Elimination of Heavy Metal Ions from Industrial Wastewater: A Review

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ABSTRACT : One of today's most serious environmental concerns is heavy metal pollution. Heavy metal cleanup is of special relevance because of their tenacity and persistence in the environment. In recent years, a number of methods for removing heavy metals from wastewater have been studied in depth. A review and analysis of the wastewater treatment for elimination of heavy metals are presented in this paper. A few of these techniques include chemical precipitation, ion exchange, membrane filtration, coagulation and flocculation techniques as well as electrochemical approaches. From 2011 through 2021, this article analyses a wide range of published studies. As demonstrated by the literature survey, ion exchange, adsorption and membrane filtration are the most widely investigated techniques for the treatment of heavy metal wastewater. In addition to the initial metal concentration, wastewater composition, investment and operating costs, plant flexibility and reliability, and environmental impact, among other factors, play a role in determining most suited treatment process. For low-concentration heavy metal wastewater treatment, adsorption employing inexpensive adsorbents and biosorbents is considered a cost-effective and efficient technique. Membrane filtering technique may be used to remove heavy metal ions with remarkable efficiency.

Keywords: Heavy metal , Treatment Methods ,Industrial effluents ,Review ,Bisorbents

1 INTRODUCTION

Fresh drinkable water resources are the world's most vital reservoirs. It is critical for all living things on the planet to have access to sufficient amounts of clean water. Due to global population expansion, growing industries, and long-term droughts, available water supplies are diminishing. Aside from over- exploitation, pollution of natural water supplies by refractory pollutants discharged by industry exacerbates water scarcity, even in regions with abundant water. To minimize water shortages for a short period, rainfall streams or storm water can be stored, but the ideal solution is to clean and reuse wastewaters (polluted water coming from industries, businesses, and residences) Toxic contaminants from human enterprises, such as mining or agricultural operations that do not use environmentally friendly practices, or natural phenomena, such as volcanoes, earthquakes, or storms, are nearly always found in wastewaters. (Fu, F., & Wang, Q. (2011).) Organic, inorganic, and biological particles are the three primary categories of contaminants. Heavy metals and toxic must be removed since they are poisonous and carcinogenic chemicals that should not be released directly into the environment. Because of their poisonous, non-biodegradable, and long-lasting nature, heavy metals such as arsenic, copper, cadmium, chromium, nickel, zinc, lead, and mercury are significant contaminants of fresh water reservoirs. Heavy metals are introduced into many segments of the environment, including the air, water, soil, and biosphere, as a result of industrial expansion. Due to their high solubility in aquatic settings, heavy metals are rapidly absorbed by fish and plants. As a result, through the food chain, they may accumulate in the human body. To reduce heavy metal concentrations in water and wastewater, several techniques have been devised and used. Membrane filtration, ion exchange, adsorption, chemical precipitation, nanotechnology treatments, electrochemical, and advanced oxidation processes are among these technologies. Heavy metal ions are elements from the periodic table's fourth period, primarily chromium (Cr), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), and mercury (Hg) .Heavy metal ions are found naturally in the environment, but their concentration is increasing due to growing industrial wastes. Toxic metal ions make their way into the food chain and ultimately into the human body. (Azimi, A., Azari& Ansarpour, M. (2017)). When they build up to dangerous levels in an organ, they can lead to significant health problems. Too much zinc, for example, might lead to skin irritations, vomiting, and stomach pains. Lung and kidney cancer are caused by excessive Ni concentrations. Because wastewater is a major source of illnesses and a barrier to human population development, it must be treated to breakdown contaminants into less harmful forms. Because heavy metals are not biodegradable, they stay in the human body for a long period.[1,2]

