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HEAVY METAL REMOVAL FROM WASTEWATER BY USING WIDE RANGE OF LOW-COST ADSORBENTS: A REVIEW

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Abstract:
In wastewater treatment, adsorption processes are widely employed to remove heavy metals. The most popular adsorbent, activated carbon, provides the best results, but its application is limited by its high cost. It is expensive to produce and regenerate. Since freshwater resources are scarce worldwide, finding alternatives that decrease strain on existing resources is unavoidable. Since heavy metals are dangerous even at trace concentrations, an eco-friendly approach to their removal requires inexpensive adsorbents. Adsorption is a low-cost technique that has gained popularity due to its minimal waste disposal requirements. The various adsorbents currently available on the market and the adsorption process are the primary focus of this study. The low-cost adsorbents that explain adsorption reaction conditions include both agricultural and industrial waste. Before choosing an adsorbent, consideration should be given to its technical suitability, cost-effectiveness, or ease of availability of raw materials with minimal adverse effects on the system. Research is novel in that it discusses a variety of adsorbents and their effectiveness in eliminating heavy metals from wastewater.

Keywords: Activated carbon, Heavy metal, Adsorption, Low-cost adsorbents.

Introduction:

A major global concern is the rapidly increasing amount of water contamination resulting from the addition of heavy metals from industrial processes. Heavy metal-containing effluents are produced by metallurgical, mining, and mineral processing activities. The wastewater contains persistent and non-biodegradable heavy metals. Additionally, they are soluble in water, making it simple for living cells to absorb them. They can therefore be bioaccumulated or biomagnified in higher trophic levels as they enter food chain. If ingested more than allowable levels, the heavy metals may cause major health problems. Given the circumstances, heavy metal-containing industrial effluent needs to be treated before being discharged into environment. Therefore, treating wastewater containing heavy metals economically is challenging task for scientists or environmental engineers. Conventional techniques for eliminating heavy metals from wastewater involve ion exchange, reverse osmosis, chemical oxidation, chemical precipitation, membrane separation, electrodialysis, or more. These techniques are costly, inefficient, or energy-intensive. They are linked to the production of hazardous sludge, whose disposal is costly and detrimental to the environment. Recently, several techniques for safe or economical treatment of wastewater containing heavy metals were investigated. Adsorption is a superior option to other treatment techniques. Its comparatively low cost makes it both inexpensive and effective. Adsorption has emerged as a more effective alternative therapy method. Its relatively cheap price makes it successful as well as cost-effective. Adsorption is the simplest, safest, and most economical method for treating waste effluents that contain heavy metals, according to the authors [1, 2]. The adsorption method for heavy metal removal offers several advantages, including a simple design, lower startup and process costs, and fewer control system requirements [3]. Even at as little as one mg/L of metal ion concentration in wastewater, adsorption works. Wastewater usually contains trace amounts of heavy metals. Thus, adsorption is useful and affordable technique of eliminating heavy metals from wastewater. Adsorbents may come from organic, biological, or mineral sources. These could include biomass, polymeric material, zeolites, agricultural waste, and industrial leftovers. Activated carbon is a traditional adsorbent that was extensively utilized in various applications. Nevertheless, usage of activation techniques in wastewater treatment is limited due to their high cost-effectiveness. The current research project is to aid in search for low-cost or cost-effective natural adsorbents and their suitability for heavy metal elimination or recovery from industrial wastewater.

