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Adsorption of Heavy Metals: A Review

Dimple Lakherwal

Department of Environmental Studies,
Panjab University, Chandigarh, India.

Abstract

Environmental pollution particularly from heavy metals and minerals in the wastewater is the most serious problem in India. Due to extensive anthropogenic activities such as industrial operations particularly mining, agricultural processes and disposal of industrial waste materials; their concentration has increased to dangerous levels. Heavy metals in industrial effluent include nickel, chromium, lead, zinc, arsenic, cadmium, selenium and uranium. So far, a number of efficient methods have been reviewed for the removal of heavy metals such as chemical precipitation, ion exchange, reverse osmosis, electrodialysis, ultrafiltration, nanofiltration, coagulation, flocculation, floatation, etc. However these methods have several disadvantages such as high reagent requirement, unpredictable metal ion removal, generation of toxic sludge etc. Adsorption process being very simple, economical, effective and versatile has become the most preferred methods for removal of toxic contaminants from wastewater. This paper reviews the use of various readily available natural materials as adsorbents of heavy metals from industrial wastewater. Various low cost adsorbents reviewed includes sand, waste tea leaves eggshell, rice husk, activated carbon, zeolites, olive stones, wood sawdust etc.

Keywords: heavy metals, adsorption, activated carbon, low cost adsorbents.

1. Introduction

The quality of our environment is deteriorating day by day with the largest cities reaching saturation points and unable to cope with the increasing pressure on their infrastructure. Industrial effluents, sewage and farm wastes are the major pollutants contaminating the environment. Most of the industries discharge wastewater and their effluents containing toxic materials into rivers without adequate treatment. Environmental pollution particularly from heavy metals and minerals in the waste water is the most serious problem in India. Heavy metals are major pollutants in marine, ground, industrial and even treated wastewater. Most of the point sources of heavy metal pollutants are industrial wastewater from mining, metal processing, tanneries, pharmaceuticals, pesticides, organic chemicals, rubber and plastics, lumber and wood products. The heavy metals are transported by runoff water and contaminate water sources downstream from the industrial site. To avoid health hazards it is essential to remove these toxic heavy metals from waste water before its disposal. Most of the heavy metals discharged into the wastewater are found toxic and carcinogenic and cause a serious threat to the human health. (Srivastava *et al*., 2006). The release of large quantities of hazardous materials into the natural environment has resulted in a number of environmental problems and due to their non-biodegradability and persistence, can accumulate in the environment elements such as food chain, and thus may pose a significant danger to human health

2. Heavy Metal Toxicity

Heavy metals are elements having atomic weights between *63.5* and 200.6, and a specific gravity greater than *5.0.*Most of the heavy metals are dangerous to health or to the environment. Heavy metals in industrial wastewater include lead, chromium, mercury, uranium, selenium, zinc, arsenic, cadmium, silver, gold, and nickel (Ahalya *et al.,* 2003). The main threats to human health from heavy metals are associated with exposure to lead, cadmium, mercury and arsenic. These metals have been extensively studied and their effects on human health regularly reviewed by international bodies such as the WHO. Acute heavy metal intoxications may damage central nervous function, the cardiovascular and gastrointestinal (GI) systems, lungs, kidneys, liver, endocrine glands, and bones. Chronic heavy metal exposure has been implicated in several degenerative diseases of these same systems and may increase the risk of some cancers.

Table 1: Sources and toxicological effects of some heavy metals: (Alluri *et al,*. 2007).

Heavy Metal	**Sources**	**Effects**
Copper	Water pipes; Copper water heaters;; Frozen greens and canned greens using copper to produce an ultra-green color, Alcoholic beverages from copper brewery equipment; Instant gas hot water heaters; Hormone pills; Pesticides. insecticides; fungicides; Copper jewelry; Copper cooking pots	Mental disorders, Anaemia; Arthritis/rheumatoid arthritis; Hypertension, Nausea/vomiting, Hyperactivity, Schizophrenia, Insomnia, Autism, Stuttering, Postpartum psychosis, Inflammation and enlargement of liver, heart problem, Cystic fibrosis.

