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Heavy Metal Removal Technologies with Details of Ion Exchange: Review study

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Abstract

Heavy metals are currently recognized as one of the most serious environmental challenges, as well as one of the most dangerous environmental contaminants. Due to these metals' toxicity, inability to biodegrade, and tendency to accumulate in organisms and enter the human food chain, they are responsible for a wide range of diseases. Many techniques, including chemical precipitation, membrane filtration, coagulation and flocculation, flotation, electrochemical methods, adsorption, and ion exchange, can be used to remove heavy metal ions from wastewater. several key factors should be considered to ensure effective and efficient treatment methods such as effectiveness, cost, scalability, compatibility with wastewater characteristics, residual management, and environmental impact. A detailed explanation of the ion exchange method was provided because this technique shows great promise in terms of selectivity, availability, thermal stability, chemical compatibility, ionic capacity, and regeneration capability. This study will contribute to the field of sustainable materials science and environmental remediation.

Keywords: Heavy metals, Wastewater, Removal technologies, Ion exchange.

I. Introduction

Globally, the contamination of water, especially groundwater, presents a significant hazard to both human health and the environment, given its status as a primary water source. The primary causes of groundwater pollution are municipal trash and industrial wastewater. The rates of industrial pollution have been continuously rising as a result of fast development and industrialization. Because of the toxicological and physiological consequences of heavy metals, the emission of wastewater from the manufacturing sector into water bodies poses a major environmental risk [1].

Many industries, including those that produce metal coatings, batteries, mining, printing, ceramics, glass, pulp and paper, petrochemicals, pigments, burnish steel, the coal-mining industry, textiles, plating, chemical fertilizers, and plastics, are producers of heavy metals. The health effects of elevated heavy metal concentrations in water can be attributed to their non-biodegradable nature[2].

Table 1 shows the sources and impacts of various heavy metals. These metals cause a variety of diseases because of their toxicity, non-biodegradability, and propensity to build up in organisms and enter the human food chain. Heavy metals are now regarded as one of the most significant environmental issues and are one of the most dangerous environmental pollutants due to strict regulations[3].

While heavy metals are necessary for life and are found in the environment naturally, when they accumulate in an organism, they can be dangerous. The most common heavy metals found in the environment are lead, nickel, copper, chromium, cadmium, arsenic, and mercury[4].

Table 2 compares the heavy metal concentration (mg/l) for the World Health Organization WHO with Iraqi guidelines[5] - [6].

Therefore, these hazardous metals need to be taken out of wastewater and industrial effluent to protect people and the environment. Heavy metal ions can be eliminated using a variety of techniques, such as electrochemical methods, ion exchange, filtering with membranes, chemical precipitation, and adsorption [3].

The main advantages and disadvantages of using wastewater treatment techniques to remove heavy metals are indicated in Table 3.

Table 1: list of the sources and impacts of various heavy metals[7].

Heavy metals	**Sources**	**Impact on health**
Cadmium	Erosion of bedrock rain in industrial regions leaking from the landing.	carcinogenic, damaging the bones, and lungs, and anemia.
Lead	Lead batteries, glass and ceramic industries, electronic trash.	Temporary memory loss, cardiovascular disorders, impaired child development.
Arsenic	manufacture of smelted coal, mining of arsenic	Vascular and skin disorders,
Nickel	Mining, petroleum refineries.	Neurotoxic, skin disease, lung cancer.
Copper	Metals smelting metals, extracting minerals, producing steel.	Wilson disease, damage to the liver, brain, and kidney.
Zinc	Mining, dust, nickel plating, etc.	nausea and vomiting, anemia, and abdominal pain.

Table 2: Iraqi and WHO guidelines for the concentration of heavy metals (mg/l).

Heavy metals	Iraqi determinants for maintaining the rivers and streams from 1967[5].	Iraqi standards for residential use and drinking water quality from 1984, with an initial upgrade from 2001[8].	WHO drinking water standards from 2022[6].
Cd	0.005	0.003	0.003
Pb	0.05	0.01	0.01
As	0.05	0.01	0.01
Ni	0.1	0.02	0.07
Cu	0.05	1	2
Zn	0.5	3	3

Table 3: Major advantages and disadvantages of wastewater treatment techniques for heavy metal removal[9].

