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REVIEW ARTICLE

Treatment of water from heavy metal by using electrochemical techniques

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Abstract

A matter of concern worldwide is the pollution of water by heavy-metal ions. These ions happen naturally, and additionally waste of industrial, waste of emitting radiation, spills of environmental and different waste. Quantification and detection of heavy metals, in addition to their control below certain permitted limits in air, soils, water and media of food, has become the main priority of numerous countries and international organizations because of the destructiveness of these elements. This review shows the water treatment using electrochemical techniques to remove different heavy-metal ions, biodegradability, and toxicity levels, including their advantages and disadvantages. Ion-selective electrodes are instruments used in potentiometric analysis. They have analytical applications in fields, for example, pharmaceutical analysis, environment analysis, and quality assurance in different fabrications.

1. Introduction

Heavy metals in drinking water are considered the main issue for health and prosperity communities. Nowadays, children are most dangerous and have crucial problems with the health effects of lead and other metals. Lead harms children's physical and mental development; it indicates that a low amount has enough to cause reducing in the intelligence quotient (IQ) in children's blood. Also, it can be noticed other mental issues such as behaviour, learning issues and attention span. Many studies emphasized that high amounts of lead in water drinking can affect severe neurological activities like kidney failure, coma and convulsions [1]. Due to treatments facility, water sources generally contain tiny amounts of lead and other metals. At the same time, heavy metals in water are corrosions of metal produced through the peripheral water distribution system, particularly when the households connect lines by ignoring the control treatments of corrosion lead-based plumbing [2,3]. In 1991, United States Lead and Copper Rule (LCR) was first established to measure metals (lead and copper) in tap water. [4]. More attention to the different organizations was increased to control metals in water, especially with growing wastewater from human activities such as metal smelting, plating process, pesticides, mining industry, tanning industry, textile industry, petrochemicals, paper manufacturing, fluidized bed bioreactors, batteries and other industrial electrolysis applications.
One of the most significant problems of the presence of metals in wastewater is the danger of these metals to the environment, ecosystem and healthy life because heaviest metals are toxic, non-biodegradable and can be considered cariogenic substances [5-9]. Therefore, it is essential to control the amount of metals in the water to prevent most the health issues and protect our environment and living organisms. The major

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heavy metals that could detect in trace and moderate amounts in water are zinc (Zn), cadmium (Cd), arsenic (As), lead (Pb), nickel (Ni), copper (Cu), chromium (Cr), mercury (Hg), silver (Ag), manganese (Mn), iron (Fe), boron (B), molybdenum (Mo), antimony (Sb), calcium (Ca) and cobalt (Co). Table 1 shows some heavy metals, depending on their primary sources and the possible saving amount in water.

Table 1: Most heavy metals founded in wastewater with permitted amounts in drinking water depend on the world health organization (WHO) recommendations [9].

Popular heavy metal	Essential sources[10-12]	Essential system affected [13-17]	Acceptable extents (μg) [10]
Arsenic (As)	Production of glass and electronics.	Kidneys, skin, brain, lungs, system of cardiovascular, system of metabolic, endocrine, and system of immunological.	10
Cadmium (Cd)	Paint, industry of steel, industries of plastic, corroded galvanized pipes, batteries, metal refineries.	System of cardiovascular, tests, lungs, brain, liver, kidneys, system of immunological.	3
Chromium (Cr)	Mills of pulp, steel and tanneries.	Liver, lungs, skin, brain, kidneys, system of gastrointestinal, pancreas, tastes, and system of reproductive.	50
Copper (Cu)	Industry of cables and systems of corroded plumbing.	Lungs, brain, liver, cornea, kidneys, system of gastrointestinal system of immunological.	2000
Lead (Pb)	Batteries depended on lead, cable sheathing pigments, alloys, solder, inhibitors of rust, ammunition, plastic stabilizers. and glazes.	System of reproductive, immunological, cardiovascular, and hematological, bones, kidneys liver, lungs, brain, spleen.	10
Mercury (Hg)	Production of electrolytic caustic soda and chlorine, runoff from agriculture and landfills, appliances of electrical , control instruments and industrial apparatus of laboratory, refineries	Kidneys, brain, liver, lungs, system of immunological, reproductive and cardiovascular.	6
Nickel (Ni)	Production of nickel alloy and stainless steel	Skin, kidney, lung, pulmonary fibrosis and gastrointestinal distress.	70
Zinc (Zn)	Production of rubber, coating of brass, aerosol deodorants and various cosmetics.	Anemia, skin irritations, stomach cramps, convulsions, vomiting, and nausea.	3000