2. METHODS FOR TREATING HEAVY METAL WASTEWATER

2.1 CHEMICAL PRECIPITATION

$Ca(OH)_2$, (NaOH) and soda ash were used for simultaneous removal of Cu(II) and Zn(II) from industrial effluent. Copper and zinc removal efficiency was improved by increasing the precipitating reagent dosage (10–400 mg/L) for each reagent utilized. Over 90 percent efficiency may be attained. (Benalia, M. C. & Menasra, H. (2021).) The effectiveness of chemical precipitation depends on the pH of the treatment. For each precipitating agent, the removal of copper is somewhat greater than that of zinc at high pH levels. The residual metal concentration was in compliance with industrial discharge regulations. $Cu(OH)_2$ precipitated as amorphous hydroxides in the sludge product. copper has been shown to include extra phases, as determined by X-ray diffraction (XRD). Imagery taken using a scanning electron microscope (SEM) shows that the sludge's generated are not big and dense in structure. All recovered sludge had a greater copper content than zinc, according to EDX (energy-dispersive X-ray spectroscopy). Water treated with soda ash produced a smaller volume and larger sludge product.[3]

2.1.1 HYDROXIDE & SULPHIDE PRECIPITATION

Water from the plating business may include a variety of heavy metals. Copper, nickel, cadmium, chromium, silver, zinc, and lead are the most prevalent heavy metals. Hydroxide precipitation and sulphide precipitation were used in this work to remove three types of metals, copper, zinc and chromium trivalent. jar test used to establish the optimal pH level and dose of coagulant and precipitant agents. A ferric chloride ($FeCl_3$), polyaluminum chloride (PAC), sodium hydroxide and sodium sulphide were employed as coagulants and precipitants, respectively. Metabisulfite of sodium was used to convert chromium hexavalent to trivalent. (Yatim, S. R. M., Zainuddin,& Kamsuri, S. N. H. (2021)) A hydroxide precipitation may remove 86.61 percent of copper, 99.81 percent of zinc, and 99.99 percent of chrome trivalent. 99.37 percent of zinc and 99.99 percent of trivalent chrome were removed by sulphide precipitation. Sulfide precipitation may remove mixed heavy metals better than hydroxide precipitation, and generates less total suspended solid compared to hydroxide.[4]

The electroplating effluent contains a huge amount of hexavalent chromium which is quite toxic. Therefore, the reduction of Cr(VI) to Cr(III) which is less harmful is the easiest thing to do at the site. The sodium metabisulfite is a better reducing agent than ferrous sulfate for the case of Cr(VI) since the amount of reducing agent required to reduce is considerably less. It was observed that 99.86% and 99.97% of Cr(VI) was reduced by using 1100 mg/L ferrous sulfate and 100 mg/L sodium metabisulfite, respectively. (Verma, B., & Balomajumder, C. (2020)). The maximum reduction is achieved at a pH of 2. In order to precipitate the Cr(III), precipitating agents are used in alkaline medium (pH around 9). The best combination is hybrid of $Ca(OH)_2$ + NaOH as the removal efficiency is maximum (98.2%). Also the sludge generated is quite low (9.7 mL/L). Therefore, the electroplating effluent containing huge amounts of Cr(VI) can be first treated with chemical precipitation for the most effective wastewater treatment strategy. However, in spite of its advantages, chemical precipitation requires a large amount of chemicals to reduce metals to an acceptable level for discharge. Therefore, reducing agents with the fast reductio kinetics, and the precipitating agents with less sludge production should be explored for the more efficient treatment of industrial effluent.[5]

2.1.2 HEAVY METAL CHELATING PRECIPITATION

The effective removal of organic-Ni and -Cu compounds from electrolytic plating effluent (EPE) remains a major problem. For the efficient elimination of organic-Ni and -Cu compounds from EPE, a new and practical technique of heterogeneous catalytic ozonation is presented. The technique was tested in a pilot- scale setup (CPSS). The use of synchronous bi-directional flow improved overall Ni and Cu removal. The total Ni and Cu in the effluent dropped to 0.1 and 0.3 mg L^{-1} under ideal circumstances, fulfilling Chinese discharge standards. The suggested method reliably removed total Ni and Cu (>95%) for 300 days, according to the CPSS. The major complexes found in EPE were ethylenediamine tetraacetic acid-Ni (EDTA-Ni) and citrate-Cu (CA-Cu). Overall, these findings support the practical use of the proposed technique in advanced EPE treatment and other industrial wastewater treatment systems. [6]

