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Perspectives on Heavy Metal Ions Pollution of Water Sources –A Review

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Abstract:

Among the various inorganic pollutants in water bodies, heavy metal ions are very toxic and carcinogenic in nature. The presence of heavy metal ions in the aquatic environment has been of great concern because of their toxicity at lower concentration. Some metal ions are cumulative poisons capable of being assimilated and stored in the tissues of the organisms, causing noticeable adverse physiological effects. This review presents the sources and toxicity of heavy metal ions like Pb(II), Cd(II),Hg(II), Co(II), Cu(II), As(III), Zn(II) and the remediation techniques adopted in general for the treatment of heavy metal ions from wastewater.

Keywords — **Heavy metal ions, wastewater, toxicity, techniques**

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I. INTRODUCTION

Water is an essential part of our life. It is an important natural resource that has to be conserved. Nowadays there is a critical shortage of clean and fresh water. The problem is not the supply of water. Earth has virtually the same amount today as it had at dinosaur's period[1]. Water pollution is the cause for shortage of fresh water and is a serious issue because of acute toxicities and carcinogenic nature of the pollutants.

Metal ions in water can occur naturally from anthropogenic sources and from leaching of ore deposits, which mainly include solid waste disposal and industrial effluents. The levels of heavy metal ions in water system have substantially increased over time with rapid development of industrial activities**.** Heavy metals are generally considered to be those whose density exceeds 5 g per cubic centimeter. The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. Examples of heavy metals include Lead(II), Cadmium(II), Mercury(II),Cobalt(II), Copper(II), Arsenic(III), Zinc(II) etc. Heavy metals are natural components of the Earth's crust. They cannot be degraded or destroyed. To a small extent they enter our bodies via food, drinking water and air. Some heavy metal ions like (e.g. Copper, Zinc) are essential to maintain the metabolism of the human body. However, at higher concentrations they can lead to poisoning. Heavy metal ions poisoning could result, for instance, from drinking-water contamination (e.g. lead pipes), high ambient air concentrations near emission sources, or intake via the food chain. Heavy metal ions are dangerous because they tend to bio accumulate[2]

The Maximum Contaminated Level (MCL) standards, for some heavy metal ions, established by USEPA are summarized in Table 1. Therefore it is necessary to treat metal ions contaminated wastewater prior to its discharge.

Table 1 The MCL standards for the some hazardous heavy metal ions discharge to the environment[3]

Heavy metal ions	Limit in mg/L
Lead(II)	0.05
Cadmium(II)	0.01
Mercury(II)	0.002
Copper(II)	0.25
Arsenic(III)	0.05
Zinc(II)	0.80

II. SOURCES AND TOXICITY OF SOME HEAVY METAL IONS

Lead(II)

Lead is a natural constituent of the earth's crust. It is present in a number of minerals, the principal ore being Galena (lead sulfide). Lead metal ion is very toxic and carcinogenic in nature. Different industrial wastewater effluent, such as those from electroplating, mining, lead smelting and metal finishing, discharge significant amounts of lead ion in water bodies [4]. Inorganic forms of lead typically affect the central nervous system, peripheral nervous system, renal, gastro vascular, gastrointestinal and reproductive system [5]

Cadmium(II)

Cadmium which is a deadly heavy metal of work related and environmental worry has been recognized as a substance that is teratogenic and carcinogenic to human. Common ways via which Cd get leached to the environment include industrial processes like smelting, alloy manufacturing, and pesticide and anthropogenic activities such as improper disposal of cigarette, unused paints, fertilizers, and Ni/Cd batteries. If ingested beyond the limit, it would affect the kidney or probably damage it [6].

Mercury(II)

Mercury is a major toxic element found in wastewater in the environment. Mercury is released from various pollution sources, such as mining, municipal waste, and chloralkali industry into the environment [7]. As a dominant constituent of environmental inorganic mercury, Hg(II) can combine with the cysteine of human protein. Through sulfate methylation, Hg(II) converts into CH_3Hg – a major organic mercury causing high bioaccumulation in food chains. Serious damage has been reported in the brain, heart, liver and kidneys as well as nervous and metabolic systems, and it even leads to cancer. The gathering effect of food chains would increase the mercury concentration in water by 1000 times with straightforward delivery into the human body[8].

Cobalt(II)

Cobalt is a very toxic element affecting the environment. Cobalt is present in the wastewater of nuclear power plants and many other industries such as mining, metallurgical, electroplating, paints, pig-ments and electronic industries. High levels of cobalt causes several health problems such as paralysis, diarrhea,low blood pressure, lung irritation and bone defects[9].

