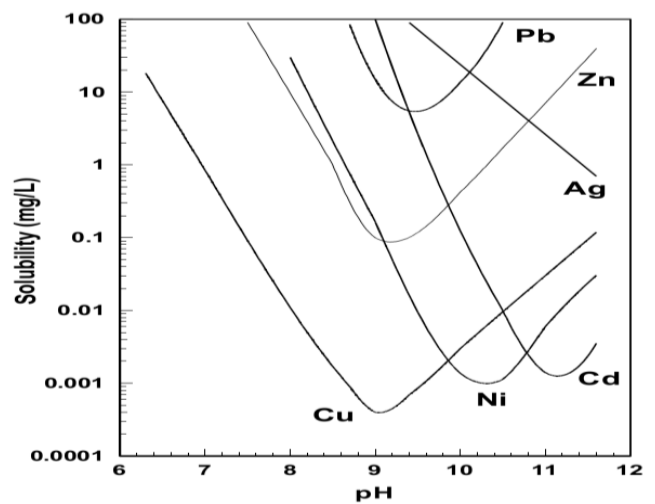


Fig: 1 Solubility of Metal Hydroxides as a Function of pH (Babel, & Kurniawan, 2003)

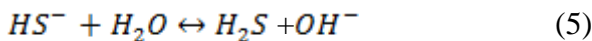
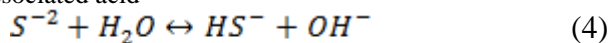
3.1.2. Sulfide Precipitation

Sulfide precipitation is also an effective process for the treatment of toxic heavy metals ions. One of the primary advantages of using sulfides is that the solubilities of the metal sulfide precipitates are dramatically lower than hydroxide precipitates and sulfide precipitates are not amphoteric. The sulfide precipitation process can achieve a high degree of metal removal over a broad pH range compared with hydroxide precipitation. Metal sulfide sludge's also exhibit better thickening and dewatering characteristics than the corresponding metal hydroxide sludge's.

Metal sulfides are typically very insoluble therefore metals can be precipitated by adding sulfide ions (S^{2-}). Metal sulfides have much lower solubility than the corresponding metal hydroxides, thus allowing lower residual metal concentrations in the treated wastewater. Hydrogen sulfide (H_2S) is a weak acid and dissociates in two steps according to



Sulfide salts undergo hydrolysis, partially reforming the dissociated acid



S^{2-} is not the dominating species until the pH is very high (~14). Hence, by adding a sulfide, salt equilibrium is generated resulting in only the partial formation of the S^{2-} ions actually used in precipitation. Sulfide precipitation is always conducted under alkaline conditions to promote sulfide ion formation. Sulfide precipitation is rather insensitive to the presence of chelating agents. Sulfide precipitates tend to form colloidal particles requiring the addition of coagulants to settle. However, sulfide sludge's are easier to dewater than hydroxide sludge's. Sulfide sludge's are more prone to oxidation resulting in resolubilization of the metals as sulfates. Evolution of H_2S is a potential hazard if the pH is not carefully maintained in the alkaline region (Kurniawan *et al.*, 2006).

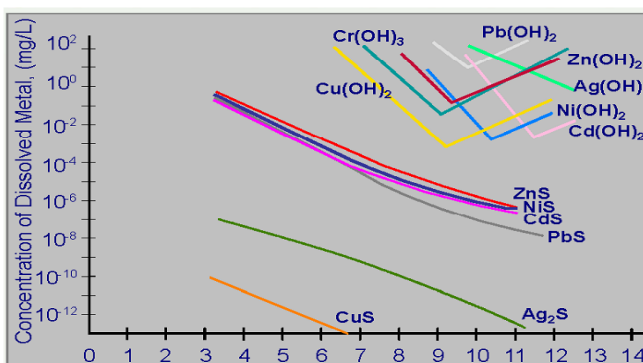


Fig: 2 Solubility of Metal Hydroxides and Sulfides as a Function of pH

(Wan Ngah & Hanafiah, 2008)

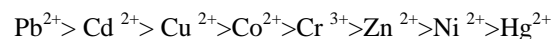
3.2 Low Cost Adsorbents

Adsorption is as an effective and economic method for heavy metal wastewater treatment. The adsorption process offers flexibility in design and operation. Many cases will produce high-quality treated effluent. In addition, because adsorption is sometimes reversible, adsorbents can be regenerated by suitable desorption process.

