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Review Paper

A review on sorption of toxic element from aqueous solution

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Abstract

Water pollution in environment is well known problem in worldwide due to increase in population in the world, pollution is also increases in air, water and soil sources. But water pollution affects the environment most. The presence of metal ions in aqueous solutions represents a major environmental problem. These inorganic species are persistent and non-biodegradable pollutants that should be eliminated from water. In the recent years biosorption have emerge as an environmental friendly and economical method for the removal of contaminant of polluted water. The present review work based on removal of different heavy metals present in the environment, their sources and affects. Utmost emphasize on Lead, Cadmium and Arsenic. Literature is also discussing about convention removal technologies and their limitations. In this review, research on removal of heavy metal by biosorption is well known environmental topic; biosorption process performs on the basis of individual concentration removal from wastewater. Various interdisciplinary approaches to study the methodology of biosorption in which facts can be investigated, performed and interpreted by different analyst of various field such as biologist, chemist, engineer, etc. Experiments and practical approaches reveal the facts and mechanism that help to understand the biosorption process. Different parameters are studied which affects the biosorption efficiency, still we have to focus on new biosorbent and their technique.

Keywords: Water, Heavy metal, Biosorption, Biosorbents, Pollution.

Introduction

Over 70% comprise to the Earth's surface, water is definitely the most valuable natural resource presented on our planet. Survival of life without this precious solvent on Earth is might be impossible. Despite this aspect is also prominent that the presence of contaminant in water is common and gradually increases with time. In our earth crust many minerals and heavy metals are naturally present. But due to obstruction of human, balance between biochemical and geochemical cycles are remarkably changed. Due to this, the presences of heavy metals in aquatic streams are so frequent. Various heavy metals sources such as fertilizer, pesticides, metal plating, storage battery industries, paper industries, alloy industries radiator manufacturing, mining refining ores, tanneries batteries, etc[1]. This all releases effluent and get introduced into water resources which causes serious health risk to ecosystem. Heavy metal penetrates from one source of water (Surface) to other sources (Ground water) or vice versa and creates toxicological effects to environment[2].

Metabolism of human body are change when heavy metals get introduced into body, this changes are: i. Heavy metals cumulate in body and disturb the metabolic functions of brain, kidney, liver, heart, bone and other systems of body. ii. Heavy metals prohibit biological function by exchange itself with other essential elements from its main functioning part. Up to large extent environment are not free from heavy metal and it gets into human body easily by numerous means like drinking water and beverages, consumption of foods, breathing of air and skin exposure[3].

Heavy metal can be easily entered into the living organism as it is present in mobilized form in water systems. Concentrations of heavy metals are increases in living organism as it accumulate in body when it enters through food chain. It can causes well known toxicological effects when it ranges beyond permissible limit listed in Table-1[4].

Wang and Chen[5] classify heavy metals into three groups: toxic metals [such as Zn, Hg, Pb, Cd, Co, Cu, Ni, Cr, As, Sn, etc.], precious metals [such as Pd, Au, Ag, Pt, Ru etc.] and radionuclides [such as U, Ra, Am, Th, etc.][6]. Cd, Pb and As are well known highly toxic contaminant from last few decades for whole environment[7-8]. As these heavy metals are non-biodegradable and biomagnifications characters are present in which heavy metal concentration increases in organism by each tropic level in food chain[9-10]. Anthropogenic sources contribute a large amount of Cd, Pb and As pollutant in the environment[11]. These pollutants damage vital human organs functioning and cause various disease. Chronic exposure of these metals increases risk of cancer and death[12].

Table-1: Health disorders of heavy metal with its sources[5].