2.2 ION EXCHANGE

Polyacrylic acid capped Fe_3O_4 – Cu-MOF (i-MOF) hybrid was prepared for rapid and selective lead removal, with 93% removal efficiency, exceptional selectivity, and adsorption capacity of 610 mg/g and

91% of i-MOF hybrid could be easily separated from the contaminated water using magnetic separation. (Goyal, P., Tiwary, C. S., & Misra, S. K. (2021).) The adsorption process followed a pseudo-second- order model and the adsorption efficiency decreased from 93% to 83% on raising the temperature from

25 °C to 40 °C. The change in equilibrium adsorption capacity with respect to equilibrium adsorbate concentration followed the Langmuir isotherm model. i-MOF had a high selectivity coefficient and removal efficiency for lead ions even when exposed simultaneously with naturally abundant cations (Na(I), Ca(II), Mg(II)). Release of Cu(II) ions from the i-MOF after Pb(II) removal suggested ion- exchange to be the dominant removal mechanism. This new finding for Pb(II) removal with excellent adsorption performance using i-MOF through ion exchange based approach is a viable option for treating lead contaminated water.[7]

2.3 ADSORPTION

Despite many technical developments and achievements, wastewater treatment remains a serious issue internationally. If heavy metals in wastewater are not adequately handled, they represent a serious hazard to human health, thus their removal is critical. Because of its flexibility in design, operation, and cost- effectiveness, adsorption is the most often used wastewater treatment technology to remove heavy metals.

Because of its micro porous nature, activated carbon is the most common adsorbent for removing heavy metal ions from wastewater. However, separating activated carbon from wastewater solutions has proven challenging, and its expensive cost has limited its widespread use. Different new materials have recently emerged, demonstrating their competitiveness in heavy metal ion removal. These intriguing new materials have a lot of good qualities, like a lot of surface area, a lot of mechanical strength, and a lot of chemical inertness.[8]

- ➢ Adsorption is most common technique for heavy metal removal in wastewater treatment.
- ➢ Activated carbon is the conventional adsorbent material.
- ➢ Usage of conventional and novel materials towards heavy metal removal

2.3.1 ACTIVATED CARBON ADSORBENTS

Toxic metals such as lead (Pb) and cadmium (Cd) must be removed as soon as possible because of their harmful effects. Pb and Cd metals were adsorpted from an aqueous solution using seeds from Albizia lebbeck and Melia azedarach plants turned into activated carbon adsorbents. Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy were used to characterise the adsorbents as they were manufactured (SEM). Both metals' removal efficiencies were greatly influenced by their initial concentration, contact time, pH, temperature, and adsorbent amount. In 120 minutes at pH 5 and 20°C,

0.2 g of both adsorbents removed 75 and 62 percent Pb and 77 and 66 percent Cd from 100 ml of a 40 mg/l concentrated solution, respectively. The Freundlich and Langmuir isotherms both suit the experimental data well. To protect our ecosystem for future generations, we need low-cost activated carbon adsorbents for the cleanup of extremely hazardous metals from wastewater. Activated carbon adsorbents were prepared from Albizia lebbeck and Melia azedarach seeds and applied for the adsorption of lead and cadmium metals from wastewater by changing some basic parameters. The studies (Ullah, M., Nazir, R., Khan, (2019).)showed that activated carbon can be considered an effective, easily available, low cost and natural adsorbent for removing Pb and Cd from contaminant wastewater. The removal efficiencies of both metals were strongly dependent on their initial concentration, contact time, pH and amount of adsorbent. Interestingly, the Albizia lebbeck seeds were more superior to the Melia azedarach seeds. 0.2 g adsorbent each of Albizia lebbeck and Melia azedarach removed 75 and 62% Pb and 77 and 66% Cd from 100 ml of a 40 mg/l concentrated solution at 120 min at pH 5, respectively. The Freundlich isotherm and Langmuir isotherm were well fitted to the experimental data.[9]