Low Cost Adsorbents: - Activated carbon is the most popular and widely used adsorbent in wastewater treatment applications throughout the world. Activated carbon is an expensive so now days, the depleted source of commercial coal-based AC results in the increase of price. Resulting of this we need to search some alternative low-cost adsorbents for heavy metal removal from contaminated water such as chitosan, zeolites, and other adsorbents, which have high adsorption capacity and are locally available (Chen *et al.*, 2006).

3.2.1 Zeolites

Basically zeolites are naturally occurring crystalline aluminosilicates consisting of a framework of tetrahedral molecules linked with each other by shared oxygen atoms. Natural zeolites have gained a significant interest among scientists due to their ion-exchange capability to preferentially remove unwanted heavy metals such as strontium and cesium. This unique property makes zeolites favorable for wastewater treatment. The price of zeolites itself is considered very cheap about US\$ 0.03–0.12/kg (Barakat, 2011). Zeolites consist of a wide variety of species such as clinoptilolite and chabazite. Clinoptilolite is most abundant in nature and is readily available from more than 40 natural zeolites species. Among the most frequently studied natural zeolites, clinoptilolite was shown to have high selectivity for certain heavy metal ions such as Pb^{2+} , Cd^{2+} , Zn^{2+} , and Cu^{2+} . The selectivity of the series of the heavy metals studied was determined to be as follows:



It was indicated that clinoptilolite is more selective for Pb^{2+} , but Cd^{2+} is also exchanged at satisfactory level. It was also reported that conditioning of zeolites with NaOH solution improved the removal efficiency. Chabazite and clinoptilolite treated with sodium hydroxide performed best with Pb^{2+} and Cd^{2+} exchange capacity exceeding 100 mg/g. In a further study, the removal performance of clinoptilolite and chabazite was compared. The two zeolites were evaluated with respect to their performance for treating effluents contaminated with Pb^{2+} , Cd^{2+} , Cu^{2+} , Zn^{2+} , Ni^{2+} , and Co^{2+} . It was reported that both the zeolites exhibited 100% removal efficiency at the metal concentration of 10 mg/l. It was also found that clinoptilolite and chabazite exhibited different selectivity for all metals studied except Pb^{2+} , for which both performed exceptionally well (Aklil *et al.*, 2004).

3.2.2 Fly Ash

Fly ash, an industrial solid waste of thermal power plants located in India, is one of the cheapest adsorbents having excellent removal capabilities for heavy metals such as copper ions. It was reported that an adsorption capacity of 1.39 mg of Cu^{2+} /g was achieved by fly ash at pH of 8.0. It was also found that the adsorption capacity increases with an increase in temperature. Other studies have been conducted to

show the effectiveness of fly ash on the removal of Cr^{6+} from aqueous solution using a homogenous mixture of fly ash and wollastonite (1:1). It was reported that an adsorption capacity of 2.92 mg of Cr^{6+} /g could be achieved at pH of 2.0. The adsorption process followed Langmuir model of isotherm. This mixed adsorbent performed better than fly ash–China clay, where the maximum adsorption capacity was found to be 0.31 mg of Cr^{6+} /g at pH of 2.0. This difference could be due to the fact that the adsorptive force between adsorbate and mixture (fly ash–wollastonite) is stronger than that of the other one (fly ash–China clay and adsorbate) so that Cr^{6+} is adsorbed more effectively. The adsorption of mercury using fly ash was carried out. It was reported that the maximum adsorption capacity of 2.82 mg of Hg^{2+} /g took place at a pH range of 3.5–4.5 and that adsorption followed the Freundlich model (Gupta *et al.*, 2003).