Treatment technology	advantages	disadvantages
Adsorption method	Low cost, simple conditions for operation, broad pH range, strong metal binding abilities, and quick kinetics.	Poor selectivity.
Membrane filtration method	Low generating of solid waste, low use of chemicals, and reduction of operating space.	Limited flow rates, fouling of membranes and High operating, maintenance, and capital costs.
Chemical method	Low initial cost and simple to operate.	Formation of sludge, high cost of maintenance, and high cost of removing sludge.
Electrochemical method	High selectivity of separation and there is no need for chemicals.	Higher operating costs and needs filtration for flocs.
Ion exchange method	High selectivity for metals, higher regeneration, and low ability to tolerate pH.	High cost of investment and operation.

The objective of this review is to make a comparison between the different technologies that are used for the removal of heavy metal ions from wastewater as shown in Table 4 and to study the structure, classification, properties, applications, advantages, and disadvantages of the ion exchange resin.

Table 4: Maximum range of heavy metal removal efficiency for different techniques[10].

Technology	Heavy metal	Maximum removal efficiency range %
Adsorption method	Cd	75-98 %
	Pb	90-99 %
	As	90-99 %
	Ni	89-99 %
	Cu	90-99 %
	Zn	90-99 %
Membrane filtration method	Cd	85-95 %
	Pb	93-99 %
	As	86-98 %
	Ni	94-99 %

	Cu	85-98 %
	Zn	90-99 %
Chemical method	Cd	85-95 %
	Pb	85-97 %
	As	85-95 %
	Ni	> 97 %
	Cu	> 97 %
	Zn	80-95 %
Electrochemical method	Cd	85-99 %
	Pb	80-97 %
	As	80-95 %
	Ni	88-99 %
	Cu	80-95 %
	Zn	85-99 %
Ion exchange method	Cd	90-97 %
	Pb	86-97 %
	As	85-98 %
	Ni	90-99 %
	Cu	88-98 %
	Zn	90-98 %

II. Heavy Metal Removal Technologies:

1. Adsorption method

In most cases, the adsorbent's surface can absorb the heavy metal ions. It has been noted that regenerating the adsorbed heavy metal ions has cheap operating costs, an excellent removal capacity, is simple to execute, and requires minimum treatment [11].

Adsorbents can be classified into two categories: natural and synthetic. Natural adsorbents include clay and zeolite, which are inexpensive and widely available. However, scientists can create artificial adsorbents (activated carbon) using trash from industry, households, and agriculture. The distinct surface area and porosity structure of each of these adsorbents improve their adsorption abilities[12].

The next sections will concentrate on the most popular adsorbent material.

Carbon adsorbents: adsorbents with a nanoporous carbon base, particularly activated carbons (ACs), carbon nanotubes (CNTs), and graphene (GN), are frequently used in heavy metal removal applications due to their large surface area (500–1500 m^3 /g)[13].

functional groupings on the surface (such as carboxyl, phenyl, and lactone groups) can increase the surface charges of carbon to improve heavy metal absorption. The most widely used modification techniques to improve the specific surface area, pore structure, adsorption capacity, thermal stability, and mechanical strength are nitrogenation, oxidation, and sulfuration [14], [15].

Surface modification frequently results in a decrease in surface area and an increase in the number of surface functional groups. This increases the amount of metal ions that can be adsorbed [16].

Adsorbent surface area, dose, initial metal ion concentration, and length of contact time all influence adsorption uptake [17].

Chitosan adsorbents: Because it contains hydroxyl (OH^-) and amino (NH_2^-) groups, chitosan (CS), a naturally occurring adsorptive polymer, has an affinity for pollutants found in wastewater streams [18].

Its weak stability and inadequate mechanical durability, despite its unique features, render the regeneration ineffective. Furthermore, because of its high crystal structure, poor porosity, low surface area, resistance to mass transfer, and poor mass transfer, chitosan is difficult to use in powder or flake form [19].

Consequently, recommendations have been made on structural and chemical modifications to rectify these deficiencies [20].

Mineral adsorbents: Mineral adsorbents with low running costs, such as zeolite, silica, and clay, are thought to be good options for treating water [21].

High swelling/expanding capacity, ion exchange selectivity, surface hydrophilicity, and surface electronegativity are just a few of the remarkable qualities of clay [22].

In addition, the pore size, pore volume, and specific surface area can be enhanced by pillar bearing, heat treatment, and acid washing, all of which would lead to notably better adsorption effectiveness. The most prevalent processes regulating wastewater treatment using mineral adsorbents are ion exchange, chemical adsorption, and physical adsorption, according to research studies [23].