2.4 MEMBRANE FILTRATION

In terms of better treated water quality, effective nutrient recovery, and long-term operation, direct membrane filtration has shown tremendous promise in wastewater treatment and resource recovery, particularly in situations where biological treatment is not possible. This study intends to provide a thorough overview of the state-of-the-art of direct membrane filtration methods (including pressure- driven, osmotic-driven, thermal-driven, and electrical-driven) for water reclamation and resource recovery in various types of wastewater. In these direct membrane filtering procedures, the variables impacting membrane performance and treatment efficiency are effectively highlighted, with membrane fouling recognised as the primary issue. Physical and chemical cleaning procedures, as well as preparation of feed water, are highlighted as options for increasing direct membrane filtering performance. The problems and opportunities for scaling-up and long-term operation of direct membrane filtration for successful wastewater reclamation and resource recovery are explored.[10]

Over the last few decades, reclaiming heavy metal-contaminated wastewaters has become a serious concern. As a result, nanoporous membrane technologies have piqued the interest of industry and the local community, and academics are focusing on ways to improve their performance. Metal removal enhancement by polymer addition is a possible method that is thoroughly studied in this paper on nickel ion rejection using chitosan and carboxymethyl cellulose. Ion rejection decreases dramatically when electrostatic interactions disappear as a result of the significant quantity of salt commonly found in effluents. However, a significant amount of polymer (more than 10^{-2} M of monomer unit) can counteract this reduction and allow excellent metal removal, although increasing viscosity reduces permeation flux. (Déon, S., Morin-Crini, N., Crini, G., & Fievet, P. (2018)).The pH of the filtered solution has a significant impact on performance, with an increase in pH significantly improving metal rejection. Finally, ultra filtration of an industrial discharge water with and without the chitosan enhancement step reveals that the rejection increase caused by the polymer addition is extremely little due to the competing phenomena between the different species present in the complex combination.[11]

➢ Removal of Ni(II) by UF membranes falls drastically in salty conditions

➢ Polymer addition increases Ni(II) removal with both chitosan and CMC 5

➢ Impact of polymer is weak for real effluents due to competition between ions

Effective treatment of RO reject and domestic sewage water in a single step using indigenously developed tilted solar distillation unit has been proposed. Behavior of the unit along with its characteristics, treated water quality, environmental benefits and economics has been reported based on experimental observations. Around, 4.79 and 4.48 L/d of treated water are produced by the unit at a thermal efficiency of 48.5% and 45.3% during RO reject and sewage water distillation, respectively. Suspended particles of re-circulated sewage water caused clogging of wick and affected tilted solar distillation unit's performance and efficiency. Smooth operation of the unit is noticed during RO reject distillation. The proposed unit could prevent at least 23.73 tons of CO_2, 158.54 kg of SO_2 and 64.75 kg of NO emissions during its 20 Yr life span.(Reddy, K. S., Sharon, H., Krithika, D., & Philip, L. (2018).) Wick replacement frequency and interest rate have a signification impact on distillation unit's treated water production cost. The proposed distillation unit's treated water production cost is lower than basin solar stills reported in literatures. Treated water is clear, odor free and bacterial free. Physical properties and heavy metal concentrations of treated water are well within the standards for safe drinking water except BOD (Biological Oxygen Demand) and COD (Chemical Oxygen Demand) such that the treated water can be used for other domestic and irrigation purposes. The results obtained from this study confirm solar distillation as an effective and sustainable option for wastewater treatment.[12]

➢ Tilted solar distillation unit for RO reject & sewage water treatment.

➢ Clogging of wick occurs during sewage water distillation.

➢ Thermal efficiency - 48.5% & 45.3% for RO reject & sewage water distillation.

➢ High BOD, COD & heavy metal removal efficiency- 23.73 tons of CO_2 mitigated.