Chromium	Steel and textile industry	Skin rashes, respiratory problems, haemolysis, acute renal failure, weakened immune systems, kidney and liver damage, alteration of genetic material, lung cancer, Pulmonary fibrosis.
Nickel	Effluents of silver refineries, electroplating, zinc base casting and storage battery industries.	Dermatitis, Myocarditis, Encephalopathy, pulmonary fibrosis, cancer of lungs, nose and bone, headache, dizziness, nausea and vomiting, chest pain, rapid respiration.
Lead	Industries such as mining, steel, automobile, batteries and paints. Pollutants arising from increasing industrialization	Nausea, Encephalopathy, Headache and vomiting, Learning difficulties, Mental retardation, Hyperactivity, Vertigo, kidney damage, Birth defects, Muscle weakness, Anorexia, Cirrhosis of the liver, Thyroid dysfunction, Insomnia, Fatigue, Degeneration of motor neurons, Schizophrenic-like behaviour.
Mercury	Industries like chloro-alkali, paints, pulp and paper, oil refining, rubber processing and fertilizer, batteries, dental fillings adhesives, fabric softeners, drugs, thermometers, fluorescent light tubes and high intensity street lamps, pesticides, cosmetics and pharmaceuticals	Tremors, Birth defects, Kidney damage, Nausea, Loss of hearing or vision, Gingivitis, Chromosome damage, Mental retardation, Tooth loss, Seizures, Cerebral palsy , Blindness and deafness, Hypertonia - muscle rigidity, Minamata disease.

Non-biodegradable contaminants pose a serious health and environmental hazard and removal of these wastes cannot be achieved using secondary methods. Hence, tertiary/advanced wastewater treatment methods such as ion exchange, precipitation, membrane separation, electrolysis and adsorption_ can be used to remove these recalcitrant wastes. So far, a number of efficient methods have been developed for heavy metal removal. Fenglian *et al.* (2011) and Rao *et al.* (2011) reviewed various methods for the removal of heavy metals such as chemical precipitation, ion exchange, reverse osmosis, electrodialysis, ultrafiltration, nanofiltration, coagulation, flocculation, floatation, etc. Generally, these processes are efficient in removing the bulk of metals from solution at high or moderate concentrations. However, chemical processes produce a large amount of metallic sludge, making metal recovery difficult. The sludge also needs further disposal. In addition, effluent after such treatment usually has unacceptably high total dissolved solids. When applied to dilute metal waste or lower concentrations of metal ions, these processes are either ineffective or not cost-effective and require high level of expertise; hence they are not applied by many end-usersHowever, most of these methods are costly and require high level of expertise; hence they are not applied by many end-users. For these reasons, adsorption technology has gained a wider application due to its inherent low cost, simplicity, versatility and robustness. Low cost adsorbents derived from agricultural by-products and industrial solid wastes could be used to remove recalcitrant wastes from synthetic wastewater. Conversion of these materials into adsorbents for wastewater treatment would help to reduce the cost of waste disposal. The adsorption of toxic waste from industrial wastewater using agricultural waste and industrial by-products has been massively investigated (Basu *et al.*, 2006; Srivastava *et al*., 2006). The technical feasibility of various low-cost adsorbents for heavy metal removal from contaminated water has been reviewed (Babel *et al*.,2003).Instead of using commercial activated carbon, researchers have worked on inexpensive materials, such as chitosan, zeolites, and other adsorbents, which have high adsorption capacity and are locally available.

3. Various Conventional Methods of Heavy Metal Removal

3.1 Chemical precipitation

Chemical precipitation processes involve the addition of chemical reagents, followed by the separation of the precipitated solids from the cleaned water. Precipitation of metals is achieved by the addition of coagulants such as alum, lime, iron salts and other organic polymers. Gopalratnam *et al.* (1988) found 80% re moval of Zn, Cu, and Pb, and up to 96.2% removal of oil from industrial wastewaters by using a joint hydroxide precipitation and air floatation system.