2. Membrane Filtration methods

Ultrafiltration: For ultrafiltration (UF), lower transmembrane operating pressure (TMP) is used. Additives may be linked to the heavy metal ions to increase their size since the Ultrafiltration membrane pores could be larger than the metal ions themselves. Therefore, it is advised to use polymer-enhanced ultrafiltration (PEUF) and micellar-enhanced ultrafiltration (MEUF). Bonding between ultrafiltration UF and surfactant forms micellar-enhanced ultrafiltration MEUF. MEUF has elevated selectivity and high flux, which results in high removal efficiency, low energy consumption, and reduced space requirement [22].

Wastewater with low concentrations of heavy metals is best suited for MEUF. Wastewater is combined with a surfactant in micellar-enhanced ultrafiltration (MEUF) at a concentration higher than the critical micellar concentration (CMC). Surfactant monomers combine and promote the formation of certain micelles in the solution over and beyond the critical micellar concentration. The hydrophilic head and hydrophobic tail of the surfactant are present. The interior hydrophobic core of the micelles can dissolve low molecular weight organic molecules, while the surface of the micelles uses electrostatic interactions to adsorb counter-metal ions [24].

Nanofiltration: It is a method that is used to remove solutes with molecular weights larger than 200 Da and concentrate components with molecular weights greater than 1000 Da. Consequently, NF's operational range falls between Ultrafiltration and Reverse Osmosis procedures [25].

Polymer composites with multiple-layer thin-films containing chemical groups with negative charges make up the nanofiltration membranes. PES, CeO_2/Ce_7O_{12}, and phase inversion were utilized to build anti-fouling NF membranes. Then these membranes were used to extract Fe^{2+}, Al^{2+}, Co^{2+}, Cd^{2+}, Cu^{2+}, and humic acid from wastewater, with extraction efficiencies ranging from 94% to 98% [18].

Microfiltration: In order to extract micron-sized particles, bacteria, viruses, protozoa, contaminants, pollutants, etc. from a solvent, fluid, or solution, microfiltration (MF) uses a microporous membrane. The membrane method known as MF runs at low pressure and has membrane holes with a diameter ranging from 0.1 to 10 µm. Certain MF membranes are made from alumina, zirconia, silica, ceramics, polysulfone, PTFE, polypropylene, PVDF, polyamides, polycarbonate, cellulose acetate, cellulose esters, and composite materials [25].

Reverse osmosis: A semipermeable membrane with pore sizes of 0.5–1.5 nm is used in separation process due to pressure known as Reverse Osmosis (RO) to restrict the passage of larger molecules. Pressure (20–70 bar) >to reverse the natural osmosis process, the feed solution's osmotic pressure is applied during the RO process. The inhibited solutes typically have molecular sizes between 0.00025 and 0.003 µm. The recovery rate of charged organic and inorganic salts using the Reverse Osmosis method is 95–99%. Reverse osmosis is a compact technique with a high rejection rate. However, the main flaw with RO systems is membrane fouling and deterioration [25].

With a removal efficiency of >98.75, ions of heavy metals, including Ni^{2+}, Cr^{6+}, and Cu^{2+} were extracted from electroplating wastewater using the Reverse Osmosis separation process [26].

Forward osmosis: A membrane is needed for the process known as forward osmosis (FO) to balance permeated water flux and selectivity [22].

A semi-permeable membrane divides the feed solution and the draw solution in forward osmosis. The osmotic pressure of the draw solution is usually higher than that of the feed solution. Water migrates from the feed solution to the draw solution as a result of the osmotic pressure differential between the two solutions, keeping the rejected solutes on the feed side and the treated water in the draw solution. Energy is saved by the Forward Osmosis since it doesn't require hydraulic pressure. The Forward Osmosis method is widely used in wastewater treatment because it has low fouling, is easy to clean, and is environmentally friendly. For example, to achieve a high Cd, Ni, and Pb removal (> 94%), a novel polydopamine/metal-organic framework thin film nanocomposite (PDA/MOF-TFN) forward osmosis (FO) membrane was created for salt rejection and heavy metal ion removal [27].

Electrodialysis: Electrodialysis (ED) employs an electric potential difference to separate ions. Anion exchange membranes (AEM) and cation exchange membranes (CEM), alternatively organized in parallel, are the series of membranes that ED uses to separate ionic solutes [22].