2.5 COAGULATION AND FLOCCULATION

Because of their great effectiveness in removing turbidity, coagulation and flocculation procedures are frequently employed in potable water treatment. In 1500 BC, Egyptians devised this method by using alum to settle suspended particles in water. Coagulation and flocculation techniques are used nowadays to agglomerate colloids and small particles in water into bigger particles, which are referred to as floc. As a result, turbidity and contaminants such as organic matter, inorganic matter, suspended solids, and others can be reduced. This chapter addresses the charge neutralization and different binding processes such as inter particle bridging, sweeping coagulation, and absorption, as well as the theory of coagulation and flocculation. [13]

Because of the rise in human population, fast industrialization, and household activities, which produced a huge volume of contaminated wastewater, the need for fresh water has risen dramatically. In industrial and household wastewater, fine suspended particulates, metals, organic and inorganic particles, and other contaminants are common. Because of their surface charge and tiny size, these contaminants are difficult to remove. To remove colloidal particles from wastewater, several techniques such as coagulation- flocculation, ion exchange, precipitation, adsorption, biological, and advanced oxidation processes have been employed. The coagulation-flocculation process is one of the oldest treatment processes and is necessary for the majority of water and wastewater treatment. Aside from water and wastewater treatment, the coagulation-flocculation process is utilized in a variety of fields, including rubber production, cheese production, and biochemistry

Coagulation-flocculation is a two-phase process that involves generating bigger aggregates that may be separated by the sedimentation process in order to remove stable colloids from water. The first phase is the coagulation process, which involves adding a coagulant to the water to destabilize the particles by decreasing the repulsive interactions between the colloids. The flocculation process, in which destabilized particles are linked together to form flocs by the attraction of Vander Waals force, was the second step. Since 1500 BC, the coagulation-flocculation technique has been largely employed in drinking water treatment to reduce turbidity. Coagulation-flocculation procedures have recently gotten a lot of interest since they've been shown to be an efficient way to remove a variety of pollutants, such as hazardous organic waste, heavy metals, and viruses. This process has been widely used in the treatment of palm oil mill effluent food and beverage wastewater textile wastewater yeast wastewater and others due to its high efficiency in removing contaminates.

The efficiency of the coagulation-flocculation process in the treatment process is largely determined by a few factors, including the coagulant type and dosage, the temperature and pH of the wastewater, the pollutant concentration in the wastewater, mixing speed, and the settling time of the floc formed. As a result, coagulant selection and optimization of all operational parameters are critical for cost reduction in industrial applications. Inorganic metal salts, such as ferric chloride and aluminum sulphate, have traditionally been employed in industrial wastewater treatment. However, inorganic coagulants are being used less frequently these days due to their limited applicability and low inefficiency at tiny doses Natural or synthetic polymeric flocculants, on the other hand, are preferred for the treatment procedure.

2.6 FLOTATION

Flotation is a separation technique that has its roots in mineral processing. In recent years, further uses for water and wastewater treatment have been discovered and compared to flotation. The focus of the current review study was on heavy metal ion recovery by flotation and the mechanism that was used, which was either ion, precipitate, or sorptive flotation. Adsorbents (such as powdered activated carbon, zeolites, and goethite) as well as different biosorbents are used in the latter scenario. Copper, zinc, nickel, lead, iron, chromium, arsenic, gold, and other metals were examined for flotation. The bubble production process might be used for a conventional dispersed-air flotation column, electro flotation, or dissolved-air flotation, with the latter being the most often used water treatment approach. The influence of particle size was also investigated (for example, while examining the flotation of salt-type mineral fines).

The importance of the flotation process to the economies of the entire industrial world is considered to be enormous; it is a gravity separation method, which is based on the idea of applying rising gas bubbles as the transport medium. Usually following the selective attachment of bubbles to particles, those solids are transferred from the body of water to the surface, where foam is formed. Hence, as opposed to settling, flotation is a solid–liquid separation technique that is applied to particles of which the density is lower, or has been made lower, than the liquid they are in, by collectors and modifiers. Thus, flotation initially originated from the field of mineral processing but for many years, various particulate solids, in addition to minerals, have been extracted from water by using this effective process. These flotation applications mainly include the treatment of water and wastewater, mainly containing heavy metals, being the scope of the present. The techniques followed were that of ion, precipitate and/or sorptive flotation, including the biosorptive one, summarizing to a dispersed-air flotation – microfiltration hybrid unit. Mention with certain examples will be given to the flotation separation (dispersed or dissolved-air) and recovery of the following pollutants, as selectivity was often the focus: Zn, Cd, Cu, Ni, Fe, Mn, Mo, P, As, Si.. [14]