Pollutants (mg/l)	Main sources	Major human health effects
Arsenic	Volcanic eruption, Geochemical, Pesticides, fungicides, mining.	Skin disease including skin cancer, pigmentation, liver infection, cardiovascular, bronchitis and it is carcinogenic to various body organ.
Cadmium	Intake of cadmium containing water and food, electroplating, welding, battery, smelting, refining	Osteoporosis, carcinogenic to vital organs, itai- itai disease, kidney infection.
Lead	Power plant, electroplating, pipes and fitting, pesticide, smoking, paint, metal refining industries.	Fatal infection, mental retardation in children, renal failure, neurological disorders, gastrointestinal damage, reproductive damage.
Zinc	Mining, refineries, manufacturing of brass,	Metal fumes causes adverse effects on body, gastrointestinal, nervous damage.
Manganese	Petrochemical, tanneries, fertilizer, ferromanganese production	Taste and color of water change, neurotoxicity, decreases haemoglobin level. Gastrointestinal, nervous damage
Chromium	Electroplating, textile dyeing, metal industries, leather tanning	Irritability, fatigue, mutagenic, human carcinogenic, nausea.
Mercury	Volcanic eruption, batteries, paper industries	Kidney and nervous system disturbances, gingivitis, corrosive to eyes characterized by pink skin.
Copper	Mining, mineral processing, chemical process industries, pesticide production, metallurgical operations	Renal infection, stomach diseases, liver damage, anemia intestinal problem.

Cadmium: International Agency for Research on Cancer (IARC) has considered Cadmium as a Class 1 carcinogenic in human being[13]. Cadmium was noticed as major environment pollutant since 1980, medicinal and health science focuses on study about affect in health by exposure of cadmium and its toxicity in living organism at low concentration[14]. Cadmium intake permissible limit should not exceed 0.4–0.5mg per week or 0.057–0.071mg per day as recommended by World Health Organization[15]. Itai-itai disease caused due to rice consumption in which cadmium contaminant was present and this is still a health risk[16]. Renal damage, bone disease, cancer, etc. causes due to long term exposure of cadmium[17]. So cadmium is considered as one of the important pollutants form monitoring by many countries and international organizations.

Lead: Water supply either for drinking purpose or other uses, almost all countries are using the product like solder, plumbing fitting, pipes etc. are made by lead element[18]. Lead is naturally present in water resources at some limit in mobilized form. Most common source of lead to get introduced into drinking water are plumbing system like pipes, pipes solder, fitting and service connection. PVC pipes increases the lead concentration at higher level as it contain lead element which can be leached[19]. Bureau of Indian standards for drinking water[20] has recommended permissible limit of drinking water is 0.01 mg/L. For all age group the permissible weekly intake of Lead are 25 µg/l per kg body wt or 93.5 µg/kg body wt/day was recognized[21]. Lead is a common poison; contamination of lead is increases to alarming rate. Lead exposure affects infants, reproductive system[22] neurological system, kidney, anemia[18] and other organs of human body[23].

Arsenic: Arsenic contamination enters in the environment by natural sources such as volcanic emissions, geochemical weathering of rocks, oxidation, methylation, arsenic bearing minerals, and this all make arsenic dissolution in the biosphere[24]. Anthropogenic sources also contribute contamination to soil, water and air such as coal combustion, fly ash disposal, agricultural pesticides, germicides, herbicides, mining, run off through mine tailing, tanning waste, etc[25]. In this way, large extent arsenic contaminations are increases serious health hazard due to short term and long term exposure of As compounds. US EPA and WHO has recommended the maximum permissible limit of As for drinking purpose is 0.001mg/L[26,27]. Short term exposure causes oesophageal, bloody “rice water”, vomiting and abdominal pain[28]. Long term exposure causes chronic diseases such as pigmentation changes, neurological disorders, loss of appetite, skin thickening, muscular weakness and cancer at kidney, lung, skin and bladder[28].

Various conventional techniques has been used to remove heavy metals and other contaminant present in water resources and wastewaters like chemical precipitation, membrane filtration, ion-exchange, electro chemicals, reverse osmosis etc. These methods are usually used in industries and some places to remove pollutant but it has many negative aspects like expensive capital, a large quantity of chemicals and energy required, incomplete metal removal, and formation of toxic chemical sludge which again require treatment[29,30]. Thus we need new removal method to overcome with these problems which shows complete metal removal, cost effective and less sludge formation, this all gives new method biosorption process.

As compared with the conventional method, biosorption process is better technique in all purpose. This consist of an efficient metal removal method, no chemical or minimum chemicals required, low cost, convenient to use, eco friendly and very less amount of biological/ chemical sludge are produce[30,31]. Biosorption method was one of the efficient technologies used for removal of heavy metals from wastewaters[32].