During the Electrodialysis (ED) process, anions go through AEM and cations through CEM. Here, the concentrated stream is ejected from one-half of the ED stack channels while the treated stream (diluate) is generated from the other. Excellent water recovery, no phase shift, no reaction, and no chemical involvement are all provided by ED. It functions throughout a broad pH range [28].

3. Chemical method

Heavy metals may be extracted from wastewater using well-proven chemical methods.

Chemical precipitation: One of the most well-known and effective procedures, chemical precipitation, often referred to as coagulation precipitation, is used extensively in industry. To aid in sedimentation, it transforms dissolved metal ions into solid particles. Co-precipitation is the process by which metal ions and other substances in the solution precipitate simultaneously. Metal ions' solubility can be changed by pH modification, which encourages their precipitation. The term "electro-oxidizing potential" describes the use of an electrical potential to cause metal ions to oxidize and precipitate. After precipitating, the metal ions combine to create insoluble compounds that eventually settle as sediments. The metal pollutants in the wastewater are subsequently eliminated by physically separating these particles from the liquid phase using techniques like sedimentation or filtering. [22].

Hydrogen precipitation is a commonly used method since its pH may be adjusted, it's easy to use, and it costs not too much. For instance, a reaction between a metal ion and calcium hydroxide (lime) might result in the precipitation of both calcium ions and metal hydroxide [22].

$$\text{Metal}^{n+} + Ca(OH)_2 \leftrightarrow \text{Metal}(OH)n \downarrow + Ca^{+2}$$

Coagulation and flocculation: Agglomeration of destabilized particles is known as flocculation, whereas instability of colloids by the removal of forces holding them apart is known as coagulation. Typical coagulants consist of ferrous sulfate, ferric chloride, and aluminum, which neutralize ion charges. Large agglomerate-forming particles are joined by flocculation, which is facilitated by a flocculant such as poly aluminum chloride (PAC), poly ferric sulfate (PFS), polyacrylamide (PAM), or other macromolecule flocculants. The sludge that was created may be toxic, despite the fact that the PE was thought to be among the most beneficial flocculations. The flocculants are often neither natural nor biodegradable [29].

Flotation: A method for removing different metal ions is flotation. Extensive research was conducted on precipitation flotation, ion flotation, and dissolved air flotation. Dissolved air flotation raises the flocs through the wastewater by feeding air (or gas) into the wastewater, which forms micro-bubbles that may adhere to metal ions and produce lower-density agglomerates. The slug that has gathered at the upper surface is easy to remove [30].

4. Electrochemical method

Electrocoagulation: In electrocoagulation, coagulants are created in the field by the electrical dissolution of iron or aluminum ions from iron or aluminum electrodes, respectively. Hydrogen gas is emitted from the cathode while metal ions are generated at the anode. The flocculated particles would float out of the water with the assistance of the hydrogen gas. This method is often referred to as electrofloculation. Both mono-polar and bi-polar configurations for the electrodes are possible. The materials can be packaged as scraps like millings, steel turnings, or iron or aluminum plates[31].

Electroflotation is a simple method that uses hydrogen and oxygen bubbles created by water electrolysis to float contaminants to the water's top. Consequently, the electrochemical events occurring at the cathode and anode are reactions involving the evolution of hydrogen and oxygen, respectively[32].

5. Ion exchange treatment

Ion exchange is a technique used to get rid of dissolved ionic constituents that can have negative effects on one's appearance and health. Since large-scale plants rarely employ the ion exchange method for water treatment, it is regarded as a nonconventional process [33].

The ion exchange resins, also known as IERs, serve as a medium for different organic polymers while they exchange different ions. Typically, it takes the shape of insoluble, solid microbeads with a 0.25–1.43 mm radius that are made of organic substrate and are yellowish or white in color [34].

It contains a synthetic functional organic polymer material and an active group. It is obtained by covalently bonding a polymer, also known as a copolymer or cross-linked polymer, to ion exchange groups. Usually, nitrogen and oxygen serve as donor atoms in resin molecules. Current ion exchange techniques capture dissolved ions for the purpose of purifying aqueous solutions or mixtures. The ability to maintain high temperatures, its insoluble nature in a wide range of aqueous and organic solutions, and its broad pH range of application are among an IER's most beneficial qualities. Crosslinking of polystyrene is commonly found in IERs[35].

There are two types of materials that make up the exchange resin: synthetic organic material and naturally occurring materials like zeolite. A resin might be anionic or cationic.