Heavy Metals and Industrial Ravage Water

The effluent of many different sectors often contains free levels of heavy metals. Heavy metals (involving nickel, chromium, vanadium, copper, platinum, cadmium, lead, zinc, silver, titanium) are produced in large amounts as a result of electroplating or surface treatment procedures. Manufacturing of photographic film, leather, pigment, tanneries, paint, wood processing, textile & dyes, or petroleum refining all contain significant quantities of heavy metals in their wastewater. Animals as well as humans are both poisoned by these heavy metal ions. Toxic metals can lead to physical discomfort, potentially fatal illnesses, and irreversible harm to essential bodily systems [4]. Along the food chain, metals tend to bioaccumulate or then biomagnify in aquatic environment. As result, higher trophic level animals are more vulnerable to the negative effects of their toxicity. These twenty or so metals are nearly unbreakable and nearly indestructible. The following heavy metals are harmful from an ecotoxicological perspective: nickel (Ni), lead (Pb), chromium (Cr [VI]), zinc (Zn), mercury (Hg), cadmium (Cd), arsenic (As), etc. USEPA-recognized MCL (Maximum Contaminant Level) criteria for a few heavy metals are displayed in the table below [5]. Significant consequences from these heavy metals include stunted growth, cancer, damage to vital organs, brain damage, or, in certain situations, even death. Health risks linked to heavy metal poisoning are not new. Overconsumption of heavy metals causes diseases in humans, such as fluorosis, arsenicosis, itai, and minamata. Instead of treating enormous amount "of wastewater in an all-purpose sewage treatment facility", an organized technique of eliminating heavy metals from industrial effluents is to treat them on industrial site before they are released. Therefore, it is beneficial to expand use of distinct handling "techniques for removal of heavy metals from industrial effluents. Study into natural coagulants as an economical or practical alternative treatment" approach for industrial wastewater that removes heavy metals is the focus of the current position. (Table 1)

Table 1: The MCL standards for the most Hazardous heavy metals [5].

Heavy "Metal	**Toxic**	**MCL(Mg/L)**
Arsenic(As)	Skin manifestations, visceral cancers, vascular disease	0.020
Cadmium(Cd)	Kidney damage, renal disorder, human carcinogen	0.01
Chromium (Cr)	Headache, diarrhea, nausea, vomiting, carcinogenic	0.04
Coppper(Cu)	Liver damage, Wilson's disease, insomnia	0.23
Nickel(Ni)	Dermatitis, nausea, chronic asthma, coughing, human carcinogen	0.21
Zinc (Zn)	Depression, lethargy, neurological signs, and increased thirst	0.70
Lead (Pb)	Damage the fetal brain, diseases of kidney, circulatory system and nervous system	0.005
Mercury (Hg)	Rheumatoid arthritis and disease of kidneys circulatory, and nervous system"	0.00002

Adsorption

As previously discussed, adsorption has emerged as successful, cost-effective, as well as environmentally responsible treatment technique. Its strong enough technique to meet industry-high effluent regulations and water recycling requirements. Substance is changed from liquid phase to surface of solid by process called as adsorption, where its bound by chemical or/and physical interactions [5]. Small number of liquid phase constituents are moved to solid adsorbents' surface during this division process. Solid-liquid equilibrium or mass transfer rates are essential to all adsorption processes. There are three possible adsorption processes: semi-batch, batch, or continuous. Adsorption at the molecular level is majorly caused by attractive surfaces among group being absorbed and a surface. The sorts of intermolecular attractive forces that could lead to adsorption include the following:

Physical Adsorption

It happens frequently in any system that combines liquids and solids or solids and gases. The adsorbate sticks to adsorbent surface during physical adsorption because of van der Waals forces of attraction. Almost nothing disturbs atom's or molecule's electronic structure.

Chemical Adsorption

In this kind of adsorption, adsorbent or adsorbate undergo a chemical reaction. Covalent and ionic electronic bonds are two new forms that are produced by strong interaction among adsorbate and substrate surface. Active adsorption is another term for chemical adsorption. A monolayer may form from the adsorbate. In catalytic processes, it is employed. Generally speaking, the primary processes in which contaminants are adsorbed onto solid adsorbents are: Transfer of toxins from bulk solution to outside surface of adsorbent. Through pore diffusion, mass is moved from adsorbent's outer surface to leaky structure's inner surface. Adsorbate is adsorbed on active sites of adsorbent's holes. Since last stage of adsorption is quicker than the previous two, intraparticle diffusion, film formation, or both can often affect rate of adsorption.

Low-Cost Adsorbents

Utilization of low-price adsorbents to remove heavy metals is more hopeful in the long run because there are numerous easily accessible and reasonably priced materials that can be used as inexpensive adsorbents, involving industrial by-products, natural materials, agricultural wastes [6]. High selectivity to facilitate quick or simple separations, good transport or kinetic characteristics, fouling resistance, mechanical strength, revival capacity, or low solubility in liquid in contact are all necessary for an adsorbent to be economically successful. Compared to traditional technique of heavy metal removal, adsorption process offers numerous benefits. The adsorption process has several advantages, including (I) being economical, (II) having metal selectivity, (III) being regenerative, (IV) not producing hazardous sludge, (V) having metal recovery, —above all—being effective. There are several inexpensive adsorbents that come from both natural and man-made sources that were utilized to clean wastewater that contains heavy metals. Common adsorbents involve natural materials, modified biopolymers, industrial wastes, and agricultural waste.