2. Methods uses for treatment water from heavy metals

Heavy metals in water surfaces originated from anthropogenic or natural sources. Natural/Geological sources contain eruptions of volcanic, rocks containing metal, sprays of sea salt, fires of the forest, and processes of natural weathering that can start to lose metals from their endemic skies to various sections of the environment. Organic compounds, sulfates, phosphates, oxides, silicates, and hydroxides are some of the forms in which heavy metals can be found out [18]. Fig.1. show the different sources of heavy metals.

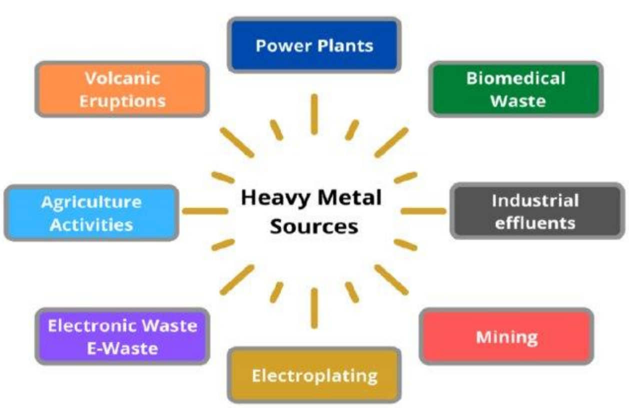

Fig.1: Sources of heavy metal contamination in water and aquaculture [19].

Many chemical methods have been applied to remove toxic metals from water, such as changing hydronium ions' concentration by adsorption capacity. The process is considered one of the most popular and effective methods based on the specific surface area of the adsorbents between hydrogen ions and metal ions. It works by increasing pH with rising in the adsorption of metal ions; in most cases, the best pH for absorption of metal ions asses a good result when it's around 3-5 with keeping the increased metal ions concentration which leads to decreases in the amount of absorption. It should also retain the time of the adsorbent when absorption of the solution increases. This leads to an increased possibility of more contact of the adsorbent substances with the adsorbent. To understand the impact of time, it usually examines the adsorption of specific quantities of adsorbent at different times by leaving other components constant. When the adsorption increases simultaneously, the content time increases, subsequently, until the equilibrium happens. At this point, the concentration of metal ions decreases with increasing in adsorbent quantities at a constant concentration as the amount of absorption increases [20].

Electrocoagulation with adsorption methods is popularly used for removing trace amounts of metals containing zinc (Zn), chromium (Cr) and copper (Cu). The removal of these metals was influenced by increased electrocoagulation time, applied current and amount of sodium chloride. pH 4 is the best value with 60 min for electrolysis time at 2 A of electric current. The data reported good agreement of metal removing around