5.1. Ion exchange resin structure

The three parts of an ion exchange resin are the ion functional group attached to the insoluble three-dimensional space network polymer skeleton, the exchangeable ion pore with opposing charges on the functional group, and the ion skeleton[36].

Polymer skeleton: It is made up of cross-linked polymers, such as polyacrylic acid and cross-linked polystyrene[36].

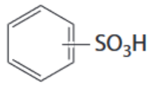
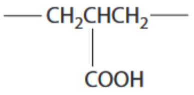
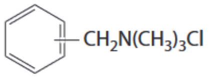
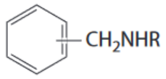
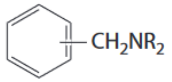
Ion exchange group: It is attached to the skeleton of the polymer and contains polar non-ionic functional groups like -N(CH3)2, -N(CH3)H, etc., or ionic functional groups containing exchangeable ions like -SO3Na, -COOH, -N(CH3)3Cl, etc [36].

Pore: This refers to the capillary pore that exists between the polymer structures in both wet and dry ion exchange resins, as well as the pore found in the polymer structure (gel pore)[36].

5.2.Classification of Ion Exchangers Employing Functional Groups

Depending on the functional group of the resin, synthetic exchangers may be categorized into four main categories as shown in Table 5. The functional group governs whether cations or anions are exchanged and if the resin is a strong or weak electrolyte [36].

Table 5: The Classification of Synthetic Ion Exchangers Employing Functional Groups [36]

Type	Active group	Typical Configuring
Strong Acid Cation Resins	Sulfonic acid	
Weak Acid Cation Resin	Carboxylic acid	 $-CH_2CHCH_2-$ with $COOH$ below
Strong Base Anion Resins	Quaternary ammonium	
Weak Base Anion Resins	Secondary amine	
	Tertiary amine (aromatic matrix)	

A. Strong Acid Cation Resins (SAC):

Strong acid resins get their name from the fact that they behave chemically like strong acids do. Both the acidic ($R-SO_3H$) and the basic ($R-SO_3Na$) forms of the resins are highly ionized. Through a reaction, they can change a metal salt into the appropriate acid [37].

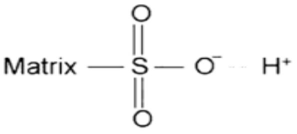
$$2(R-SO_3H) + NiCl_2 \rightarrow (R-SO_4)Ni + 2\ HCl$$

R stands for the resin's organic component, and SO_3 stands for the ion active group's immobile component. SAC resin is available in highly dissociated forms for both sodium and hydrogen, with easy access to exchangeable H^+ and Na^+ over the pH range.Therefore, the pH of the solution has no effect on the exchange capacity of SAC resin. These resins are used for complete deionization in the hydrogen form and for water softening (removal of calcium and magnesium). Once the resin has run out, it may be converted back into either the sodium or hydrogen forms by coming into contact with a strong acid solution or a sodium chloride solution [38].

B. Weak Acid Cation Resin (WAC):

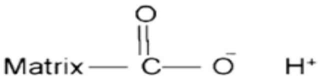
While the ionizable group (i.e. functional group) in SAC resin is a sulfonic acid group (SO_3H), in WAC resin it is a carboxylic acid (COOH). These are the functional groups of the SAC and WAC resins.

Strong Acid
Cation (SAC)



(Sulphonic acid group)

Weak Acid
Cation(WAC)



(Carboxylic acid group)

Due to the strong electro-negative nature of the sulfur atom in SAC resin, electrons are drawn from the oxygen atom by the sulfur, which in turn sucks electrons from the hydrogen atom, increasing the electro-positiveness of the hydrogen atom. This characteristic allows the resin to function similarly to a strong acid. As a result, it has the ability to separate both alkaline and neutral salts. However, a WAC resin behaves more like a weak acid because the carbon atom in it is relatively less electronegative and, as a result, there is a relatively smaller flow of electrons from the hydrogen atom. It does not affect neutral salts; however, it can split alkaline salts. Compared to SAC resins, WAC resins show a significantly stronger affinity for hydrogen ions at the other site. Because of this property, regeneration to the hydrogen state is possible with significantly less acid than is needed for SAC resins. The pH of the solution has a significant impact on a WAC resin's degree of dissociation. As a result, the pH of the solution affects resin capacity in part; that is, the resin can exchange ions only if the pH allows for the ionization of their functional groups [38].

