

Selective Separation of Iron & Chromium from acidic waste water: - A Review

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Abstract- Heavy metal pollution has become one of the most serious environmental problems today. There are several acidic waste water from chemical process industries which consist of heavy metals. The treatment of heavy metals is of special concern due to their recalcitrance and persistence in the environment. One of the waste water from process industries has been selected to separate selectively iron and chromium from acidic wastewater. In recent years, various methods for heavy metal removal from wastewater have been extensively studied. The concentration of both metals are in range of 500-600 ppm first precipitation of iron and chromium will be evaluated to reduce the concentration. After maximum removal reactive extraction will be applied to separate metals. Design of experiments will be applied for metals selectively. This waste water treatment has not found in literature as per our findings. It is applied first time as per methodology explained. This paper reviews the current methods that have been used to treat heavy metal wastewater and evaluates these techniques. These technologies include chemical precipitation, ion-exchange, adsorption, membrane filtration, coagulation flocculation, flotation and electrochemical methods. It is evident from the literature survey articles that ion-exchange, adsorption and membrane filtration are the most frequently studied for the treatment of heavy metal wastewater.

Index Terms- pH meter, Reagents, Experiment setup, Heavy metal wastewater Treatment technology Review.

1. INTRODUCTION

Heavy metal pollution has become one of the most serious environmental problems today. The treatment of heavy metals is of special concern due to their recalcitrance and persistence in the environment. In recent years, various methods for heavy metal removal from wastewater have been extensively studied.

In this reviews the current methods that have been used to treat heavy metal wastewater and evaluates these techniques. These technologies include chemical precipitation, and another methods likes (ion-exchange, adsorption, membrane filtration, coagulation flocculation, flotation and electrochemical). If the most frequently studied for the treatment of heavy metal wastewater.

Heavy metals are elements having atomic weights between 63.5 and 200.6, and a specific gravity greater than 5.0 (Srivastava and Majumder, 2008). With the rapid development of 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 increasingly, 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 treatment of industrial wastewaters include zinc, copper, nickel, mercury, cadmium, lead and chromium. 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 (Oyaro et al., 2007). Copper does essential work in animal metabolism. But the excessive ingestion of copper brings about serious toxicological concerns, such as vomiting, cramps, convulsions, or even death (Paulino et al., 2006). Nickel exceeding its critical level might bring about serious lung and kidney problems aside from gastrointestinal distress, pulmonary fibrosis and skin dermatitis (Borba et al., 2006). And it is known that

nickel is human carcinogen. Mercury is a neurotoxin that can cause damage to the central nervous system. High concentrations of mercury cause impairment of pulmonary and kidney function, chest pain and dyspnoea (Namasivayam and Kadirvelu, 1999). The classic example of mercury poisoning is Minamata Bay. Cadmium has been classified by U.S. Environmental Protection Agency as a probable human carcinogen. Cadmium exposes human health to severe risks. Chronic exposure of cadmium results in kidney dysfunction and high levels of exposure will result in death. Lead can cause central nervous system damage. Lead can also damage the kidney, liver and reproductive system, basic cellular processes and brain functions. The toxic symptoms are anemia, insomnia, headache, dizziness, irritability, weakness of muscles, hallucination and renal damages (Naseem and Tahir, 2001). Chromium exists in the aquatic environment mainly in two states: Cr(III) and Cr(VI). In general, Cr(VI) is more toxic than Cr(III). Cr(VI) affects human physiology, accumulates in the food chain and causes severe health problems ranging from simple skin irritation to lung carcinoma (Khezami and Capart, 2005). Faced with more and more stringent regulations, nowadays heavy metals are the environmental priority pollutants and are becoming one of the most serious environmental problems. So these toxic heavy metals should be removed from the wastewater to protect the people and the environment. Many methods that are being used to remove heavy metal ions include chemical precipitation, ion-exchange, adsorption, membrane filtration, electrochemical treatment technologies, etc. The present review article deals with the current techniques for the removal of heavy metal ions from wastewater.

1.1 Separation of Fe(III) & Cr(III) From acidic waste water various methods uses

- (i) Chemical Precipitation
- (ii) Ion-exchange
- (iii) Adsorption
- (iv) Membrane filtration
- (v) Coagulation
- (vi) E-Flocculation
- (vii) Flotation
- (viii) Electrochemical
- (ix) Solvent Extraction

1.2 Theory of Chemical Precipitation and Efficiency
Three theories have been profounded to explain the effects and efficiency of chemical precipitation.

The first theory uses the fact that heavy metal salts when treated with alkaline substances, form heavy voluminous precipitates which carry down true and colloidal suspensions by means of mechanical entrapment. Salts of iron, aluminium and zinc fall into this classification.

The second theory is electronic in nature. It has been demonstrated that colloidal particles possess an electric charge. Since these charges are alike, the particles repel each other and thus tend to remain in suspension. If a colloidal particle with an opposite charge is added, the charges neutralize and settling of the particles is effected. This explains the efficiency of the multivalent ions and why ferric salts are more efficient than ferrous salts. Clay suspensions are also claimed to exert, a charge neutralizing effect.

The third theory pertaining to the final theoretical effect is largely physical. Insoluble substances which have a large particle surface area can effectively absorb colloids; they can also act as nuclei for the initiation of precipitation. Activated charcoal is a material with this type of action.

1.3 Hydroxide Precipitation

The most widely used chemical precipitation technique is hydroxide precipitation due to its relative simplicity, low cost and ease of pH control (Huisman et al., 2006). The solubilities of the various metal hydroxides are minimized in the pH range of 8.0 to 11.0. The metal hydroxides can be removed by flocculation and sedimentation.

A variety of hydroxides has been used to precipitate metals from wastewater, based on the low cost and ease of handling, lime is the preferred choice of base used in hydroxide precipitation at industrial settings (Baltpurvins et al., 1997) (Table 1). Hydroxide precipitation process using Ca(OH)_2 and NaOH in removing Cu(II) and Cr(VI) ions from wastewater was evaluated by Mirbagheri and 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.

The concentrations of chromium, in effluents can be reduced from initial concentration of 100.0 mg/L to 0.08 mg/L. 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. Charemtanyarak (1999) employed chemical coagulation and precipitation by lime to treat synthetic wastewater consisting of Zn, Cd, Mn and Mg at the concentration of 450, 150, 1085 and 3154 mg/L, respectively.

He found that the optimum pH was more than 9.5 and the treated wastewater could meet the Wastewater Standard of the Ministry of Industry. Moreover, if coagulant was added, the residual concentration of heavy metal can be decreased further. Although widely used, hydroxide precipitation also has some limitations. Firstly, hydroxide precipitation generates large volumes of relatively low density sludge, which can present dewatering and disposal problems (Kongsricharoern and Polprasert, 1995). 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. Thirdly, when complexing agents are in the wastewater, they will inhibit metal hydroxide precipitation.