3.2 Electrodialysis

Electro Dialysis (ED) is a membrane process, during which ions are transported through semi permeable membrane, under the influence of an electricpotential. The membranes are cation- or anion-selective, which basically means that either positive ions or negative ions will flow through. Cation-selective membranes are polyelectrolytes with negatively charged matter, which rejects negatively charged ions and allows positively charged ions to flow through.

3.3 Coagulation/ flocculation

Coagulation and flocculation are an essential part of drinking water treatment as well as wastewater treatment. Coagulation is the chemical reaction which occurs when a chemical or coagulant is added to the water. The coagulant 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. Randtke *et al.*(1997) reviews the basic mechanisms involved in the removal of organic contaminants by coagulation. Kuo *et al.*(2001) studied the effects of initial pH and turbidity, alum and pre ozonation doses, and flocculation time on the removal of dis solved organic matter during alum coagulation.

3.4 Ultrafiltration

Ultrafiltration is a separation process using membranes with pore sizes in the range of 0.1 to 0.001 micron. Typically, ultrafiltration will remove high molecular-weight substances, colloidal materials, and organic and inorganic polymeric molecules. 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.

3.5 Reverse osmosis

In the reverse osmosis process cellophane-like membranes separate purified water from contaminated water. RO is when a pressure is applied to the concentrated side of the membrane forcing purified water into the dilute side, the rejected impurities from the concentrated side being washed away in the reject water. Applications that have been reported for RO processes include the treatment of organic containing wastewater, wastewater from electroplating and metal finishing, pulp and paper, mining and petrochemical, textile, and food processing industries, radioactive wastewater, municipal wastewater, and contaminated groundwater (Slater *et al.*, 1983; Cartwright, 1985; Ghabris *et al*, 1989; Williams *et al*., 1990).

3.6 Adsorption

Adsorption is a process that occurs when a gas or liquid solute accumulates on the surface of a solid or a liquid (adsorbent), forming a molecular or atomic film (the adsorbate). Adsorption is operative in most natural physical, biological, and chemical systems, and is widely used in industrial applications such as activated charcoal, synthetic resins and water purification. Among these methods, adsorption is currently considered to be very suitable for wastewater treatment because of its simplicity and cost effectiveness (Yadanaparthi *et al*.2009, Kwon *et al.,* 2010,). Adsorption is commonly used technique for the removal of metal ions from various industrial effluents (Gottipati *et al*., 2012).

Activated carbon is the most widely used adsorbent. It is a highly porous, amorphous solid consisting of micro crystallites with a graphite lattice, usually prepared in small pellets or a powder. It can remove a wide variety of toxic metals.

Some widely used adsorbents for adsorption of metal ions include activated carbon (Pollard *et al*., 1992, Satapathy *et al*., 2006), clay minerals (Wilson *et al*. 2006), biomaterials, industrial solid wastes and zeolites (Wang *et al*, 2008). Natural material or certain waste from industrial or agricultural operation is one of the resources for low cost adsorbents. Generally, these materials are locally and easily available in large quantities. Therefore, they are inexpensive and have little economic value (Mohana *et al*., 2007)

Scattered research has already been conducted on a wide variety of sorbents. Some of the reported low-cost sorbents include bark/tannin-rich materials, lignin, chitin/chitosan, dead biomass, seaweed/algae/alginate, xanthate, zeolite, clay, ash, peat moss, bone gelatin beads, leaf mould, moss, iron-oxide-coated sand, modified wool, modified cotton.

4. Conclusion

A review of various processes and adsorbents for heavy metal removal shows that adsorption process has great potential for the elimination of heavy metals from Industrial wastewater using low cost adsorbents. More studies should be carried out for low-cost adsorption process to promote large scale use of non-conventional adsorbents. Low cost adsorbents should be used to minimize cost and maximize heavy metal removal efficiency.

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