The present study provide a review of the recent researches discussing the potential of biosorbent used to removal Cd(II), Pb(II) and As(III) ions from aqueous solutions.

Conventional Method

Conventional technologies were using to remove heavy metals from many years in industries and plants. But these methods are somehow improper in various ways like high capital cost and not easy to handle, etc. Some conventional methods with their advantages and disadvantages are listed in Table-2, which gives information about this techniques and are inadequate to use for removal of metals from wastewaters. So there is in quest of new method to conquer disadvantages of conventional method together.

Biosorption: Biosorption process is being considered for metal removal from last few decades; it is one of the promising methods to decontaminant water system. In this process heavy metal present in aqueous solution get removed using natural products obtain from biological sources[36].

In other words biosorption is defined as a certain type of solid biomass (dead, microbial, inactive biosorbent) is used to bind the dissolve species present in aqueous solution (heavy metals). Biological material have binding sites to adsorb sorbate, different mechanism are involved to explain this phenomenon. Metal ions are adsorbed by sorbent until equilibrium condition is obtained between both the phases. This equilibrium condition is established with various factors and condition[37]. Biosorption are environmental friendly method still its mechanism not fully understood, some advantages and disadvantages of biosorption are listed in Table-3.

Biosorbent: Biosorbent are the biological material either living or dead which has higher affinity to adsorb various heavy metal but many sorbent has specific priority to bind with particular to metal[38]. Main attraction for selections of biomass are effective to remove heavy metal, large quantity of materials are easily available, should be minimum cost and prolonged treatment not require to use sorbent. Distinct type of biomaterial has been using such as natural biosorbent (agricultural waste, leaves, seeds, stems, roots of different plants, etc.), saw dust, industrial waste, microbial biomass, algae etc.

Table-2: Conventional techniques used for the treatment of heavy metal: Advantages and disadvantages.

Method	Advantages	Disadvantages
Ion- exchange	Maximum material regenerate, Metal selectivity.	Less number of heavy metal ions removed, Expensive[34].
Chemical Precipitation	Inexpensive, Maximum metals can be removed, Simple.	Disposal problems, Large amounts of sludge produced[33].
Chemical coagulation	Sludge formation and setlling, Dehydrating.	Large consumption of chemicals, High cost[33].
Membrane process and ultra filtration	Less sludge formation, Minimum chemical required, High potential for single metal (>95%).	Removal percentage decreases with the interference of other metals. Low flow rates, Expensive initial and operating cost[35].
Using natural zeolite	Comparatively low cost material, Almost all metals can be removed.	Low efficiency[35].
Adsorption (activated carbon)	High efficiency to remove metals (>99%). The majority of the metals can be removed.	Cost of activated carbon, No regeneration, Performances depend upon adsorbents[34].
Electrochemical methods	No chemical consumed, Selective metals, Pure metals can be attained.	Expensive capital, High operating cost, Current density and initial pH solution[33].
Evaporation	Resulting sludge, Energy intensive, Expensive.	Pure sewage produces (for recycle)[32].

Table-3: Biosorption: Advantages and Disadvantages[35].

Advantages	Disadvantages
Efficient to metal uptake	Early saturation (when metal binding sites are occupied).
High efficiency	Valence state of the metal cannot be altered biologically.
Low cost if low sorbents are used.	Process mechanism of high complexity.
Minimization of biological and chemical sludge.	Limited studies at industrial and pilot scale.
No additional or very less chemicals required.	
Very rapid	
Regeneration of biosorbents	
Simple operation procedure	

Biosorbent used in last decades

Adsorbents used for removal of Cd(II), Pb(II) and Arsenic: In recent years various studies have been performed on biosorption to remove heavy metal and these represents a potential source to remove toxic heavy metals. Biosorption removal of Cd(II) was carried out, numerous adsorbents were used such as immobilized *Microcystis aeruginosa*[39] algae[40], Olive stone and sugar cane bagasse by-products[41], Flowerlike Magnesium Oxide Nanostructures[42], *Cocos nucifera* L.[43], *Opuntia ficus indica*[44]. For removal of Pb(II) biosorbents reported were *Otostegia persica*[45], algae[40], *Cocos nucifera* L.[43], *Sophora japonica* pods[46], *Opuntia ficus indica*[44]. Removal of As(III) using various adsorbent were reported such as *Cocos nucifera* L.[43], algae[40], activated *Moringa oleifera*[47], Marble Powder and Bricks Powder (industrial waste)[48], Blue Pine (*Pinus wallichiana*) and Walnut (*Juglans regia*)[49].