1.4 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. And hence, the sulfide precipitation process can achieve a high degree of metal removal over a broad pH range compared with hydroxide precipitation. Metal sulfide sludges also exhibit better thickening and dewatering characteristics than the corresponding metal hydroxide sludges. Özverdi and Erdem (2006) The mechanism governing the metal removal processes was determined as chemical precipitation at low pH (<3) due to H₂S generation and adsorption at high pH (in the range of 3 to 6)

Hydrogen sulfide reacts with divalent soluble metals to form insoluble metal sulphides. Some attractive findings were reported by Kousi et al. (2007) who

developed an upflow fixed-bed SRB to monitor for the treatment of zinc-bearing wastewater. They found that the reactor has a considerable capacity of completely reducing sulfates for initial concentrations up to 6000 mg/L, completely removing soluble zinc for initial concentrations up to 400 mg/L and completely removing TOC for initial concentrations up to 1500 mg/L. The possibility of using SRB for the treatment of an acid mine drainage was also studied (Alvarez et al., 2007). However, there are potential dangers in the use of sulfide precipitation process. As we know, heavy metal ions often in acid conditions and sulfide precipitants in acidic conditions can result in the evolution of toxic H₂S fumes. It is essential that this precipitation process be performed in a neutral or basic medium. Moreover, metal sulfide precipitation tends to form colloidal precipitates that cause some separation problems in either settling or filtration processes.

1.5 Chemical precipitation combined with other methods

Chemical precipitation has been shown to be successful in combination with other methods. González-Muñoz et al. (2006) reported sulfide precipitation to reuse and recover heavy metal ions and employed nanofiltration as a second step. Results indicated sulfide precipitation was successful in reducing the metal content and nanofiltration yielded solutions capable to being directly reused in the plant. Ghosh et al. (in press) used electro-Fenton process and chemical precipitation to treat rayon industry wastewater to reduce its COD (2400 mg/L) and Zn²⁺ (32 mg/L). Results revealed that approximately 88% COD was reduced using electro-Fenton method and zinc removal (99 to 99.3%) was attained in the range of pH 9 to 10 using lime precipitation. There are some reports on chemical precipitation in combination with ion-exchange treatments. Papadopoulos et al. (2004) reported using ion-exchange processes individually and then combining with chemical precipitation in removing nickel from wastewater streams from a rinse bath of aluminum parts. They found that the individual application of ion exchange led to the removal of nickel up to 74.8%, while using the combination of ion exchange and precipitation processes, higher removal from 94.2% to 98.3% was obtained. Besides, treating acid mine water by the precipitation of heavy metals with

lime and sulfides, followed by ion exchange was also reported (Feng et al., 2000).

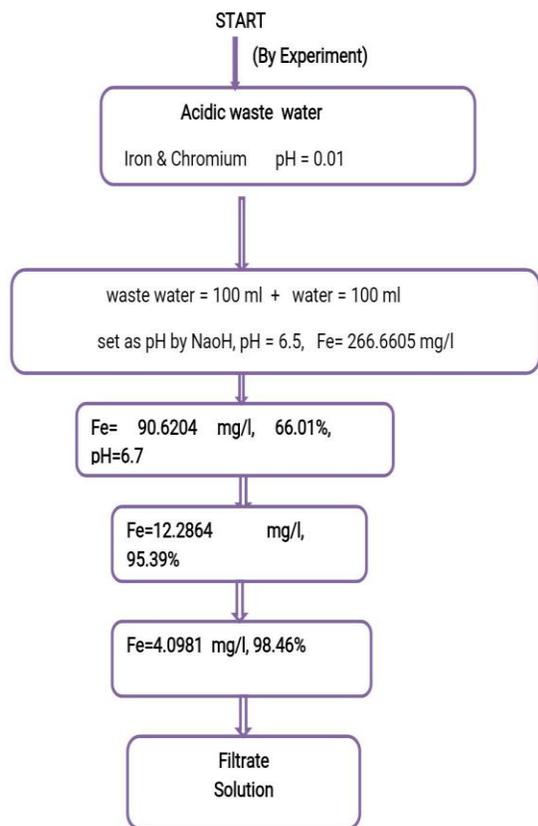
1.6 Different Reagents

Sr. No.	Reagent	Material
1	Na ₂ CO ₃	Ores of Sb, As, Cr, Fe, Mo, V, Zr, sulphides, pyrites etc
2	Na ₂ O ₂	Ores of Sb, As, Cr, Mo, Ni, V, Sn etc. in sulphide for sulphur determination
3	NaOH, KOH	Oxidized Sb ore, ores of Cr, Sn, Zn, Zr, sulphides and sulphates etc
4	KHSO ₄ , K ₂ S ₂ O ₇	Ores of Al, Sb, Cu, Cr, Co, Fe, Mn, Ni, Rh, Ta, Ti, W etc
5	Na ₂ CO ₃ & K ₂ CO ₃	Silicates of Al, Fe, F, N, Se, Te, etc.
6	Na ₂ CO ₃	Silicates of Al, Fe, Ca, Cr etc, halides of Ag, sulphates of Ba & Pb.

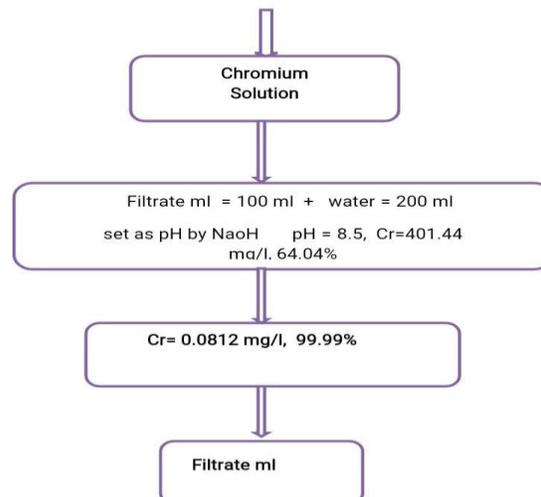
Different Reagents

2 EXPERIMENT PROCEDURES

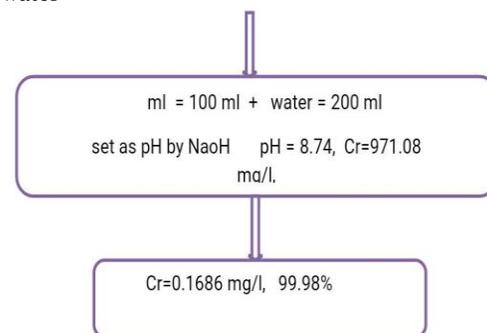
Part 1 Fe(III) Separation from acidic Waste water



Part 2 Cr(III) Separation from Fe(III) Filtrate after ml



Part 3 Cr(III) Separation from initial acidic waste water



- if three parts separation of Fe(III) & Cr(III) from acidic waste water.
- First of Fe(III) separate after Cr(III) separate .
- Sample Check for AAS

2.2. Ion exchange

Ion-exchange processes have been widely used to remove heavy metals from wastewater due to their many advantages, such as high treatment capacity, high removal efficiency and fast kinetics (Kang et al., 2004). Ion-exchange resin, either synthetic or natural solid resin, has the specific ability to exchange its cations with the metals in the wastewater. Among the materials used in ion-exchange processes, synthetic resins are commonly preferred as they are effective to nearly remove the heavy metals from the solution (Alyüz and Veli, 2009). The most common cation exchangers are strongly acidic resins with sulfonic acid groups (-SO₃H) and weakly acid resins with carboxylic acid groups (-COOH). Hydrogen ions in the sulfonic group or carboxylic group of the resin can serve as exchangeable ions with metal cations. As the solution containing heavy metal passes

through the cations column, metal ions are exchanged for the hydrogen ions on the resin with the following ion-exchange process:

The uptake of heavy metal ions by ion-exchange resins is rather affected by certain variables such as pH, temperature, initial metal concentration and contact time (Gode and Pehlivan, 2006). Ionic charge also plays an important role in ion-exchange process. The influence of ionic charge on the removal of Ce^{4+} , Fe^{3+} and Pb^{2+} from aqueous systems by cation-exchange resin purolite C100 was tested by Abo-Farha et al. (2009). They found that the metal ions adsorption sequence can be given as $Ce^{4+} > Fe^{3+} > Pb^{2+}$. Similar results for Co^{2+} , Ni^{2+} and Cr^{3+} on an Amberlite IRN-77 cationexchange resin were previously obtained by Kang et al. (2004).