C. Strong Base Anion Resins (SBA):

Similar to strong acid resins, SBA resins are highly ionized and may be employed in any pH range. Water deionization uses these resins in their hydroxide (OH) form. They can change an acidic solution into pure water by reacting with anions in the solution.

$R\text{-}NH_3OH + HCl \rightarrow R\text{-}NH_3Cl + H\text{-}OH$

The depleted resin is transformed into the hydroxide form through regeneration using concentrated sodium hydroxide (NaOH) [37].

D. Weak Base Anion Resins (WBA):

These resins are similar to WAC resins in that pH has a significant impact on the degree of ionization. As a result, the pH ranges up to 7.0 is where WBA resins exhibit their maximum exchange capacity. They cannot split salts, but they hardly ever adsorb strong acids [38].

5.3.Ion exchange resin properties:

Swelling:

Ion exchange resins have a tendency to swell. The kind of functional group and cross-linking in a resin control how much moisture it hydrates. Low cross-linking gel resins that include quaternary ammonium or sulfonic acid functional groups contain a lot of water, which causes swelling. Resin's lifetime is shortened by frequent expansion and contraction[1].

Capacity:

It is the quantity of chemical equivalents of ions that a unit of resin (dry weight/wet weight/wet volume) can absorb. Cross-linking reduces the dry basis capacity because strongly cross-linked polymer molecules may have fewer functional groups attached to them. As a result, the wet basis capacity increases as the cross-linking amount increases and the resin becomes more hydrated[1].

Particle size:

Ion exchange resins come in various particle or bed sizes. Ion exchange resins that are often employed are produced as uniform particle size (UPS) or as polydisperse spherical beds with sizes varied between 0.01 and 0.05" (0.25 and 1.25 mm). While smaller particles increase the water pressure drop and reduce flow rate, they also enhance the ion exchanging reaction's kinetics[1].

Stability:

The toughness of the polymer structure (cross-linking) and the frequency of swelling-contraction cycles influence the mechanical (physical) stability of ion exchange resins. Ion exchange resins can degrade chemically due to precipitates (such iron hydroxide), clogging the resin pores through polymer structural disruption, or loss of ion exchange capability as a result of functional group modifications. Researchers are interested in the ion exchange approach because of its high sorption efficiency in liquid media and selectivity when compared to other methods used for the removal of harmful metal ions. The synthesis of some organic-inorganic hybrid materials has attracted attention recently due to their appealing mechanical qualities, stiff inorganic backbone, and flexible organic functional groups that offer particular chemical reactivity[1].

5.4.Ion exchange resin applications:

1. **Metal recovery and removal from various industries:** utilized in wastewater treatment to extract, separate, and remove heavy metals[1].
2. **Softening:** a strong acid cation exchange resin with sodium form is used to eliminate hardness by removing calcium and magnesium ions from water[39].
3. **Demineralization:** The water must pass through anion resins in hydroxyl group, where all the anions will be removed along with the ones from the resins, after first passing through cation resins in hydrogen form, where all the cations in the water will be removed. Therefore, we assume that these new ions—H+ and OH-—will join to produce a water molecule at the end of the process[40].
4. **In sugar industry:** Anion exchange macroporous resins with high basicity are used in the color removal process. High molecular mass molecules can be eliminated due to the macroporous structure of the material[39].
5. **In beverage industry:** used to treat the water to produce soft drinks, remove metals, eliminate bad tastes and odors, add or remove color using non-ionic adsorbent, and demineralize gelatin[39].
6. **Chemical industry:** in the removal or recovery of metals, in the synthesis of caustic soda and chlorine, and in the elimination of organic acids and sulfuric acid from streams during the phenol production process[39].
7. **As a catalyst:** Strongly acidic cation exchange resin in the H+ form is utilized in the petrochemical industries for the processes of alkylation, condensation, etherification, dehydration, and hydrogenation[39].

8. **In pharmaceutical industries:** used for antibiotic extraction, purification, and taste masking[39].