Copper(II)

Copper is an essential element and is required for enzyme synthesis as well as tissue and bone development. Copper(II) is toxic and carcinogenic when it is ingested in large amounts and causes headache, vomiting, nausea, liver and kidney failure, respiratory problems and abdominal pain[10]. Copper is usually found at high concentrations in wastewater, because it is commonly used metal in many industrial applications, such as metal finishing, electroplating, plastics, and etching . Moreover, copper is a very toxic metal even at low concentration and copper-contaminated wastewater must be treated before discharging it to the environment[11]

Arsenic(III)

Naturally occurring elemental arsenic is ubiquitous and is present in both organic and inorganic forms. Natural water is mostly contaminated with the more toxic inorganic form rather than organic one. Over 200 different mineral forms of arsenic occur, of which Arsenates are about 60%, sulfides and sulfosalts make 20%, and arsenides, arsenites, oxides, silicates, and elemental arsenic make the remaining 20% .Anthropogenic sources exceed the natural sources of arsenic by 3 : 1.The major man-made sources of arsenic contamination are arsenial pesticides, fertilizers, dust of burning fossil fuel, animal, and industrial waste disposal. In natural water, arsenic exists as inorganic arsenate (As(V)) and arsenite (As(III)). Ground water mainly contains As(III) due to the prevailing reducing conditions, while As(V) is mainly found in the more oxidized surface waters.[12]

Arsenic is one of the most toxic elements that can be found. Humans may be exposed to arsenic through food, water and air. Exposure may also occur through skin contact with soil or water that contains arsenic. Levels of arsenic in food are fairly low, as it is not added due to its toxicity. But levels of arsenic in fish and seafood may be high, because fish absorb arsenic from the water they live in. Luckily this is mainly the fairly harmless organic form of arsenic, but fish that contain significant amounts of inorganic arsenic may be a danger to human health. Exposure to inorganic arsenic can cause various health effects, such as irritation of the stomach and intestines, decreased production of red and white blood cells, skin changes and lung irritation. It is suggested that the uptake of significant amounts of inorganic arsenic can intensify the chances of cancer development, especially the chances of development of skin cancer, lung cancer, liver cancer and lymphatic cancer. A very high exposure to inorganic arsenic can cause infertility and miscarriages with women, and it can cause skin disturbances, declined resistance to infections, heart disruptions and brain damage with both men and women[13].

Zinc(II)

Zinc is one of the major heavy metal which finds application in pharmaceutical, paint, catalyst, piping , battery, insecticides and many other industries[14]. High zinc can cause health problems, such as stomach cramps, vomiting, skin irritations, anemia and nausea[15].

III.TECHNIQUES OF HEAVY METAL IONS REMEDIATION FROM WASTEWATER

Some of the techniques for removing heavy metal ions from wastewater are chemical precipitation, adsorption, electrodialysis, ion exchange, coagulation, membrane techniques, biological process, electrochemical treatments etc.

Chemical Precipitation

Chemical precipitation is one of the most widely used for heavy metal removal from inorganic effluent in industry due to its simple operation. These conventional chemical precipitation processes produce insoluble precipitates of heavy metals as hydroxide, sulfide, carbonate and phosphate. The mechanism of this process is based on to produce insoluble metal precipitation by reacting dissolved metals in the solution and precipitant. In the precipitation process very fine particles are generated and chemical precipitants, coagulants, and flocculation processes are used to increase their particle size to remove them as sludge . Once the metals precipitate and form solids, they can easily be removed, and low metal concentrations, can be discharged. Removal percentage of metal ions in the solution may be improved to optimum by changing major parameters such as pH, temperature initial concentration, charge of the ions etc. The most commonly used precipitation technique is hydroxide treatment due to its relative simplicity, low cost of precipitant (lime), and ease of automatic pH control. The solubilities of the various metal hydroxides are minimized for pH in the range of 8.0 to 11.0.[16]

Adsorption

Adsorption is a process where the atoms, ions or molecules of dissolved solids from liquid grips on the surface of solid; i.e. it is a process of mass transfer in which the dissolved solid from liquid gets deposited on the surface of solid because of physical or chemical interaction. The major factors of this method are the technical applicability and the cost effectiveness that needs to be considered while selecting adsorbent to treat wastewater. Adsorbents are of different types and are classified as natural materials, industrial waste, agricultural and biological waste. This provides an economical alternative for removing toxic heavy metals from industrial wastewater and aid in environmental remediation.[17]

Electrodialysis

Electrodialysis process is basically a membrane separation process and it is commonly used for the treatment of waste water. The electric potential is used as a driving force and ion exchange membrane is applied between anode and cathode. On the application of electric current negative and positive ions are moved towards the respective electrodes based on their polarity. Cations are passed though the compartment containing membrane having negative charge and vice versa for anions. The compartments are diluted and concentrated in alternative way. The performance of this process depends upon following parameters current density, pH, flow rate, cell structure, feed water ionic concentration, properties of ion exchange membrane. Membrane fouling is an important factor that results in enhancement of energy consumption and decline of membrane flux.[18].