Adsorption by Natural Materials (Zeolites)

Tetrahedral molecules joined by mutual oxygen atoms form the backbone of naturally occurring crystalline aluminosilicates. Zeolites' ability to exchange ions makes them suitable candidate for removing heavy metals. Surface area is not a significant factor since adsorption in zeolite is actually specific or reversible filling of crystal cages. Zeolites include a broad range of species, including clinoptilolite, chabazite. Clinoptilolite has been extensively researched among the dissimilar zeolites and has demonstrated strong selectivity for metals involving Pb (II), Zn (II), Cu (II), Cd (II). To increase their effectiveness, several zeolites have been modified over the past few years. Because of its ion exchangeability, clinoptilolite has been shown to be more successful at eliminating heavy metals than pretreatment [5,7].

Clay

The 3 main clay groups are kaolinite, montmorillonite-smectite, and mica. In comparison to activated carbon, montmorillonite has highest cation switch capacity or a 20-fold lower fresh market value. Compared to zeolites, they have a far lower capacity to remove heavy metals, but their affordability and ease of use make up for this. Switching to clay-polymer composites could increase the effectiveness of clay's heavy metal removal process.[8-10].

Peat moss

It is abundant or contains high amount of organic matter. Its large surface area (greater than and equal to 200 m^2 per g) as well as high porosity make it an active wastewater heavy metal removal agent. For treatment of metal-bearing industrial effluents, including Zn2+, Ni2+, Cd2+, Cu2+, peat moss has been observed to be important [11]. In the pH range of 1.2-2.7, sphagnum peat moss has been reported to have an adsorption capacity of 128 milligrams of Cr6+/g. This adsorbent's most obvious benefits in treatment are its inexpensive cost, ease of use, and capacity to accept a broad range "of effluent composition [12].Chitin: After cellulose, its next most abundant natural biopolymer. Chitin is long-chain polymer of N-acetyl glucosamine" that functions similarly to glucose. It is the primary component of the exoskeletons of arthropods, including crustaceans (involving crabs, lobsters, shrimp), insects, and fungal cell walls. In the past, it was used to eliminate variety of heavy metals. More research is being done on chitosan, that is formed by alkaline N-deacetylation of chitin, due to its chelating qualities, which enable it to eliminate heavy metals. Shrimp and other crustacean shells can be prepared by using sodium hydroxide, an alkali. The following elements have been treated with chitosan: Cu2+, Ni2+, Hg2+, Zn2+, Cd2+, Cr6+, Pb2+.

Adsorption by Agricultural Wastes

These days, more and more agricultural by-products are being utilized as adsorbents to eliminate heavy metals from wastewater. Numerous researchers have examined plant waste, particularly neem bark. "Black gram husk [15], tea waste, walnut shell [16], rice husk [13,14], etc. Additional adsorbents are also being studied, such as papaya wood [17], maize leaf [18], teak leaf powder [19], coraindrum sativum [20], lalang (Imperata cylindrica) leaf powder [21], peanut hull pellets [22], sago waste [23], saltbush (Atriplex canescens) leaves [24,25], tree fern [26–28], grape stalk wastes" [29], etc. The "selective adsorption of heavy metal ions, enhanced adsorption abilities, or simplicity of use are some advantages of utilizing agricultural waste for wastewater treatment. Plant wastes involving neem bark and rice husk [13,14], black gram husk [15], waste tea, Turkish coffee, walnut shell" [16], etc., were the subject of the majority of the investigations. Several other adsorbents are also thoroughly examined, including "papaya wood [17], maize leaf [18], teak leaf powder [19], coraindrum sativum [20], lalang (Imperata cylindrica) leaf powder [21], peanut hull pellets [22], sago waste [23], saltbush (Atriplex canescens) leaves [24,25], tree fern [26–28], grape stalk wastes [29], etc. Using" agricultural wastes to treat wastewater has several advantages, involving requiring little processing, being simple to use, having a high adsorption capacity, selectively adsorbing heavy metal ions, being inexpensive, readily available, and easily revived. However, using unprocessed agricultural wastes as adsorbents can also result in several negative effects, including reduced adsorption capacity, elevated COD and BOD levels, and total organic carbon (TOC), because the plant materials contain soluble organic compounds [30, 31]. The dissolved oxygen (DO) content of water may decrease as a result of rising COD, BOD, and TOC levels, endangering aquatic life. Consequently, before being used to clean heavy metals, plant wastes must be altered or treated. According to Ozer et al. [32], "wheat bran, by-product of wheat milling industry, is high-quality adsorbent for the elimination of various heavy metal ions, that eventually" leads to improved copper ion adsorption efficiency. Ni (II) can be extracted from simulated wastewater utilizing orange peel [33]. Similarly, Annadurai et al. (2002) carried out "adsorption of divalent heavy metal ions, primarily Zn2+, Ni2+, Cu2+, Co2+, Pb2+, onto" banana as well as orange peels that had been treated with acid and alkali [34]. Lead is removed from electrochemical industry wastewater using activated charcoal powder (ACP) and ACSCP (activated coconut shell carbon powder) as adsorbents [35]. Additionally, adsorption capacity is affected by variables involving temperature, "pH, initial metal concentration, contact time, adsorbent dosage”, agitation rate, etc [36].