3.2.3 Coal

The removal of Cd^{2+} using Giridih coal (GC) was intensively investigated. It was reported that an adsorption capacity of 0.91 mg of Cd^{2+} /g GC was achieved. It was also found that adsorption followed Freundlich isotherm and that it decreased beyond pH 10 due to the formation of soluble hydroxy complexes. A similar study for Hg^{2+} adsorption using Giridih bituminous coal (GBC) was also conducted. It was noted that chemical pretreatment for bituminous coal with nitric acid significantly enhanced mercury sorption to a level higher than that exhibited by activated carbon in terms of initial rate of sorption and adsorption capacity. It was also reported that an adsorption capacity of 10 mg of Hg^{2+} /g was observed at a pH range of 7.0–8.5. (Wan Ngah & Hanafiah, 2008).

3.2.4 Activated carbon (AC)

Based on its size and shape, there are four types of activated carbon: powder (PAC), granular (GAC), fibrous (ACF), and cloth (ACC). Activated carbon has its specific application as well as inherent advantages and disadvantages in wastewater treatment depend on its quality (Kurniawan, 2006). It was observed that the adsorption of $\text{Cu}(\text{II})$ ions by granular activated carbon (GAC) from synthetic solution at pH 4.0, removed 93% of 10 mg/L. The results were lower than that of GAC type Filtrasorb 400, for $\text{Cr}(\text{VI})$ removal from simulated wastewater. They reported that the maximum metal adsorption capacity of 145 mg/g was achieved at pH ranging from 2.5 to 3.0. The adsorption of $\text{Cd}(\text{II})$ ions from synthetic solution using GAC type Filtrasorb 400 was investigated. The metal adsorption capacity of GAC was 8 mg/g at pH 8.0. This result was slightly higher than GAC type Filtrasorb 200 for $\text{Cu}(\text{II})$ removal with an adsorption capacity of 6.10 mg/g, indicating that the initial concentration of adsorbate plays major roles in determining the extent of the adsorption capacity of an adsorbent. For $\text{Zn}(\text{II})$ removal, the adsorption capacity of GAC type C was significantly higher than that of GAC type Filtrasorb (Kadirvelu *et al.*, 2001). To improve its removal performance on $\text{Cr}(\text{III})$ ions, the surface of GAC was chemically modified with nitric acid. The adsorption capacity on the oxidized carbon for $\text{Cr}(\text{III})$ was enhanced three times to 30 mg/g. This could be due to the greater negative charge on the surface of oxidized GAC compared to the non-

oxidized material. Due to electrostatic attraction between the $\text{Cr}(\text{III})$ ions and the negatively-charged surface, more adsorption of $\text{Cr}(\text{III})$ ions might occur on the carbon surface, resulting in higher metal uptake by the adsorbent. It also found that electrostatic attraction played a major role in metal adsorption on the surface of the carbon. Overall, chemical modification of activated carbon can improve its removal of heavy metal. Among the various types of activated carbon presented, GAC type Filtrasorb 400 and HNO_3 -oxidized activated carbon fiber (ACF) stand out high metal removal with adsorption capacities of 145 mg of $\text{Cr}(\text{VI})$ /g and 146 mg of $\text{Cd}(\text{II})$ /g, respectively. The results were lower than those of adsorbent derived from agricultural waste such as hazelnut shell activated carbon ($\text{Cr}(\text{VI})$: 170 mg/g) and chemically modified soybean hull ($\text{Cu}(\text{II})$: 154.9 mg/g). It is interesting to note that activated carbon performs effectively in an acidic pH range of 2.5–7.0 and has the ability to treat inorganic effluent with metal concentration ranging from 10 to 1000 mg/L (Salamat *et al.*, 2011).