Biosorption Mechanisms

Biosorption process involves sequestering of heavy metal present in dissolution form in aqueous/liquid phase even in very low concentration using solid biosorbent. It is due to high attraction force present between two phases. Various functional groups like carboxyl, amine, hydroxyl, nitro compounds, hydrocarbons, alky halides etc[50]. are generally present in biosorbent material, this may be responsible for sorption process. Various mechanisms are used to explain biosorption mechanism such as ion- exchange, precipitation, complex formation, electrostatic forces, etc.

Nowadays many instrument analysis are using to understand mechanism of biosorption. Recently instrument using for analysis are FTIR, SEM, EDS, XRD, TEM[51] etc. This analysis also gives confirmation about metal sequestering in biomass by involvement of shifting and formation of peak in functional group, structural change, ion exchange mechanism by showing sorbed metals in peak and so on. Biosorbent materials are generally used before and after biosorption process.

Factor affecting biosorbent

Various factors are affecting the biosorption to establish equilibrium. Many parameters are important to study including concentration of initial metal ions and the biomass dose, temperature, contact time, agitation and pH etc. as it effects on biosorption of heavy metals. Factors affecting biosorption is discussed in Table-4.

Table-4: Factors affecting biosorption of heavy metal[52].

Features	Biosorption
pH	Competitive hydrogen ion with metal ions effects removal capacity of biosorbent. So pH parameter study can be carried out by varying solution pH.
Cost	Biosorbent cost is generally low as natural biosorbent, agricultural waste, industrial waste, saw dust are using. Minimum processing and transport charge involves.
Selectivity	Unfortunate selection of biomass. Selectivity of biomass can be enhanced by some processing or modification.
Maintenance/ storage	Storage, handling and use of biosorbent are easy and cost effective.
Temperature	Temperature does not affect uptake capacity as biosorbent are inactive or dead. However, many researchers reported higher sorption with increase in temperature.
Contact time	Rapid, minimum time required to complete the process.
Concentration/Uptake capacity	>99% of removal and some biosorbent sorbed soluble metal ion more than its dry weight.
Versatility	Multiplicity of metal ion can be bind on the surface of biosorbent. Excellent
Toxicant affinity	High under optimum conditions.
Regeneration and reuse	Regeneration of biosorbent are maximum, biosorbent can be reuse up to many cycles.
Metal recovery	Metal recovery is possible with appropriate selection of pollutant. Alkaline and acidic medium can be used efficiently to recover metal ions.

Conclusion

This paper indicates that the heavy metal pollution increases in wastewater and purity of water resources are one of the major concerns to save environment. Industrialization and urbanization has increased worldwide and sources of heavy metal are also increases in environment. Mobilized from of heavy metals are toxic and carcinogenic. Life on the earth is not protected until water is free from contaminant, toxic heavy metal recovery and removal from wastewaters should be our top priority from an environmental point. Industries working with heavy metal should be acquainted with these facts and to take responsibility to maintain the regulatory limit for safe disposal of residue containing heavy metal. Conventional techniques are applicable to remove heavy metals from industrial effluent and wastewater with many disadvantages. Over to this biosorption is more efficient and eco friendly process as it provide more effective to remove heavy metal even in low concentration, low capital cost, less amount of biological and chemical sludge produce, easy to operate, minimum chemical required and regeneration of sorbents. By products, natural adsorbent, waste materials are also used to remove heavy metals. Various instrumental analysis are improved for understanding the complete mechanism of biosorption. More searches are required in the field of pilot scale study, search of new biosorbent, multi metal removal methods.

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