Besides synthetic resins, natural zeolites, naturally occurring silicate minerals, have been widely used to remove heavy metal from aqueous solutions due to their low cost and high abundance. Many researchers have demonstrated that zeolites exhibit good cation-exchange capacities for heavy metal ions under different experimental conditions (Motsi et al., 2009; Ostroski et al., 2009; Taffarel and Rubio, 2009). Clinoptilolite is one of the most frequently studied natural zeolites that have received extensive attention due to its selectivity for heavy metals. Table 2 shows the efficiency of clinoptilolite for removing heavy metal ions.

Though there are many reports on the use of zeolites and montmorillonites as ion-exchange resin to remove heavy metal, they are limited at present compared with the synthetic resins. And the application of zeolites is on the laboratory experiments scale. More work is needed for the application of zeolites at an industrial scale.

2.3. Adsorption

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

2.3.1. Activated carbon adsorbents

Activated carbon (AC) adsorbents are widely used in the removal of heavy metal contaminants. Its

usefulness derives mainly from its large micropore and mesopore volumes and the resulting high surface area. A large number of researchers are studying the use of AC for removing heavy metals (Jusoh et al., 2007; Kang et al., 2008). Nowadays, the depleted source of commercial coal-based AC results in the increase of price. To make progress in heavy metals adsorption to AC without the expense of decline in the pollutants adsorption, additives and AC composite could be an option. Additives of alginate (Park et al., 2007), tannic acid (Üçer et al., 2006), magnesium (Yanagisawa et al., 2010), surfactants (Ahn et al., 2009) and AC composite could be effective adsorbents for heavy metals.

searching for alternative AC from abundant and inexpensive sources is of concern. Converting carbonaceous materials into AC for heavy metals remediation have been reported. Dias et al. (2007) reviewed the waste materials for AC preparation. Kongsuwan et al. (2009) explored the use of AC from eucalyptus bark in the binary component sorption of Cu^{2+} and Pb^{2+} .

The maximum sorption capacities for Cu^{2+} and Pb^{2+} were 0.45 and 0.53 mmol/g. A major mechanism for the uptake of both heavy metals was proven to be adsorption. Poultry litter to manufacture AC for treating heavy metal-contaminated water was explored by Guo et al. (2010). They revealed that poultry litter-based AC possessed significantly higher adsorption affinity and capacity for heavy metals than commercial AC derived from bituminous coal and coconut shell.

2.3.2. Carbon nanotubes adsorbents

Carbon nanotubes (CNTs) discovered by Iijima (1991) in 1991, have been widely studied for their excellent properties and applications.

As relatively new adsorbents, CNTs have been proven to possess great potential for removing heavy metal ions such as lead (Wang et al., 2007a; Kabbashi et al., 2009), cadmium (Kuo and Lin, 2009), chromium (Pillay et al., 2009), copper (Li et al., 2010), and nickel (Kandah and Meunier, 2007) from wastewater. The results of these studies show that CNTs are promising candidates for adsorption of heavy metal (Table 3). CNTs are divided into two types: (1) single-walled CNTs (SWCNTs) and (2) multi-walled CNTs (MWCNTs) (Odom et al., 1998). The mechanisms by which the metal ions are sorbed onto CNTs are very complicated and appear attributable to electrostatic attraction,

sorption-precipitation and chemical interaction between the metal ions and the surface functional groups of CNTs (Rao et al., 2007). The sorption capacities of metal ions by raw CNTs are very low but significantly increase after oxidized by HNO₃, NaClO and KMnO₄ solutions. Wang et al. (2007a) reported the adsorption of Pb (II) using acidified MWCNTs and found the oxygenous functional groups on MWCNTs play an important role in Pb(II) adsorption to form chemical complex adsorption, which accounts for 75.3% of all the Pb(II) adsorption capacity. Pillay et al. (2009) investigated the adsorption capabilities for the removal of parts per billion levels (ppb) of Cr(VI) by three adsorbents, namely AC, functionalized MWCNTs and unfunctionalised MWCNTs.

The unfunctionalised MWCNTs showed the highest adsorption capability with up to 98% of a 100 ppb Cr(VI) solution being adsorbed. Both functionalized and non-functionalised MWCNTs showed a superior adsorption capability to that of AC. Widespread usage of CNTs will eventually be discharged to the water environment and poses a risk to humans. To resolve this problem, an environmental friendly adsorbent, CNTs immobilized by calcium alginate (CNTs/CA) was prepared and tested to remove copper (Li et al., 2010). The copper adsorption capacity by CNTs/CA can attain 67.9 mg/g at copper equilibrium concentration of 5 mg/L. 2.3.3. Low-cost adsorbents AC has been the most used adsorbent, nevertheless it is relatively expensive. Searching for low-cost and easily available adsorbents to remove heavy metal ions have become a main research focus. To date, hundreds of studies on the use of low-cost adsorbents have been published.

Agricultural wastes, industrial byproducts and wastes and natural substances have been studied as adsorbents for the heavy metal wastewater treatment. Several reviews are available that discuss the use of low-cost adsorbents for the treatment of heavy metals wastewater. Bhattacharyya and Gupta (2008) reviewed the adsorption of a few heavy metals on natural and modified kaolinite and montmorillonite. Sud et al. (2008) reviewed agricultural waste material as potential adsorbent for sequestering heavy metal ions from aqueous solutions. Wan Ngah and Hanafiah (2008) reviewed the removal of heavy metal ions from wastewater by chemically modified plantwastes as adsorbents. Babel and Kurniawan

(2003) reviewed the use of lowcost adsorbents for heavy metals uptake from contaminated water.