Ion exchange

Ion exchange is a reversible process during which foreign ions in water are absorbed to functional groups on polymer network (solid phase), and any ionic impurities of water removes. After saturation of the functional groups, the system is under recovery and chemical cleaning operation and re-used. An ion-exchange resin or ion-exchange polymer is an insoluble matrix (or support structure) normally in the form of small (0.5-1 mm diameter) beads, usually white or yellowish, fabricated from an organic polymer substrate. The beads are typically porous, providing a high surface area. The trapping of ions occurs with concomitant releasing of other ions; thus the process is called ion exchange. The ion exchange is selectively characterized as the gradual elimination of specific ion and then the coefficient will selectively fluctuate by resin type, ionic strength, the relative amounts of different ions and water temperature. The exchanger resins are normally shaped beads with approximately 0.1 to 1 mm diagonal, and according to the exchangeable ion, are classified into two groups of anions and cations . Cation resins are able to remove cations, and anionic resins are able to remove anions available in solution [19].

Coagulation

Coagulation with chemical coagulants involves combining insoluble particles and dissolved organic matter into larger aggregates which can be removed in subsequent sedimentation and filtration stages . Coagulants destabilise suspended and colloidal particles in wastewater by forming microfocs. These are aggregated by focculation, which consists of a stirring/agitation procedure that encourages particles to clump allowing their removal in subsequent treatment stages . Mechanisms through which particles and colloids are aggregated and, thus, removed can involve a combination of charge neutralisation, adsorption, entrapment and complexation processes[20]

Membrane techniques

The membrane processes are non-polluting separation methods used in wastewater treatment. In pressure driven membrane separation processes such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO), a pressure gradient over the membrane enables the solvent (water) to permeate the membrane. Solutes existing in the feed solution are rejected to a certain extent, which depends on the membrane type. NF membranes allow passage of dissolved molecules with molecular weight less than 200-1000 Da and of some salts, rejecting the other ones. NF membranes have a less dense structure compared to RO membranes, these configurations require lower operational pressure and energy consumption, also assuring a higher water flux[21].

Biological process

Biosorption of heavy metals by microbial cells has been recognized as a potential alternative to existing technologies for recovery of heavy metals from industrial waste streams. Most studies of biosorption for metal removal have involved the use of either laboratory-grown microorganism or biomass generated by the pharmacology and food processing industries or wastewater treatment units. Many aquatic microorganisms, such as bacteria, yeast and algae can take up dissolved metals from their surroundings onto their bodies and can be used for removing heavy metal ions successfully[22].

Electrochemical treatments

Electrolytic recovery is one technology used to remove metals from wastewater streams. This process uses electricity to pass a current through an aqueous metal-bearing solution containing a cathode plate and an insoluble anode. Electricity can be generated by movement of electrons from one element to another. Electrochemical process to treat wastewater containing heavy metals is to precipitate the heavy metals in a weak acidic or neutralized catholyte as hydroxides. Electrochemical treatments of wastewater involve electro-deposition, electrocoagulation, electro-flotation and electro-oxidation [23].

Table 2. Comparision of technologies to heavy metal removal from wastewater[24]

Method	Advantage	Disadvantage
Chemical precipitation	Simple, inexpensive	Large amount of sludge produced, disposal problems
Chemical coagulation	Most of the metals can be removed	Large consumption of chemicals
Ion exchange	High regeneration of materials	High cost, less number of metal ions removed
Electrochemical methods	No consumption of chemicals, pure metals can be achieved	High capital cost, high running cost
Adsorption using activated carbon	Most metals can be removed, high efficieny(99%)	Cost of activated carbon. Performance depends upon adsorbent
Membrane processes	Less solid waste produced, less chemical consumption, high efficiency	High initial and running cost, low flow rates, removal decreases with presence of other metals

IV.CONCLUSION

This review has focused on the sources, toxicity of some heavy metal ions and various remediation methods like chemical precipitation, adsorption, electrodialysis, ion exchange, coagulation, membrane techniques, biological process and electrochemical treatments for the removal of heavy metal ions from wastewater. By these methods water sources can be saved from contamination of heavy metal ions and the critical shortage of clean water can be overcome.

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