3.3 Coagulation and Flocculation

Coagulation and flocculation are an essential part of drinking water treatment as well as waste water treatment. Coagulation is the chemical reaction which occurs when a chemical or coagulant is added to the water. The coagulation encourages the colloidal material in the water to join together into small aggregates called ‘‘flocs’’. Suspended matter is then attracted to these flocs. Flocculation is a slow gentle mixing of the water to encourage the flocs to form and grow to a size which will easily settle out. The effects of initial pH and turbidity, alum and pre ozonation doses, and flocculation time for the removal of dissolved organic matter during alum coagulation are important factors. The optimization of these factors may influence the process efficiency (Wang *et al.*, 2007). Coagulation-flocculation treatments are done by adding coagulant and auxiliary coagulant viz. ferum chloride, aluminium sulphate and polychlorinated aluminium are commonly used as coagulant. Polymer coagulant is used as auxiliary coagulant. The coagulation - flocculation process is usually used for treating fresh locate and it is applied as a pre-treatment before biological treatment. It is used to remove heavy metal and non-biodegradable organic compounds from landfill leachate. Coagulation and flocculations are useful because the flocculated particles can reduce fouling by producing more permeable deposits has been made to study the treatability of printing ink wastewater generated from an Indian currency printing press using coagulation-flocculation process (Nandy *et al.*, 2003). Poly-aluminium chloride (PAC) is most efficient coagulant, achieving removals of colour, suspended solids (SS). Biochemical oxygen demand (COD) of 95.9-96.5%, 96.5-97.0%, 61.3-65.8% and 54.8-61.8%, respectively at an optimum concentration of 1500 mg L⁻¹ other coagulants such as ferrous sulphate, ferric chloride and aluminium sulphate did not show substantial remove colour, BOD and COD except suspended solids in comparison to the performance of PAC has been done by the viability of recycling waste plastic cups for synthesizing polysterene sulfonate which was used as an auxiliary agent of coagulation flocculation and floatation in water and waste water treatment (Lendim *et al.*, 2006).

3.4 Membrane Filtration

Membrane filtration has received considerable attention for the treatment of inorganic effluent since it is capable of removing not only suspended solid and organic compounds, but also inorganic contaminants such as heavy metals. Depending on the size of the particle that can be retained, various types of membrane filtration such as ultra-filtration, nano-filtration, electro-dialysis and reverse osmosis can be employed for heavy metal removal from waste water. Unique specialist enables UF to allow the passage of water and low molecular weight solutes, while retaining the macromolecules which have a size larger than the pore size of the membrane. The main disadvantages of this process are the generation of sludge (Wingenfeldar *et al.*, 2005).

3.4.1 Reverse osmosis

The reverse osmosis process depends upon a semi-permeable membrane through which pressurized water is forced reverse osmosis, simply stated, is the opposite of the natural osmosis process of water. Osmosis is the name for the tendency of water to migrate from a weaker saline solution to a stronger saline solution, gradually equalizing the saline composition of each solution when a semi-permeable membrane separates the two solutions. In reverse osmosis water is forced to move from a stronger saline solution to a weaker solution again through a semi-permeable membrane. Because molecules of salt are physically larger than water molecules, the membrane blocks the passage of salt particles. The end result is desalinated water on one side of the membrane and a highly concentrated, saline solution of water on the other side (Barakat, 2011). The disadvantages of this method are that it is expensive (Ahalya 2003). Reverse osmosis and nano-filtration technologies can be used for the treatment of wastewater containing copper and cadmium ions. High removal efficiency of the heavy metals could be achieved by RO process. Nano-filtration, however was capable of removing more than 90% of the copper ions existing in the feed water (Kajitvichyanukul *et al.*, 2006).

3.4.2 Ultra-filtration

Ultra-filtration is a separation process using membranes with pore sizes in the range of 0.1 to .001 micron. Ultra-filtration will remove high molecular weight substances, colloidal materials and organic and inorganic polymeric molecules. These unique specialties enable UF to allow the passage of water and low-molecular weight solutes, while retaining the macromolecules, which have a size larger than the pore size of the membrane. It is a pressure-driven purification process in which water and low molecular weight substances permeate a membrane while particles, colloids, and macromolecules are retained. The primary removal mechanism is size exclusion, although the electrical charge and surface chemistry of the particles or membrane may affect the purification efficiency (Ahalya *et al.*, 2003).