Researchers investigated industrial by-products such as lignin (Betancur et al., 2009; Reyes et al., 2009), diatomite (Sheng et al., 2009), clino-pyrrhotite (Lu et al., 2006), lignite (Mohan and Chander, 2006), aragonite shells (Kohler et al., 2007), natural zeolites (Apiratikul and Pavasant, 2008a), clay (Al-Jilil and Alsewailem, 2009), kaolinite (Gu and Evans, 2008) and peat (Liu et al., 2008a), etc. Jiang et al. (2010) investigated the kaolinite clay obtained from Longyan, China to remove heavy metal ions Pb(II), Cd(II), Ni(II) and Cu(II) from wastewater. The uptake is rapid with maximum adsorption being observed within 30 min. And kaolinite clay was used for removing metal ions from real wastewater containing Pb (II), where its concentration was reduced from 160.00 mg/L to 8.00 mg/L. Agoubordea and Navia (2009) reported zinc and copper removal from aqueous solutions using brine sediments, sawdust and the mixture of both materials. The maximum adsorption capacity was found to be 4.85, 2.58 and 5.59 mg/g for zinc and 4.69, 2.31 and 4.33 mg/g for copper, respectively, using an adsorbent/ solution ratio of 1/40. 2.3.4. Bioadsorbents Biosorption of heavy metals from aqueous solutions is a relatively new process that has been confirmed a very promising process in the removal of heavy metal contaminants. The major advantages of biosorption are its high effectiveness in reducing the heavy metal ions and the use of inexpensive biosorbents. Biosorption processes are particularly suitable to treat dilute heavy metal wastewater. Typical biosorbents can be derived from three sources as follows (Apiratikul and Pavasant 2008b).

(1) non-living biomass such as bark, lignin, shrimp, krill, squid, crab shell, etc.; (2) algal biomass; (3) microbial biomass, e.g. bacteria, fungi and yeast. Different forms of inexpensive, non-living plant material such as potato peels (Aman et al., 2008), sawdust (Kaczala et al., 2009), black gram husk (Saeed et al., 2005), eggshell (Jai et al., 2007), seed shells (Amudaa et al., 2009), coffee husks (Oliveira et al., 2008), sugar-beet pectin gels (Mata et al., 2009) and citrus peels (Schiewer and Patil, 2008), etc., have been widely investigated as potential biosorbents for heavy metals. Algae, a renewable natural biomass proliferates ubiquitously and abundantly in the littoral zones of world has attracted

the attention of many investigators as organisms to be tested and used as new adsorbents to adsorb metal ions. Several advantages in applying algae as biosorbent include the wide availability, low cost, high metal sorption capacity and reasonably regular quality (Apiratikul and Pavasant, 2008b). There are a large number of research works on the metal biosorption using algal biomass. Examples of recent reports include the biosorption of Cu^{2+} and Zn^{2+} using dried marine green macroalga *Chaetomorpha linum* (Ajjabi and Chouba, 2009), the biosorption of Cu^{2+} , Cd^{2+} , Pb^{2+} , and Zn^{2+} using dried marine green macroalga *Caulerpa lentillifera* (Pavasant et al., 2006), the biosorption of chromium from wastewater using green alga *Ulva lactuca* (El-Sikaily et al., 2007), and the biosorption of lead (II) from wastewater by green algae *Cladophora fascicularis* (Deng et al., 2007). The biosorption of Cu^{2+} and Zn^{2+} by dried marine green macroalga (*C. linum*) was investigated by Ajjabi and Chouba (2009). At the optimum particle size (100e315 mm), biosorbent dosage (20 g/L) and initial solution pH 5, the dried alga produced maximum Cu^{2+} and Zn^{2+} uptake values of 1.46 and 1.97 mmol/g, respectively. Microbial removal of metal ions from wastewater has been indicated as being highly effective.

Biosorption of heavy metals in aqueous solutions by bacteria includes *Bacillus cereus* (Pan et al., 2007), *Escherichia coli* (Souiri et al., 2009; Quintelas et al., 2009), *Pseudomonas aeruginosa* (Gabr et al., 2008; Tuzen et al., 2008), etc. Fungi and yeasts are easy to grow, produce high yields of biomass and at the same time can be manipulated genetically and morphologically. Fungi biosorbents include *Aspergillus niger* (Amini et al., 2009; Tsekova et al., 2010), *Rhizopus arrhizus* (Aksu and Balibek, 2007; Bahadir et al., 2007), *Saccharomyces cerevisiae* (Chen and Wang, 2008; Cojocar et al., 2009), *Lentinus edodes* (Bayramoglu and Arica, 2008), etc. There are a number of reports involving removal of heavy metals using *Rhizopus* biomass. Bhainsa and D'Souza (2008) investigated the removal of copper ion using NaOH treated *Rhizopus oryzae* biomass in a batch reactor. The maximum copper loading capacity of the viable and pretreated biomass was 19.4 and 43.7 mg/g, respectively. Biosorbents were characteristic of broad sources, low-cost and rapid adsorption. Unfavorably, these researches were still in the theoretic and experimental phase. Moreover,

the separation of bio sorbents would be difficult after adsorption.

2.4. Membrane filtration

Membrane filtration technologies with different types of membranes show great promise for heavy metal removal for their high efficiency, easy operation and space saving. The membrane processes used to remove metals from the wastewater are ultrafiltration, reverse osmosis, Nano filtration and electro dialysis.

2.4.1. Ultrafiltration

Ultrafiltration (UF) is a membrane technique working at low transmembrane pressures for the removal of dissolved and colloidal material. Since the pore sizes of UF membranes are larger than dissolved metal ions in the form of hydrated ions or as low molecular weight complexes, these ions would pass easily through UF membranes. To obtain high removal efficiency of metal ions, the micellar enhanced ultrafiltration (MEUF) and polymer enhanced ultrafiltration (PEUF) was proposed. MEUF was first introduced by Scamehorn et al. in the 1980s for the removal of dissolved organic compounds and multivalent metal ions from aqueous streams (Landaburu-Aguirre et al., 2009). MEUF has been proven to be an effective separation technique to remove metal ions from wastewater (Table 4).

This separation technique is based on the addition of surfactants to wastewater. When the concentration of surfactants in aqueous solutions is beyond the critical micelle concentration (CMC), the surfactant molecules will aggregate into micelles that can bind metal ions to form large metal-surfactant structures. The micelles containing metal ions can be retained by a UF membrane with pore sizes smaller than micelle sizes, whereas the untrapped species readily pass through the UF membrane.

To obtain the highest retentions, surfactants of electric charge opposite to that of the ions to be removed have to be used. Sodium dodecyl sulfate (SDS), an anionic surfactant, is often selected for the effective removal of heavy metal ions in MEUF. Metal removal efficiency by MEUF depends on the characteristics and concentrations of the metals and surfactants, solution pH, ionic strength, and parameters related to membrane operation. Landaburu-Aguirre et al. (2009) investigated the removal of zinc from synthetic wastewater by MEUF

using SDS. They found that rejection coefficients up to 99% were achieved when the surfactant to metal molar ratio (S/M) was above 5. Sampera et al. (2009) used MEUF to remove Cd^{2+} , Cu^{2+} , Ni^{2+} , Pb^{2+} and Zn^{2+} from synthetic water using two anionic surfactants: SDS and linear alkylbenzene sulfonate (LAS) in a lab-scale membrane system. The molar concentration ratio of the surfactant to metal is higher than 5 in all the experiments. When the initial SDS concentration was below the CMC, metal retention higher than 90% was unexpectedly obtained, except for Ni^{2+} . Moreover, it was shown that complete removal of metal ions, except for Ni^{2+} , could be achieved at an LAS concentration below CMC. The retentate is the concentrated solution of surfactants and heavy metals retained by membrane.