5.5. Advantages and Disadvantages of ion exchange resins:

Advantages of the ion exchange process

Ion exchange is a widely used technique for heavy metal removal from wastewater. The following are some advantages of this process [2],[41]:

1. Demonstrated capacity to eliminate diverse contaminants from different quantities using an extensive range of resins.
2. The ability to tolerate varying feed flow rates.
3. Low usage of energy.
4. A wide range of particular resins are offered by suppliers; Technically sound solutions that satisfy all system design standards are provided by accumulated experience.
5. Certain pollutants can be effectively removed by each resin.
6. Maybe run at a high flow rate;
7. The discharged effluents can gain regulator acceptance;
8. Quick reaction and straightforward process operation
9. Cost-effectiveness, which may be enhanced even more by technological advancements like the introduction of low-cost, extremely resilient ion exchange materials.
10. Regenerating chemicals are inexpensive, and with proper care, resin beds may endure for many years before needing to be replaced.

Disadvantages of ion exchange process

Although the ion exchange process applications' many and varied applications, there are a few restrictions that need to be carefully considered during the design phase. Some of them are [2],[41]:

1. High concentrations of grease, oil, and suspended particulates (more than 10 ppm) in wastewater can block nonselective resins.
2. Although waste volume can be decreased, waste brine from the regeneration stage needs to be treated and disposed of.
3. Non-selective resins that have been used up must be replaced often and disposed of carefully.
4. Non-selective exchange resins may have a limited effectiveness due to competitive absorption by other ions.
5. The site's water chemistry, such as the pH of the water supply and the presence of competing ions, has a significant impact on the effectiveness of treatment.
6. The ion exchange resin may be harmed by oxidants found in groundwater; this is typically not possible in situations with high total dissolved solids (TDS).

7.For the majority of surface water treatments, pretreatment is necessary.

8.During the regeneration stage, wastewater is produced; further treatment and disposal are necessary.

III. Conclusion

It is evident from the explanation above that there are advantages and disadvantages to any method for eliminating metal ions as shown in table (3), and that it is not always the best choice.

Adsorption demonstrated a high sorption capacity, low cost, and simple operation. Creating economical and environmentally friendly adsorbents from waste is the current direction of research. It is challenging to appropriately dispose of these adsorbents to avoid posing a risk to the environment after the adsorption process.

Membrane techniques are becoming a more viable option for treating wastewater and play a big part in the process. For certain applications of separation, like desalination, they are already the most appropriate. Extraction efficiency of metal ions is high in membrane processes.

However, this technology has some disadvantages, such as membrane fouling and biofouling, limited recovery for the amount of wastewater fed in, process complexity, membrane cleaning intervals, and high cost.

Chemical-based separations have been widely used in the removal of heavy metals because they are low-cost and simple to utilize. Nevertheless, chemicals are used to alter pH levels and promote ion accumulation. There is a large amount of sludge accomplished, which requires further processing.

The electrochemical method offers the benefits of being quick, well-controlled, simpler to remove sludge from, and requiring fewer chemicals. The primary drawbacks of this technique are its high energy consumption, low throughput, and expensive anodes and cathodes.

Comparable to adsorption techniques, the ion exchange approach is recommended for applications requiring increased capacity, regeneration capabilities, precise control over the purification process, and selective removal.

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تقنيات إزالة المعادن الثقيلة مع مراجعة مفصلة لعملية التبادل الأيوني

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الخلاصة

تُعتَبَر المعادن الثقيلة حالياً من أكبر التحديات البيئية وأكثرها خطورة، إذ تُصَنَّف كأحد أخطر الملوثات البيئية. نظراً لسمية هذه المعادن، وعدم قدرتها على التحلل البيولوجي، وميولها للتراكم في الكائنات الحية ودخولها في سلسلة الغذاء البشري، وبالتالي هي مسؤولة عن مجموعة واسعة من الأمراض. يمكن استخدام العديد من التقنيات لإزالة أيونات المعادن الثقيلة من مياه الصرف ، بما في ذلك الترسيب الكيميائي، والترشيح بالاغشية، والتخثير والتكتل، والتعويم، والطرق الكهروكيميائية، والامتزاز، والتبادل الأيوني. يجب أخذ عدة عوامل رئيسية في الاعتبار لضمان كفاءة طرق المعالجة، مثل الفعالية، التكلفة، القابلية للتمدد، التوافق مع خصائص مياه الصرف، إدارة النفايات، والأثر البيئي. تم تقديم شرح مفصل لطريقة التبادل الأيوني لأن هذه التقنية تظهر نتائج واعدة من حيث الانتقائية، وتوافر المواد، والثبات الحراري، والتوافق الكيميائي، والسعة الأيونية، وقدرة التجديد .

الكلمات الدالة:– المعادن الثقيلة، مياه الصرف، تقنيات الإزالة، التبادل الأيوني.