99.2% Zn, 100 % Cu and 87.6 % Cr. By comparing the amount of Zn, Cu and Cr by using TiO_2: AC, it was found that 5 and 4 g/L of TiO_2:AC dose can successfully release around 96 % Zn, 97.45% Cu and 97% Cr percent from the wastewater, including 50 mg. L^{-1} of each metal. In the same context, it can be said that electrocoagulation and TiO_2: AC process is a beneficial method that can be used in industrial effluents by removing high percentages of Cu, Zn and Cr [21]. Another beneficial method is by converting seeds of some plants, such as albizia lebbeck and Melia azedarach trees. In this technique, the trees can be applied as active carbon adsorbents to eliminate metals of cadmium and lead. This study mostly addressed the collected experimental data by scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR). The controlling conditional factors of Freundlich and Langmuir isotherms systems are dependent on the pH, contact time and the amount of adsorbent used in the reaction. Thus, 0.2 g of active adsorbents at pH five can successfully convert a solution of 100 ml 40 mg/l concentrated solutions at room temperature with time around 120 min to (77- 66%) of Cd while (75 -62%) of lead. This kind of work is considered unexpansive and vital activated adsorbent of carbon to eliminate a wide range of toxic metals from wastewater to safeguard our environment in the future [22]. Green surfactant is another effective system of friendly technology in our environment. Nowadays, many researchers have applied surfactants to separate inorganic and organic contaminants from aqueous media. The main idea of this type of process is based on decreasing residual surfactants. There are three categories of surfactants synthetic chemical surfactant, biosurfactant and green surfactant. By comparison, these different surfactants' efficiency in removal of different heavy metal ions toxicity, biodegradable level and their beneficial treatments and flotation [23]. Hydrous alumino-silicate clay (AlSiM) produced in Kenya is a good adsorbed material to remove many heavy-metal ions from water by measuring the changing temperature, pH and
contact time. In this context, to remove a high level of metals, it needs to apply pH of around 5 with a typical temperature of around 289 – 333 K to realize around 66 mg /L of lead in water samples. The experimental data give agreement with Langmuir and Dubinin-Radushkevich isotherms for $R2 > 0.99$. The D-R adsorption energy gave a (−11.7 kJ/mol) value. In the adsorption reaction, the $\Delta G0$ value was around (−7.45 kJ/mol) at the primary adsorption reaction. Kinetically, it can be reported that surface-chemisorption and film-diffusion are responsible factors in this system and by verifying and investigating data obtained from tannery and leather processing manufacturing for wastewaters. It was found that high efficiency of adsorption of Alumino -Silicate Mineral (AlSiM) for Cr^{3+} (99−100%), Mn^{2+} (85−97%), Zn^{2+} (78−86%) and Fe^{3+} (96−98%).

The determination of heavy metals by AlSiM as a plausible, less expensive adsorbent is described in some of the industrial sewages. [24] Industrial waste and remaining agricultural materials has been used in the elimination of heavy metals; this achieved by using fly ash and rice husk from some companies like in EL-AHLIA, as an example, used these by-products for electroplating industries studies. Most of these studies showed that an expensive adsorbent was effectively obtained to remove around 20–60 mg/L. rice husk was an operative substance to eliminate large amounts of metals such as lead, iron and nickel, while fly ash removed copper and cadmium metals. [25].

The point of view for most studies is to obtain active and unexpansive adsorbents. Recently, pomelo fruit was found to be a good waste adsorbent for eliminating heavy metals from water by the packed bed column technique (PBC). The phytochemical materials detected of albedo then used to test the efficiency of the plant for removing metals. Phytochemical examination of the albedo reported the existence of pectin, volatile oils, tannins, coumarin, lignin, anthraquinone glycosides and terpenoids. The data showed high efficiency in multi-ion systems from these chemicals by-products better than in signal systems. The best removal of Ni and Co was around 94% in acidity 4.5. The lead removal was 96% in 156 min for time content at pH 3.5, while Cd was removed 98 % at pH 6 in 98 min [26]. Bioadsorption is a new organic manner and unexpansive bio adsorbent found to apply for removing heavy metals such in industrial and forest waste. Bioadsorption performances are green solutions for taking away many types of heavy metals from aqueous media. Although chemical methods are the most suitable treatments for contaminated inorganic combinations formed from numerous activities, which is not easy to remove from any physical and biological systems. [27]. Faujasite type zeolite: $9SiO_2: Al_2O_3: 3Na_2O: 120\ H_2O$ is one of the best mineral substances that can remove many heavy metals due to their unique properties as active adsorbent materials. Kinetic studies indicated the suitability of Faujasite to remove about 40% of analyzed heavy metals. The chemical data showed that rates of elimination of metals (Cd, Mn, Sn, Fe, Cr, Ni, Pb, Mg, Zn, Cu) orders from the highest amount in Cd with an adsorbed rate around 86.47 %, while Cu has the lowest rate to removal around 19.27 %. The best analytical method to characterize the performance of zeolite to adsorb metals are scanning electron microscopy (SEM), X-ray diffraction analysis (XRD) and Fourier transform infrared spectroscopy (FTIR). Zeolite has good behaviour as an adsorbent and reliable substance to solve many issues related to pollution caused by different industrial activities [28].

Many recent studies attempted to improve chemical methods in consuming time and high residual of elimination metals from water by a plant to assess the excellent way to decrease pollutants. Some of the literature also demonstrated that water treatment residuals may be responsible substances for improving an efficient adsorbent for the removal of metalloids and heavy metals from different media, not just aqueous systems [29].