Since the surfactant may account for a large portion of operating costs, it is essential to recover and reuse the surfactant as economically as feasible. And if the surfactant and heavy metals are not disposed, they will cause secondary pollution. Li et al. (2009) tested chelation followed by UF and acidification followed by UF for the separation of Cd^{2+} or Zn^{2+} from SDS micelles in simulated retentate solution of MEUF and the reuse of SDS. In the method using chelating agents, EDTA at pH 4.4 was the best for separating heavy metal ions (90.1% for Cd2p, 87.1% for Zn2p) and recovering SDS (65.5% for Cd^{2+} , 68.5% for Zn^{2+}). With the reclaimed SDS in MEUF, the removal efficiencies of heavy metal ions were 90.3% for Cd2p, 89.6% for Zn2p. In the method using acid agents, H_2SO_4 at pH 1.0 was the best for separating heavy metal ions (98.0% for Cd2p, 96.1% for Zn2p) and recovering SDS (58.1% for Cd2p, 54.3% for Zn2p). The efficiencies of reclaimed SDS were 88.1% for removing Cd2p and 87.8% for removing Zn2p in MEUF. PEUF has also been proposed as a feasible method to separate a great variety of metal ions from aqueous streams (Table 4).

PEUF uses water-soluble polymer to complex metallic ions and form a macromolecular, having a higher molecular weight than the molecular weight cut off of the membrane. The macromolecular will be retained when they are pumped through UF membrane. After that, retentate can be treated in order to recover metallic ions and to reuse polymeric agent. The main concern of the previous PEUF studies was to find suitable polymers to achieve

complexation with metal ions. Complexing agents such as polyacrylic acid (PAA)

(Labanda et al., 2009), polyethyleneimine (PEI) (Aroua et al., 2007; Molinari et al., 2008), diethylaminoethyl cellulose (Trivunac and Stevanovic, 2006) and humic acid (Kim et al., 2005), etc., have been proven to achieve selective separation and recovery of heavy metals with low energy requirements. The main parameters affecting PEUF are metal and polymer type, the ratio of metal to polymer, pH and existence of other metal ions in the solution. Molinari et al. (2008) used PEI as a polymer to study the complexation ultrafiltration process in the selective removal of Cu(II) from Ni(II) contained in aqueous media. Preliminary tests showed that optimal chemical conditions for Cu(II) and Ni(II) complexation by the PEI were $\text{pH} > 6.0$ and 8.0, respectively, and polymer/metal weight ratio of 3.0 and 6.0, respectively. Aroua et al. (2007) investigated the removal of chromium species from aqueous dilute solutions using PEUF process by three water-soluble polymers, namely chitosan, PEI and pectin. High rejections approaching 100% for Cr(III) were obtained at pH higher than 7 for the three tested polymers. The advantages of PEUF include high removal efficiency, high binding selectivity and highly concentrated metal concentrates for reuse, etc. There are a lot of publications in this topic, but it has not spread wide in the industry yet.

2.4.2. Reverse osmosis

The reverse osmosis (RO) process uses a semi-permeable membrane, allowing the fluid that is being purified to pass through it, while rejecting the contaminants. RO is one of the techniques able to remove a wide range of dissolved species from water. It accounts for more than 20% of the world's desalination capacity (Shahalam et al., 2002). RO is an increasingly popular wastewater treatment option in chemical and environmental engineering. Using appropriate RO systems to remove heavy metals have been investigated (Table 5), but these have yet to be widely applied. Cu^{2+} and Ni^{2+} ions were successfully removed by the RO process and the rejection efficiency of the two ions increased up to 99.5% by using Na_2EDTA (Mohsen-Nia et al., 2007). Dialynas and Diamadopoulos (2009) applied a pilot-scale membrane bioreactor system in combination with RO and they found heavy metal removal efficiencies

were very high. The major drawback of RO is the high power consumption due to the pumping pressures, and the restoration of the membranes.

2.4.3. Nanofiltration

Nanofiltration (NF) is the intermediate process between UF and RO. NF is a promising technology for the rejection of heavy metal ions such as nickel (Murthy and Chaudhari, 2008), chromium (Muthukrishnan and Guha, 2008), copper (Cséfalvay et al., 2009; Ahmad and Ooi, 2010) and arsenic (Nguyen et al., 2009; Figoli et al., 2010) from wastewater. NF process benefits from ease of operation, reliability and comparatively low energy consumption as well as high efficiency of pollutant removal (Erikson, 1988). Figoli et al. (2010) studied the removal of pentavalent arsenic from synthetic water by two commercial NF membrane (NF90 and N30F). They found that an increase of pH and a decrease of operating temperature and As feed concentration led to higher As removal for both membranes. Among the parameters affecting the As rejection, feed concentration plays a key role for the production of a permeate stream. In recent years, Murthy and Chaudhari devoted a lot in the removal of heavy metal ions using NF membrane. They reported the application of a thin-film composite polyamide NF membrane for the rejection of nickel ions from aqueous wastewater (Murthy and Chaudhari, 2008). The maximum observed rejection of nickel is found to be 98% and 92% for an initial feed concentration of 5 and 250 mg/L, respectively. And they investigated the binary heavy metals (cadmium and nickel) separation capability of a commercial NF membrane from aqueous solutions (Murthy and Chaudhari, 2009). The maximum observed solute rejection of nickel and cadmium ions is 98.94% and 82.69%, respectively, for an initial feed concentration of 5 mg/L. There are many reports on the removal of heavy metal by NF and RO membrane. Cséfalvay et al. (2009) used NF and RO to recover copper from process wastes. Liu et al. (2008b) studied the performance of different NF and RO membranes in treating the toxic metal effluent from metallurgical industry. They reported that the product water by both NF and RO desalination satisfied the State Reutilization Qualification, but NF would be more suitable for large-scale industrial practice. Koseoglu and Kitis (2009) investigated the recovery

of silver from mining wastewaters using NF or RO after the silver is taken into solution as AgCN employing re-cyanidation and subsequent sedimentation and/or pre-filtration of wastewaters. Silver recoveries achieved by hybrid cyanidation and membrane separation were 29-59% and 54-62% for NF and RO membranes, respectively.

2.4.4. Electrodialysis

Electrodialysis (ED) is another membrane process for the separation of ions across charged membranes from one solution to another using an electric field as the driving force. In most ED processes, ion-exchange membranes are used. The membranes are actually of two basic types: cation-exchange and anion-exchange membranes. This process has been widely used for the production of drinking and process water from brackish water and seawater, treatment of industrial effluents, recovery of useful materials from effluents and salt production (Sadrzadeha et al., 2009). ED has also proven a promising method in heavy metal wastewater treatment. Nataraj et al. (2007) performed a new working system to investigate the removal of hexavalent chromium ions using a built ED pilot plant comprising a set of ion-exchange membranes. Results were satisfactory in meeting the maximum contamination level of 0.1 mg/L for chromium. The effectiveness of ED for the separation of Cu and Fe and water recovery from solutions in copper electro-winning operations was studied by Cifuentes et al. (2009). They found that ED proved very effective in the removal of Cu and Fe from the working solution. Lambert et al. (2006) studied the separation of Cr(III) from sodium ion by ED using modified cation-exchange membranes. Mohammadi et al. (2004) investigated the effect of operating parameters on Pb²⁺ separation from wastewater using ED. The results showed that increasing voltage and temperature improved cell performance; however, the separation percentage decreased with an increasing flow rate. At concentrations of more than 500 mg/L, dependence of separation percentage on concentration diminished.