3.4.3 Electro-dialysis

Electro-dialysis (ED) is a membrane separation in which ionized species in the solution are passed through an ion exchange membrane by applying an electric potential. The membranes are thin sheets of plastic materials with either anionic or cationic characteristics. When a solution

containing ionic species passes through the cell compartments, the anions migrate toward the anode and the cations toward the cathode, crossing the anion exchange and cation-exchange membranes (Chen *et al.*, 2004). The principles of electro-dialysis evaluated the performance of the ion exchange membranes for the electro-dialysis of Ni(II) and Co(II) ions from a synthetic solution. The process makes use of titanium as a working electrode, which is stable, energy efficient and can treat variety of effluents. In their work they made an attempt to present a detailed view of the widely adopted treatment methods and possible clean alternative to the conventional removal processes. This technique can also be employed for other heavy metal ions, viz; Cr, Cd, Hg, etc. The performance of electrocoagulation with aluminum electrodes can be used for simultaneous removal of nickel, copper, zinc and chromium from synthetic aqueous aliquot solutions. Best removal capacity for all studied metals was achieved in the pH range 4 to 8. Mixed solutions containing the same concentrations of all metals i.e. 75, 150 and 300 mg/L were tested. Three metals i.e. nickel, copper and zinc showed similar removal rates. They were completely removed in 20, 40 and 50 minutes respectively, while for the corresponding complete removal of chromium 40, 60 and 80 minutes were needed. Increased current density accelerated the electro-coagulation process, however, on cost of higher energy consumption. The experimentation on electro-treatment of a high strength industrial lead frame nickel-plating waste-water was carried out with newly designed electro-deposition reactor by (Chen *et al.*, 2011). They circulated electrolyte rapidly past the anode and cathode at a higher flow rate, allowing for improvements in efficiency and recovery, and then nickel electrodeposited on the surface of cathode. They observed that the pH decreased during the electro-treatment. The reason, they found for this was the production of H⁺ on the anode surface, and the lower current density was accompanied with the higher current efficiency. In this study, the optimum pH value was found in the range of 2-2.5.

Table 1: The main advantages and disadvantages of the various physic-chemical methods

| Treatment method | Advantages | Disadvantages | References |
|--------------------------------|--|---|---|
| Chemical precipitation | Low capital cost, simple operation | Sludge generation, extra operational cost for sludge disposal | Kajitvichy anukula <i>et al.</i> , (2006) |
| Adsorption with new adsorbents | Low-cost, easy operating conditions, having wide pH range, high metal-binding capacities | Low selectivity, production of waste products. | Babel and kurniawan (2003); Aklil <i>et al.</i> ,(2004) |
| Membrane filtration | Small space requirement, low pressure, high separation selectivity | High operational cost due to membrane fouling . | Kurniawan <i>et al.</i> , (2006) |
| Electro-dialysis | High separation selectivity | High operational cost due to membrane fouling and energy consumption. | Mohammad <i>et al.</i> ,(2005) |
| Photocatalysis | Removal of metals and organic pollutant simultaneously, less harmful by-products | Long duration time, limited application | Barakar <i>et al.</i> ,(2004) |

IV. CONCLUSION

Hazardous heavy metal pollution of wastewater is one of the most important environmental problems throughout the world. To meet the increased more and more stringent environmental regulations, a wide range of treatment technologies such as chemical precipitation, coagulation, flocculation, ion-exchange and membrane filtration, have been developed for heavy metal removal from wastewater. It is evident from the literature survey that ion-exchange, adsorption and membrane filtration are the most frequently studied for the treatment of heavy metal wastewater. Ion-exchange processes have been widely used to remove metals from wastewater. Adsorption by low-cost adsorbents is recognized as an effective and economic method for low concentration heavy metal wastewater treatment as an alternative AC. Membrane filtration technology can remove heavy metal ions with high efficiency.

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