Adsorption by Industrial Wastes

Ability “to adsorb heavy metals from wastewater” is also present in a range of industrial wastes. These industrial wastes are rarely employed for any purpose and are created as a by-product. Because it is a by-product, it is easily accessible and reasonably priced. The purpose of these industrial wastes is to serve as effective adsorbents. These wastes could have their adsorption capacity increased and then slightly dispersed. The technical potential of “industrial by-products such as fly ash [37, 38], blast furnace sludge [39, 40], waste slurry, lignin—black liquor waste from the paper industry [41, 42, 43], iron (III) hydroxide [44, 45], and red mud [46, 47] to remove dangerous heavy metals from impure water has been investigated. Zinc” was adsorbed from wastewater using a variety of adsorbents. “73.2 mg per g of lignin, 168 mg per g of powdered waste sludge, 128.8 mg per g of dried marine green microalgae, 55.82 mg per g of cassava waste, 52.91 mg per g of” bentonite are some of the greatest Zn^{2+} adsorption capabilities that have been documented [48].

Conclusion

The recent global push to meet improved environmental standards encourages use of low-price wastewater treatment devices. Meanwhile, a variety of inexpensive adsorbents “derived from natural resources or agricultural waste were thoroughly investigated for removal of heavy metals from wastewater that has been” contaminated. Agricultural waste were shown to have exceptional heavy metal removal capabilities following chemical or thermal transformation. The parameters that determine metal adsorption capabilities are adsorbent characteristics, adsorbate concentration, and the degree of surface change. The two most important criteria for choosing an efficient low-price adsorbent for heavy metal elimination are cost effectiveness and technical applicability.

REFERENCES:

1. Shah BA, Shah AV, Singh RR (2009) Sorption isotherms and kinetics of chromium uptake from wastewater using natural sorbent material. *International Journal of Environmental Science and Technology* 6: 77-90.
2. Rahmani K, Mahvi AH, Vaezi F, Mesdaghinia AR, Nabizade R, et al (2009). Bioremoval of lead by use of waste activated sludge. International Journal of Environmental Research 3: 471-476.
3. Acar FN, Eren Z (2006) Removal of Cu (II) ions by activated poplar sawdust (Samsun Clone) from aqueous solutions. J Hazard Mater B 137: 909–914.
4. Malik A (2004) Metal bioremediation through growing cells. Environmental International, 30: 261-278.
5. Babel S, Kurniawan TA (2003) Various treatment technologies to remove arsenic and mercury from contaminated groundwater: an overview. In: Proceedings of the First International Symposium on Southeast Asian Water Environment, Bangkok, Thailand, 24- 25 October: 433-440.
6. Siti Nur AA, Mohd Halim SI, Lias Kamal Md, Shamsul Izhar (2013) Adsorption Process of Heavy Metals by Low-Cost Adsorbent: A Review. World Applied Sciences Journal 28: 1518-1530.
7. Bose P, Bose MA, Kumar S (2002) Critical evaluation of treatment strategies involving adsorption and chelation for wastewater containing copper, zinc, and cyanide. Adv Environ Res 7: 179-195.
8. Vengris T, Binkiene R, Sveikauskaite A (2001) Nickel, copper, and zinc removal from wastewater by a modified clay sorbent. Appl Clay Sci 18:183-90.
9. Solenera M, Tunalib S, O¨zcan , A S, O¨zcanc A, Gedikbey T (2008) Adsorption characteristics of lead (II) ions onto the clay/ poly(methoxyethyl)acrylamide (PMEA) composite from aqueous solutions. Desalination 223: 308-322.
10. Abu-Eishah SI (2008) Removal of Zn, Cd, and Pb ions from water by Sarooj clay. Appl Clay Sci 42 : 201-205.
11. Gosset T, Trancart JL, Thevenot DR (1986) Batch Metal removal by peat Kinetics and thermodynamics. Water Res 20: 21-26.