2.5. Coagulation and flocculation

Coagulation and flocculation followed by sedimentation and filtration is also employed to remove heavy metal from wastewaters. Coagulation

is the destabilization of colloids by neutralizing the forces that keep them apart. Many coagulants are widely used in the conventional wastewater treatment processes such as aluminium, ferrous sulfate and ferric chloride, resulting in the effective removal of wastewater particulates and impurities by charge neutralization of particles and by enmeshment of the impurities on the formed amorphous metal hydroxide precipitates. El Samrani et al. (2008) investigated the removal of heavy metal by coagulation of combined sewer overflow with two commercial coagulants, a ferric chloride solution and a polyaluminium chloride (PAC). They found excellent heavy metal elimination was achieved within a narrow range of coagulant around optimum coagulant concentrations.

Coagulation is one of the most important methods for wastewater treatment, but the main objects of coagulation are only the hydrophobic colloids and suspended particles. In order to remove both soluble heavy metal and insoluble substances efficiently by coagulation, sodium xanthogenate group was grafted to polyethyleneimine (Chang and Wang, 2007). This new kind of coagulant was an amphoteric polyelectrolyte. When the pH of water sample is lower, the colloidal substances with negative charges can be coagulated by it, but the cationic Ni^{2+} ion cannot be removed very well. When the pH of water sample is higher, the turbidity removal decreases, and the Ni^{2+} removal increases. Flocculation is the action of polymers to form bridges between the flocs and bind the particles into large agglomerates or clumps. Once suspended particles are flocculated into larger particles, they can usually be removed or separated by filtration, straining or floatation. Today many kinds of flocculants, such as PAC, polyferric sulfate (PFS) and polyacrylamide (PAM), are widely used in the treatment of wastewater, however, it is nearly impracticable to remove heavy metal very well from wastewater directly by these current flocculants. Macromolecule heavy metal flocculants is a new kind of flocculant. Chang et al. (2009b) prepared a macromolecule heavy metal flocculant mercaptoacetyl chitosan by reacting chitosan with mercaptoacetic acid. They reported that this new flocculant could not only remove turbidity, but also remove heavy metals in wastewater. Flocculants of Konjac-graft-poly (acrylamide)-co-sodium xanthate (Duan et al., 2010) and polyampholyte chitosan derivatives e N-carboxyethylated chitosans

(Bratskaya et al., 2009) were also used to remove heavy metals.

The research on flocculation by humic acid (HA) binding heavy metal is also investigated. The enhanced removal of heavy metal ions from solution, such as Pb^{2+} and Zn^{2+} , was studied by binding the ions to HA and then coagulating flocculating with the cationic polyelectrolyte polydiallyl dimethylammonium chloride (Poly-DADMAC) (Hankins et al., 2006). The removal of bound metal ions was found to increase with the extent of coagulation flocculation of the HA by PolyDADMAC. Generally, metal-HA complexes are removed from a solution by polyelectrolyte flocculation, followed by centrifugation or filtration. Recently, Tokuyama et al. (2010) proposed a flocculation technique using a thermo sensitive polymer to remove undesirable heavy metals and humic substances, and this technique is free from centrifugation and filtration. Besides, a new commercial tannin-based flocculants has been reported to remove Zn^{2+} , Ni^{2+} and Cu^{2+} by coagulation flocculation process (Heredia and Martín, 2009). Generally, coagulation flocculation can't treat the heavy metal wastewater completely (Chang and Wang, 2007). Therefore, coagulation flocculation must be followed by other treatment techniques. Plattes et al. (2007) employed precipitation, coagulation and flocculation processes using ferric chloride to remove tungsten from industrial wastewater. Tungsten removal was found to be most efficient (98e99%) in acidic conditions (pH < 6). Bojic et al. (2009) explored spontaneous reduction coagulation process using micro-alloyed aluminium composite in a laboratory semiflow system to treat model heavy metal wastewater. The residual concentrations of metals were at admissible levels after only 20 min of treatment.

2.6. Flotation

Flotation has nowadays found extensive use in wastewater treatment. Flotation has been employed to separate heavy metal from a liquid phase using bubble attachment, originated in mineral processing. Dissolved air flotation (DAF), ion flotation and precipitation flotation are the main flotation processes for the removal of metal ions from solution. DAF is to allow micro-bubbles of air to attach to the suspended particles in the water,

developing agglomerates with lower density than water, causing the flocs to rise through the water and accumulating at the surface where they can be removed as sludge (Lundh et al., 2000). DAF had been widely studied to remove heavy metal in 1990s (Waters, 1990; Tassel et al., 1997; Tessele et al., 1998). Ion flotation has been shown a promising method for the removal of heavy metal ions from wastewaters. The process of ion flotation is based on imparting the ionic metal species in wastewaters hydrophobic by use of surfactants and subsequent removal of these hydrophobic species by air bubbles (Polat and Erdogan, 2007). Yuan et al. (2008) investigated the potential of ion flotation to remove cadmium, lead and copper from dilute aqueous solution with a plant-derived biosurfactant tea saponin. The maximum removal of Pb^{2+} , Cu^{2+} and Cd^{2+} can reach 89.95%, 81.13% and 71.17%, respectively, when the ratio of collector to metal was 3:1. Polat and Erdogan (2007) implemented ion flotation to remove Cu^{2+} , Zn^{2+} , Cr^{3+} and Ag^{+} from wastewaters. SDS and hexadecyltrimethyl ammonium bromide were used as collectors. Ethanol and methyl isobutyl carbinol were used as frothers. Metal removal reached about 74% under optimum conditions at low pH. At basic pH it became as high as 90%, probably due to the contribution from the flotation of metal precipitates. Precipitate flotation process is another alternative of flotation method, based on the formation of precipitate and subsequent removal by attachment to air bubbles. Depending on the concentration of the metal solution, the precipitation may proceed via metal hydroxide formation or as a salt with a specific anion (sulfide, carbonate, etc.) (Capponi et al., 2006). The removal of Cr(III) by precipitate flotation from dilute aqueous solutions, using SDS as anionic collector and ethanol as frother was investigated at laboratory scale (Medina et al., 2005). The results showed that a 96.2% maximum removal was achieved at pH around 8.0.

2.7. Electrochemical treatment

Electrochemical methods involve the plating-out of metal ions on a cathode surface and can recover metals in the elemental metal state. Electrochemical wastewater technologies involve relatively large capital investment and the expensive electricity supply, so they haven't been widely applied.