2.7 ELECTROCHEMICAL TREATMENT

Electricity was initially used to treat water in the United Kingdom a century ago, and it has since been regarded as a highly dependable technique of wastewater treatment. The need for hydrogen gas as a valued, clean energy source has risen significantly in recent years; from this perspective, wastewater electrolysis can fulfill the demand for energy throughout the wastewater treatment process. In this study, heavy metal ion-containing wastewater was treated using an electrochemical technique that not only reduced the chemical oxygen demand value and reduced the quantity of heavy metal ions, but also produced hydrogen in the process. A series of tests were carried out using the best electrode materials, pH levels, supply power, and operating time available. The findings show that by regulating key process variables, a viable wastewater treatment system may be developed that also generates a significant quantity of green energy. Before and after treatment, differential pulse voltammetry measurements were utilized to assess the characteristics of an industrial wastewater source, while scanning electron microscopy and energy dispersive X-ray spectroscopy were employed to study the electrode material's proficiency.

Every year, a considerable quantity of wastewater is released into the environment by various businesses, and various techniques of wastewater treatment are employed to minimize the amount of contaminants. By utilizing an electric current to destabilize suspended, dissolved, or emulsified contaminants, electro coagulation (EC) is an electrochemically based method that creates coagulant species in situ from the electro dissolution of sacrificial anodes, generally consisting of iron or aluminum. It has the potential to remove a variety of pollutants from wastewater, including organic and inorganic contaminants. The efficacy of the EC process is influenced by a number of factors, including pH, electrode, operating duration, and current density. The purpose of this research is to look at the most recent relevant literatures. Electrode passivation and energy consumption are the two most significant problems in the EC process. When compared to other typical techniques, EC offers benefits such as lower energy usage and lower operational expenses.[15]

During the last several years, the environmental industry has demonstrated a rising interest in electro coagulation for the treatment of various types of wastewater (EC). Due to its flexibility, treatment effectiveness, cheap cost, and environmental compatibility, it has lately gained interest as a viable approach for treating industrial wastewater. This method employs a direct current source between metal electrodes submerged in effluent, causing electrode plates to dissolve into the effluent. At the right pH, metal ions can produce a variety of coagulated species and metal hydroxides, which can destabilize and agglomerate particles or precipitate and adsorb dissolved pollutants. performance and treatment efficiency of EC are influenced by a variety of parameters, including electrode materials, electrode distance, electrode arrangement, operating current density, electrolysis time, pH of the solution, temperature, and reactor design.This method is also used to remove heavy metals and inorganic ions, as well as to clean potable and surface water. This article also provides a summary of the ideal process parameters, such as current density, treatment duration, pH, and removal efficiencies, as well as the benefits, difficulties, and future possibilities of EC technology. [16]

3. COMMENTS ON HEAVY METAL TREATMENT METHODS

Although all wastewater treatment procedures may be used to remove heavy and toxic metals, each one has its own set of benefits and drawbacks. Chemical precipitation has historically been used to remove heavy metals from aqueous solutions due to its ease of use and low capital cost. Chemical precipitation, on the other hand, is often used to treat high-concentration wastewater containing heavy metal ions and is ineffective when the metal ion concentration is low. Chemical precipitation, on the other hand, is not cost- effective and can result in enormous amounts of sludge that must be handled with significant difficulty. For the removal of heavy metals from wastewater, ion exchange has been widely used. When ion- exchange resins are depleted, they must be regenerated using chemical reagents, which can result in significant secondary contamination. They are also prohibitively costly, especially when treating huge amounts of wastewater with low concentrations of heavy metals, therefore they cannot be utilised on a wide scale. Adsorption is a well-known technique for removing heavy metals from wastewater with low concentrations of heavy metals. AC's high cost prevents it from being used in adsorption. To remove heavy metal ions, a variety of low-cost adsorbents have been designed and evaluated. The adsorption efficiency, on the other hand, is dependent on the type of adsorbents used. Heavy metal biosorption from aqueous solutions is a relatively recent technique that has shown to be highly promising for heavy metal removal from wastewater.