12. Sharma DC, Forster CF (1993) Removal of Hexavalent Chromium using Sphagnum moss peat. Water Res 27: 1201-1208.
13. El-Said AG, Badawy NA, Garamon SE (2012) Adsorption of Cadmium (II) and Mercury (II) onto Natural Adsorbent Rice Husk Ash (RHA) from Aqueous Solutions: Study in Single and Binary System, International Journal of Chemistry 2012: 58-68.
14. Bhattacharya AK, Mandal SN, Das SK (2006) Adsorption of Zn(II) from aqueous solution by using different adsorbents. Chem Eng J 123: 43-51.
15. Saeed A, Iqbal M (2003) Bioremoval of cadmium from aqueous solution by black gram husk (Cicer arientinum). Water Res 37: 3472-3480.
16. Orhan Y, Büyükgüngör H (1993) The removal of heavy metals by using agricultural wastes. Water Sci Technol 28(2): 247-255.
17. Saeed A, Iqbal M, Akhtar MW (2005) Removal and recovery of heavy metals rom aqueous solution using papaya wood as a new biosorbent. Sep. Purif Technol 45: 25-31.
18. Babarinde NAA, Oyebamiji Babalola J, Adebowale Sanni R (2006) Biosorption of lead ions from aqueous solution by maize leaf. Int. J Phys Sci 1: 23-26.
19. King P, Srivinas P, Prasanna Kumar Y, Prasad VSRK (2006) Sorption of copper (II) ion from aqueous solution by Tectona grandis l.f. (teak leaves powder). J Hazard Mater B136: 560-566.
20. Karunasagar D, Balarama Krishna MV, Rao SV, Arunachalam J (2005) Removal of preconcentration of inorganic and methyl mercury from aqueous media using a sorbent prepared from the plant Coriandrum sativum. J. Hazard Mater B 118: 133-139.
21. Hanafiah MAK, Ngah WSW, Zakaria H, Ibrahim SC (2007) Batch study of liquid-phase adsorption of lead ions using Lalang (Imperata cylindrica) leaf powder. J Biol Sci 7: 222- 230.
22. Johnson PD, Watson MA, Brown J, Jefcoat IA (2002) Peanut hull pellets as a single use sorbent for the capture of Cu (II) from wastewater. Waste Manage 22: 471-480.
23. Quek SY, Wase DAJ, Forster CF (1998) The use of sago waste for the sorption of lead and copper. Water SA 24: 251-256.
24. Sawalha MF, Peralta-Videa JR, Romero-Gonza´lez J, Duarte-Gardea M, Gardea-Torresdey JL (2007) Thermodynamic and isotherm studies of the biosorption of Cu(II), Pb(II), and Zn(II) by leaves of saltbush(Atriplex canescens). J Chem. Thermodyn 39: 488-492.
25. Sawalha MF, Peralta-Videa JR, Romero-Gonza´lez J, Gardea-Torresdey JL (2007) Biosorption of Cd (II), Cr (III), and Cr(VI) by saltbush (Atriplex canescens) biomass: thermodynamic and isotherm studies. J Colloid Interface Sci 300: 100-104.
26. Ho YS, Wang CC (2004) Pseudo-isotherms for the sorption of cadmium ion onto tree fern. Process Biochem. 39: 759-763.
27. Ho YS, Chiu WT, Hsu CS, Huang CT (2004) Sorption of lead ions from aqueous solution using tree fern as a sorbent. Hydrometallurgy. 73: 55-61.
28. Ho YS (2003) Removal of copper ions from aqueous solution by tree fern. Water Res 37: 2323-2330.
29. Villaescusa I, Fiol N, Martínez N, Miralles N, Poch J, et al. (2004) Removal of copper and nickel ions from aqueous solutions by grape stalks wastes. Water Research. 38: 992-1002.
30. Gaballah I, Goy D, Allain E, Kilbertus G, Thauront J (1997) Recovery of copper through decontamination of synthetic solutions using modified barks. Met Metall Trans.B 28: 13- 23.
31. Nakajima A, Sakaguchi T (1990) Recovery and removal of uranium by using plant wastes. Biomass 21: 55-63.
32. Ozer A, Ozer D (2004) The adsorption of copper (II) ions onto dehydrated wheat bran (DWB): determination of equilibrium and thermodynamic parameters. Process Biochem 39: 2183-2191.
33. Ajmal M, Rao RAK, Ahmad R, Ahmad J (2000) Adsorption studies on Citrus reticulata (fruit peel of orange) removal and recovery of Ni (II) from electroplating wastewater. J Hazard Mater 79: 117-31. 34. Annadurai G, Juang HS, Lee DJ (2002) Adsorption of heavy metal from water using banana and orange peels. Water Sci Technol 47: 185-190.
35. Nishigandha JB, Suryavanshi AA, Tirthakar SN (2015) Removal of heavy metal lead (pb) from