However, with the stringent environmental regulations regarding the wastewater discharge, electrochemical technologies have regained their importance worldwide during the past two decades (Wang et al., 2007b). In this paper, the established technologies, electrocoagulation, electroflotation, and electrodeposition were examined. Electrocoagulation (EC) involves the generation of coagulants in situ by dissolving electrically either aluminum or iron ions from aluminum or iron electrodes (Chen, 2004). The metal ion generation takes place at the anode, and hydrogen gas is released from the cathode. The hydrogen gas can help to float the flocculated particles out of the water (Chen, 2004). Heidmann and Calmano (2008) studied the performance of an EC system with aluminium electrodes for removing Zn^{2+} , Cu^{2+} , Ni^{2+} , Ag^{+} and $Cr_2O_7^{2-}$. Initial concentrations from 50 mg/L to 5000 mg/L Zn, Cu, Ni and Ag did not influence the removal rates, whereas higher initial concentrations caused higher removal rates of Cr, Zn, Cu, Ni and Ag ions are

Table 1

Species	Initial metal conc.	Precipitant	Optimum pH	Removal efficiency (%)	Ref.
Zn^{2+}	32 mg/L	CaO	9-10	99-99.3	Choi et al., in press
$Cd^{2+}, Zn^{2+}, Cu^{2+}, Pb^{2+}$	100 mg/L	CaO	7-11	98.37-99.8	Chen et al., 2009
$Cu^{2+}, Zn^{2+}, Pb^{2+}$	0.018, 1.34, 2.3 mM	H ₂ S	3.0	100, >94, >92	Alvarez et al., 2007
Cu^{2+}	5363 mg/L	CaO and MgO	8.0	>99	Guo et al., 2006
Hg^{2+}	65.6, 188 µg/L	1,3-benzenediaminodithiocarbamate	4.7 and 6.4	>99.9	Blue et al., 2008
OLEFTA	25, 20, 100 mg/L	1,3-benzenediaminodithiocarbamate	3.0	90.8, 99.3, 99.6	Fu et al., 2007

Table 2

Species	Operation styles	Initial metal conc. (mg/L)	Optimum pH	Adsorption capacity (mg/g)	Removal efficiency (%)	Chitosan (g/L)	Ref.
Pb^{2+}	Fixed-bed and batch operation	2072	4.0	0.21-1	NA	20-40	Ingratato and Grigoriopolou, 2003
Pb^{2+}	Batch experiments	1036	4.0	NA	55	20	Ingratato et al., 2007
Ni^{2+}	Fixed-bed process	2000	NA	0.5-1.77	NA	50	Rodriguez-Suarez et al., 2002
Ni^{2+}	Batch experiments	25	7.0	0.11	93.6	15	Argum, 2008
Zn^{2+}	Batch experiments	65.4-654	5.0	2.237-0.15	100	25	Ahmadzadeh and Hejranfar, 2005
Pb^{2+}	Batch experiments	162.65-400	4.0	1.361, 1.372	NA	0.52-4.17	Berber-Mendoza et al., 2006

NA: not available.

Table 3

CNTs	Heavy metal	Q_m (mg/g)	Conditions	Ref.
Acidified MWNTs	Pb^{2+}	85	$[Pb^{2+}]_{initial} = 50$ mg/L with 6 acidified MWNTs	Wang et al., 2007a
MWNTs/iron oxide	Ni^{2+}, Sr^{2+}	$Ni^{2+}: 0.18$ $Sr^{2+}: NA$	$[Ni^{2+}]_{initial} = 6.0$ mg/L, $mV = 0.75$ g/L	Chen et al., 2009a
OWNTs	Pb^{2+}	102.04	pH 5, 40 mg/L of CNTs, contact time 80 min, agitation speed 50 (min)	Kabbaqi et al., 2009
Oxidized MWNTs	Cd^{2+}	25.7	Ultrasonically 45 min at 45 °C	Vukovic et al., 2010
Oxidized MWNTs	Cd^{2+}	4.262	$mV = 1.0$ g/L, $T = 20 \pm 2$ °C, pH = 3.05, contact time = 165 h	Hu et al., 2009
CNTs immobilized by calcium alginate	Cd^{2+}	67.9	Dose of adsorbent 0.05 g, $pH = 5.0$, $T = 25$ °C	Li et al., 2010
MWNTs/oxidized CNTs	Ni^{2+}	MWNTs: 18.08 Oxidized CNTs: 49.26	$mV = 0.2$ g/L, pH 6	Kandah and Meunier, 2007

Table 4

UF type	Membrane	Surfactant/complexing agent	Heavy metal	Initial conc.	Optimum pH	Removal efficiency (%)	Ref.
MF	Ceramic	Dodecylbenzenesulfonic acid	Pb^{2+}, AsO_4^{3-}	4.4-7.6 mg/L	7.47	Pb: >99%, As: 19%	Ferrillo et al., 2007
MF	Polyamide	dodecylamine	Cd^{2+}, Zn^{2+}	50 mg/L	NA	92-98	Huang et al., 2010
MF	Amicon regenerated	SDS	Cd^{2+}, Zn^{2+}	0.5 mM	NA	99	Landaburo-Aguirre et al., 2010
MF	Polyacrylate	Sodium lauryl ether sulfate	Ni^{2+}	0.2 mM	7	98.6	Danusa and Aydinler, 2009
MF	Polyethersulfone	PEI	Cu^{2+}, Ni^{2+}	50 mg/L	pH = 6.0, pH = 8.0	94, 100	Molinaro et al., 2008
PEUF	Polyethersulfone	Carboxy methyl cellulose	Cu^{2+}, Cd^{2+}	10 mg/L	7.0	97.6, 95.5, 99.1	Sarrafat and Schmidt, 2010
PEUF	AMICON 8400	Sodium polyacrylate, PEI	$Cr(VI), Cr(III)$	5, 50 mg/L	6-7, 5-6	82-100	Korus and Loska, 2009
PEUF	Ceramic	Poly(acrylic acid) sodium	Cu^{2+}	160 mg/L	5.5	99.5	Camargo et al., 2010
PEUF	Polyamide	Poly(ammonium acrylate)	Gd(III)	112.4 mg/L	6.32	99	Emigrou et al., 2009

Table 5

Membrane	Heavy metal	Initial metal Conc.	Removal efficiency (%)	Conditions	Ref.
RO	Cu^{2+}, Ni^{2+}	500 mg/L	98.5	Operation pressure 5 atm	Mohsen-Nia et al., 2007
RO	Cu^{2+}	20-100 mg/L	70-95	Low pressure reverse osmosis combined with electroswimming	Zhang et al., 2009
RO	As	<500 µg/L	98.3	Operational pressure 1100 kPa	Chan and Dudley, 2008
RO	Ni^{2+}, Zn^{2+}	$Ni^{2+}: 44-160$ $Zn^{2+}: 64-170$ mg/L	98.9	Operational pressure 1100 kPa	Ipel, 2009
NF	Cu^{2+}	10 mM	47-56	Transmembrane pressure (1-3 bar)	Chaharabadi et al., 2006
NF	$Cr(VI)$	NA	96.5	Surfactants enhanced NF	Muthukrishnan and Gaba, 2008
NF	Cu^{2+}	0.47 M	96-98	Flat-sheet NF membranes at 30 bar	Tammineo et al., 2006
RO + NF	Cu^{2+}	2.45	>95	Operating pressure 33 bar	Chaharabadi et al., 2009
RO + NF	Cu^{2+}	15 mg/L	95-99	Combination of filtration and membrane filtration, 3.8 bar	Sedilovskiy et al., 2008

hydrolyzed and co-precipitated as hydroxides. Cr(VI) was proposed to be reduced first to Cr(III) at the cathode before precipitating as hydroxide. Kabdas, li et al. (2009) experimentally investigated the treatability of a metal plating wastewater containing complexed metals

originating from the nickel and zinc plating process by EC using stainless steel electrodes. Their study demonstrated that the highest TOC abatement (66%) as well as nickel and zinc removals (100%) were achieved with an applied current density of 9 mA/cm² at the original electrolyte (chloride) concentration and original pH of the composite sample used. EC was also used to evaluate the treatment of synthetic solutions containing Hg²⁺ of concentration 2×10^{-5} M by Nansu-Njiki et al. (2009).