Although membrane filtering technology may effectively remove heavy metal ions, issues such as high cost, process complexity, membrane fouling, and low permeate flow have limited its application in heavy metal removal. The generated sludge has good sludge settling and dewatering properties when using the coagulation & flocculation for heavy metal wastewater treatment technology. However, this approach necessitates the use of chemicals and the production of more sludge. High metal selectivity, high removal efficiency, high overflow rates, low detention periods, cheap operating costs, and generation of more concentrated sludge are all advantages of flotation over more traditional techniques .However, there are a number of drawbacks, including a high initial capital cost, as well as significant maintenance and operation expenditures. Electrochemical heavy metal wastewater treatment procedures are said to be quick and precise, using less chemicals, resulting in higher reduction yields, and producing less sludge. Electrochemical technologies, on the other hand, need a large initial capital investment and a costly energy source, which limits their development. Although all of the above techniques can be used to treat heavy metal wastewater, it is important to note that the most appropriate treatment technique is determined by the initial metal concentration, wastewater component, capital investment and operational cost, plant flexibility and reliability, and environmental impact, among other factors.

From the preceding discussion, it is clear that each method for removing metal ions is not universally accepted and has its own set of benefits and drawbacks. In recent years, adsorption has become the technique of choice among all approaches. It demonstrated ease of use, low cost, and great absorption capacity. The current research trend is to develop eco-friendly and cost-effective adsorbents from trash. However, avoiding environmental concerns by disposing of such adsorbents after the adsorption process is a major problem. Adsorption onto ACs has been described as a viable industrial-scale technique. Additional study on the adsorption of metal ions from low traces and effective regeneration methods is required. Industrial applications' economic viability is also critical. Membrane techniques play an important part in wastewater treatment and have recently emerged as a more viable choice. Some separation applications, including as desalination, are already well-suited to them. High metal ion extraction efficiency is a hallmark of membrane processes. However, this technique has some drawbacks, including membrane fouling and biofouling, limited recovery for the quantity of feed wastewater, process complexity, pretreatment, frequent membrane cleaning, and high cost. In the future, innovative membrane materials with improved thermal and chemical stability will be required for industrial wastewater treatment to provide superior anti-fouling characteristics and improve membrane selectivity for the target metals.

The automated operation of industrial facilities, for both adsorption and membrane techniques, requires further implementation and development. Because of their simplicity and low cost, chemical-based separations have been frequently utilized for heavy metal removal. Despite this, chemicals are used to adjust pH levels and increase ion buildup. A considerable volume of sludge is generated, which requires further treatment. The electrochemical treatment offers the advantages of being quick to treat, well- controlled, simpler to remove sludge, and using less chemicals. The expensive cost of anodes and cathodes, as well as limited throughput and significant energy consumption, are the major drawbacks of this method. Combining various types of electrochemical treatment procedures with renewable energy sources might be a potential solution to this bottleneck. Because of their capacity to remove organic and inorganic pollutants from wastewater, aerated EC and electrochemical oxidation techniques were the best candidates to combine with other approaches. Low sludge is produced during the flotation process. As a result, this technique is a good option for integration into an electrochemical treatment system that is both efficient and cost-effective. The ion exchange approach is similar to adsorption techniques in that stability and reusability concerns may require more research. The photo catalyst technique is a straightforward procedure that uses no or few chemicals and produces no sludge. It is, however, still under development, has a poor throughput, is pH dependent, and is inefficient when several metals are present