3. Ion-Selective Electrode (ISE) Technology

Ion-selective electrodes (ISEs) are a type of electrochemical sensor that essentially convert ionic signals to a calculable electronic signal, regularly electrical. It is an effective class method of sensing metals in potentiometric applications. ISE system typically needs some leading equipment to apply in any electrochemical process, such as suitable reference electrode to quantify the concentration of selection ions in different chemical environments. Recently

ISEs have been promised to sense different heavy metals due to their low limits of detection, varied range, good selectivity, low cost, and movability for in-situ measurements [30–32]. Many composite materials, chelating, inorganic, organic, and intercalating were researched like materials of electroactive for the formulation electrodes membrane of ion-selective. Moreover, electrochemical detection via ISE electrodes has unique characterization for analysis samples; power cost is low, sensitivity with high value, and accessible and available online and in-situ. Electrochemical sensors' detection has been considered an utmost method that improved for continuous online checking of heavy metals. The principles of new detection of electrochemical sensors, attached with modern advances in micro construction and microelectronics, have managed to create powerful devices of compact analytical sensors that can possibly be quickly accepted for continuous monitoring of heavy metals [33,34]. Particularly, microfluidics and lab-on-a-chip (LOC) applications have permitted significant changes in compactness, a decrease in the volume of fluid, and lesser construction costs, amongst other benefits [35–37]. In addition, wireless communication technologies have allowed the improvement of a network for a sensor that assists further effective continuous online monitoring of heavy metals depending on technologies of electrochemical sensation [38]. Due to the points mentioned above, ISE electrode tools keep the favourable potential for online checking trace levels of metals in water. Table 2: illustrates the types of electrodes used to remove heavy metals from water.

Table 2: Types of electrodes used to removal heavy metals from water.

No.	Name of electrodes	Usage of electrodes	Ref.
1	Cadmium Potentiometric Sensor Based on 4-Hydroxy Salophen.	Fast Tool for Water Samples Analysis	39
2	Lead selective electrode based on chalcogenide bulk glass	Membranes based on the $PbI^{2-}Ag_2S\text{-}As_2S_3$ and PbS-Ag2S-As_2S_3 materials show sensitivity to the Pb^{2+} species in solution	40
3	Novel modified carbon paste electrode.	Determination of Cd(II) ions in various samples	41
4	PVC Membrane Electrode Modified by Lawson	Determination of Cadmium in Alloy and Wastewater	42
5	Lead (II) by ion selective electrode	Determination of Lead in water of drink	43
6	Ultrathin ion-selective membranes	To trace detection of lead, copper and silver ions	44
7	Polypyrrole/chitosan composite electrode	Capacitive deionization for removal ions of heavy metal from water of waste	45
8	Ultrasensitive micro ion selective sensor	Multiplex heavy metal ions detection	46
9	Ionic liquid and bismuth oxide nanoparticles modified carbon paste electrode	Determination of trace heavy metals in milk	47
10	Method of electrochemically	Elimination of arsenic oxyanions and chromium in water	48
11	Aluminum and Iron Electrodes	Removal of Heavy Metals [(Ni (II), Pb (II), Cd (II)]	49
12	ZnO Nanoparticles as Nano-Adsorbents	Highly Efficient Removal of Cu(II) Ions from Acidic Aqueous Solution	50
13	Electrocoagulation process (ECP) using aluminum and iron electrodes	Removal of heavy metals from industrial wastewater	51
14	Electrocoagulation using Iron (Fe) as a rotating electrode	Removal of Lead Ion from Wastewater	52
15	Starch Derivatives as Adsorbents to removal Fluoride ions with ion selective electrodes	From Barmer District samples of groundwater	53

4. Conclusions

Potentiometry with ion-selective electrodes is one of the utmost suitable analytical processes that can estimate the verity of organic and inorganic materials at low cost and high reproducibility. In most cases, potentiometry optimized an excellent system to control removing heavy metals in the environmental samples. This review emphasizes that many approaches were documented to improve water quality to be healthy and safe in our environment. One of the best method techniques in water treatment processes is an electrochemical ion selective electrode due to its easy application and high accuracy. Many heavy metals were determined by ion-selective electrodes given away in Table 2. Currently, studies are recommended to form the factors given that wanted modification to describe membrane of ion-selective. While the subject of ISEs is actively examined, it is necessary to increase more attention to the limited uses of ISE in determining and removing heavy metals form.

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