The removal efficiency was above 99.9% when the distance between the electrodes was 3 cm, the current density ranging from 2.5 Adm⁻² to 3.125 Adm⁻² and pH of the Hg²⁺ solutions from 3 to 7. Ölmöz (2009) studied the performance of EC to remove hexavalent chromium having a high Cr(VI) concentration of 1470 mg/L. The optimum conditions for 100% Cr(VI) removal were established as 7.4 A applied electric current, 33.6 mM electrolyte (NaCl) concentration and 70 min application time. Besides, EC has been employed to remove Mn²⁺, As(V), Mn²⁺, and Ni²⁺, etc. (Table 6)

3. REMARKS OF HEAVY METAL TREATMENT METHODS

Although all the heavy metal wastewater treatment techniques can be employed to remove heavy metals, they have their inherent advantages and limitations. Heavy metals removal from aqueous solutions has been traditionally carried out by chemical precipitation for its simplicity process and inexpensive capital cost. However, chemical precipitation is usually adapted to treat high concentration wastewater containing heavy metal ions and it is ineffective when metal ion concentration is low.

And chemical precipitation is not economical and can produce large amount of sludge to be treated with great difficulties. Ion exchange has been widely applied for the removal of heavy metal from wastewater. However, ion-exchange resins must be regenerated by chemical reagents when they are exhausted and the regeneration can cause serious secondary pollution. And it is expensive, especially when treating a large amount of wastewater containing heavy metal in low concentration, so they cannot be used at large scale. Adsorption is a

recognized method for the removal of heavy metals from low concentration wastewater containing heavy metal. The high cost of AC limits its use in adsorption. Many varieties of low-cost adsorbents have been developed and tested to remove heavy metal ions.

However, the adsorption efficiency depends on the type of adsorbents. Biosorption of heavy metals from aqueous solutions is a relatively new process that has proven very promising for the removal of heavy metal from wastewater. Membrane filtration technology can remove heavy metal ions with high efficiency, but its problems such as high cost, process complexity, membrane fouling and low permeate flux have limited their use in heavy metal removal. Using coagulation flocculation heavy metal wastewater treatment technique, the produced sludge has good sludge settling and dewatering characteristics. But this method involves chemical consumption and increased sludge volume generation.

Flotation offers several advantages over the more conventional methods, such as high metal selectivity, high removal efficiency, high overflow rates, low detention periods, low operating cost and production of more concentrated sludge (Rubio et al., 2002). But the disadvantages involve high initial capital cost, high maintenance and operation costs. Electrochemical heavy metal wastewater treatment techniques are regarded as rapid and well-controlled that require fewer chemicals, provide good reduction yields and produce less sludge. However, electrochemical technologies involving high initial capital investment and the expensive electricity supply, this restricts its development. Although all above techniques can be employed for the treatment of heavy metal wastewater

it is important to mention that the selection of the most suitable treatment techniques depends on the initial metal concentration, the component of the wastewater, capital investment and operational cost, plant flexibility and reliability and environmental impact, etc. (Kurniawan et al., 2006).

4 RESULTS AND DISCUSSION

If the Selective separation of Iron and Chromium from acidic waste water in two part separate first of Fe(III) & Cr(III)

4.1 Part (1) Fe(III) Separation

- Waste water = 100 ml
- Distilled water = 100 ml
- Ratio = 1 : 1
- NaOH= 18 gm
- pH of this mix. was adjusted dropwise with a solution of NaOH in distilled water.

Sr. No.	Waste Water	H ₂ O ml	NaOH gm	pH	Results
1	-----	----	----	0.01	Nil
2	100 ml	100	5	1	Nil
3	100 ml	100	4	2	Nil
4	100 ml	100	2	4	Nil
5	100 ml	100	2	4.5	Nil
6	100 ml	100	2	5	Nil
7	100 ml	100	1	5.8	Nil
8	100 ml	100	1	6	Nil
9	100 ml	100	1	6.5	Fe
10	100 ml	100	0.8	6.85	Fe

Fig. 7 Separation of Fe(III)

4.2 Part (2) Cr(III) Separation

- Waste water = 100 ml
- Distilled water = 200 ml
- Ratio = 1 : 2
- Na₃PO₄= 1 gm
- pH of this mix. was adjusted dropwise with a 50 % solution of NaOH in distilled water

Sr. No.	Waste Water + H ₂ O + Na ₃ PO ₄ ·7H ₂ O	50% NaOH Solution	pH	Results
1	100 ml + 200 ml -----	----	6.7	Nil
2	100 ml + 200 ml 1 gm	5 ml	7	Nil
3	100 ml + 200 ml 1 gm	5 ml	7.3	Nil
4	100 ml + 200 ml 1 gm	5 ml	7.5	Nil
5	100 ml + 200 ml 1 gm	5 ml	7.8	Nil
6	100 ml + 200 ml 1 gm	4 ml	8	Nil
7	100 ml + 200 ml 1 gm	4 ml	8.1	Nil
8	100 ml + 200 ml 1 gm	2 ml	8.2	Nil
9	100 ml + 200 ml 1 gm	1 ml	8.4	+Ve
10	100 ml + 200 ml 1 gm	1 ml	8.5	+Ve

Fig. 8 Separation of Chromium (III)

➤ Separation of Fe(III)

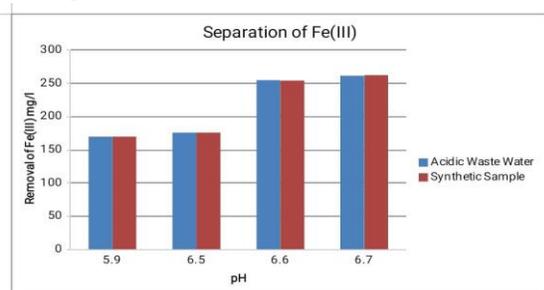


Fig. 9 Compare Pure & acidic waste water of Fe(III)

5 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, i have selective separate of Fe(III) & Cr(III) from acidic waste water. and two part separation first part Iron after Chromium separate using chemical precipitation method. separate of Chromium from (Filtrate ml Fe) acidic waste water another treatment technologies such as coagulation flocculation, flotation, ionexchange and membrane filtration, have been developed for heavy metal removal from wastewater. It is evident from the literature survey of 185 articles 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 and biosorbents 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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