4. CONCLUSIONS

Because of their poisonous, non-biodegradable, and long-lasting nature, heavy and toxic metals such as arsenic, copper, cadmium, chromium, nickel, zinc, lead, and mercury are significant contaminants of fresh water reservoirs. Heavy metals are introduced into many segments of the environment, including the air, water, soil, and biosphere, as a result of industrial expansion. Due to their high solubility in aquatic settings, heavy metals are rapidly absorbed by fish and plants. As a result, through the food chain, they may accumulate in the human body. To reduce heavy metal concentrations in water and wastewater, several techniques have been devised and used. Membrane filtration, ion exchange, adsorption, chemical precipitation, nanotechnology treatments, electrochemical, and advanced oxidation processes are among these technologies. The techniques, as well as their processes and efficacy, are described in this review. A analysis of different heavy metal removal methods and adsorbents reveals that the adsorption process has a lot of promise for removing heavy metals from industrial wastewater using low-cost adsorbents. More research on low-cost adsorption processes is needed to encourage the usage of non-conventional adsorbents on a wide scale. To keep costs down and enhance heavy metal removal effectiveness, low-cost adsorbents should be employed.

The best method for removing heavy ions from wastewater is determined by a number of criteria, including the cost of operation, the starting concentration of metal ions, environmental effect, pH values, chemicals used, removal efficiency, and economic feasibility. Adsorption treatments (using various adsorbents, such as carbon-based, carbon-composites, minerals, CS, magnetic, biosorbents, and MOFs), membrane treatments (UF, nanofiltration, microfiltration, reverse osmosis, forward osmosis, and electro dialysis), chemical treatments (coagulation-flocculation, and flotation), and electric treatment Because of its ease of use, broad application, high removal rate, and cheap cost of reusability, adsorption is the most promising technique for removing heavy metal ions from wastewater. This choice, however, is based mostly on the use of low-cost materials with high uptake and efficient regeneration processes. low cost biopolymer and bio waste can also be used for heavy metal from waste water .The membrane technique is more technically mature than adsorption because it is more practicable; nonetheless, reducing separation costs and membrane fouling remains a challenge. Chemical-based techniques, particularly chemical precipitation, are well-established and useful. They are also thought to be cost-effective. Unlike the electrochemical technique, which relies on extra variables such as electrodes, electrical energy, and other fixed expenses, they are dependent on the chemical consumed. They do, however, create a considerable volume of sludge, which need sedimentation separation. Because of the passivation of electrodes and the high electrical energy consumption, the electrochemical process is a rather costly technique. Electric techniques, aside from photo catalytic methods, are also the least advanced technology. The advantage of the photo catalytic technique is that it uses no (or very little) chemicals and produces less sludge, making it environmentally benign. Chemical, adsorption, and membrane techniques are the most commonly discussed methods in the literature. Most research employed synthetic wastewater in which only one or a few metal types are present, resulting in a significant knowledge gap in the effectiveness of treatment techniques for the removal of heavy metal ions from actual wastewater. As a result, more study into the treatment of various pollutants using real wastewater should be undertaken. More study should be done on introducing cost-effective materials and methods for removing heavy metals from wastewater. Future research should concentrate on the pilot-scale procedure. The most effective methods for recovering metals with little environmental impact and cheap cost are currently being developed and should be included in future study.

Toxic chemicals found in industrial wastewaters, such as heavy metals, phenolic compounds, and other non-biodegradable pollutants, are thought to be hazardous to individuals and the environment. Some of the most commonly utilised wastewater treatment technologies are covered in this study. Electrochemical and physicochemical techniques, membrane filtration, photo catalytic processes, and nanotechnology treatments are all examples of these. Each technique has its own heavy metal removal efficiency as well as unique factors that influence the process. Each approach and its experimental setting yields various findings. Removal efficiencies range from 12 percent to 100 percent, depending on the variables. However, the majority of them had enough removal. Under ideal conditions, several techniques, such as RO, NF, adsorption, chemical precipitation, electro flotation, and electro coagulation, can entirely remove (>99 percent) or reduce the dose of heavy metals to standard levels. The findings for electrodeposition, on the other hand, indicated a range of metal removal effectiveness from 12 to 92.1 percent.

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