electrochemical industry waste water using low cost adsorbent. Int J Research in Engineering and Technology 04: 731-733.
36. Parmar M, Thakur Lokendra Singh (2013) Heavy metal Cu, Ni and Zn: toxicity, health hazards and their removal techniques by low cost adsorbents: a short overview. Int J Plant Animal & Env. Science 3: 143-147.
37. Bayat B (2002) Combined removal of zinc (II) and cadmium (II) from aqueous solutions by adsorption onto high-calcium Turkish Fly Ash. Water Air Soil Pollut. 136: 69-92.
38. Wang SB, Li L, Zhu ZH (2007) Solid-state conversion of fly ash to effective adsorbents for Cu removal from wastewater. J Hazard. Mater 139: 254-259.
39. Dimitrova SV (1996) Metal sorption on blast-furnace slag. Water Res. 30: 228-232.
40. Srivastava S, Gupta V, Mohan D (1997) Removal of Lead and Chromium by Activated Slag-A Blast-Furnace Waste. J Environ Eng, 123: 461-468.
41. Suhas, Carrott PJM, Ribeiro Carrott MML (2007) Lignin-from natural adsorbent to activated carbon: A review Bioresour Technol 98: 2301-2312.
42. Srivastava SK, Singh AK, Sharma A (1994) Studies on the uptake of lead and zinc by lignin obtained from black liquor-a paper industry waste material. Environ Technol 15: 353-361.
43. Demirbas A (2004) Adsorption of lead and cadmium ions in aqueous solutions into modified lignin from alkali glucerol delignification. J of hazard Mater, 109: 221-226.
44. Namasivayam C, Ranganathan K (1993) Waste Fe (III)/Cr (III) hydroxide as adsorbent for the removal of Cr (VI) from aqueous solution and chromium plating industry wastewater. Environ Pollut. 82: 255-261.
45. Namasivayam C, Ranganathan K (1998) Effect of organic ligands on the removal of Pb(II), Ni(II), and Cd(II) by waste Fe(III)/Cr(III) hydroxide. Water Res 32: 969-971.
46. Gupta VK, Ali Imran (2002) Adsorbents for water treatment: Low cost alternatives to carbon, Encyclopaedia of surface and colloid science, (edited by Arthur Hubbard), Marcel Dekker, New York, USA Vol. 1: 136-166.
47 Altundogan HS, Altundogan S, Tumen F, Bildik M (2000) Arsenic removal from aqueous solutions by adsorption on red mud. Waste Manage. 20:761-767.
48 Zwain Haider M, Vakili Mohammadtaghi, Dahlan Irvan (2014) Waste Material Adsorbents for Zinc Removal from Wastewater: A Comprehensive Review. Int. J Chem Engg. 2014: 1-