# Evaluation of Conventional Methods in Reducing Heavy Metal Concentrations in Industrial Waste

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ABSTRACT

*The rapid growth of the chemical industry has increased liquid waste containing heavy metals (Cadmium, Zinc, Lead), which threaten ecosystems and human health due to persistence and biomagnification. The handling of these effluents requires specific methods according to the characteristics of the effluents. Electrochemical processes stand out in heavy metal removal efficiency, while adsorption using natural materials (fruit peels, sawdust) offers lowcost effectiveness. Ion flotation utilizes surfactants, although its efficiency depends on operational conditions. Chemical precipitation with lime is a cheap solution to reduce metal solubility, while phytoremediation relies on plants as an environmentally friendly alternative. The selection of methods is based on the type of metal, waste concentration, and economic-environmental factors. The implementation of this appropriate technology is expected to minimize the risk of heavy metal pollution in a sustainable manner.*



## 1. Introduction

The chemical industry with its rapid growth is increasingly causing disturbances to living things and the environment. One of these disturbances is the generation of large amounts of wastewater contaminated with heavy metals with high solubility in the aquatic environment. This poses a serious threat to all living organisms. Several industries contribute to this problem, with the most common contaminants being Cadmium (Cd), Zinc (Zn), Lead (Pb), Chromium (Cr), Nickel (Ni), Copper (Cu), Vanadium (V), Platinum (Pt), Silver (Ag), Tin (Sn) and Titanium (Ti) (Ti) [1], [2]

Heavy metals cannot be biologically or physically degraded and remain in the soil for a relatively long time, posing a long-term threat to the environment. Copy Paraphrase [3] Organic and inorganic components of waste can biodegrade, however, heavy metals and metalloids pose new challenges due to their prolonged persistence in the environment [4]. Because they are not beneficial, the effects of some heavy metals in biological systems require a certain range of heavy metal concentrations for several physiological and biochemical functions; humans need Fe, Co, Mn, Mo, and Zn. However, excessive amounts can have negative consequences for the environment. Some heavy metals, such as Hg, Pu, Cd, and Pb, do not have a beneficial impact on organisms [6]. They can enter the food chain through plants and accumulate in the human body through biomagnification, thus posing a great threat to human health. [7]. Some sources of heavy metals and their pathways can be seen in Fig1.

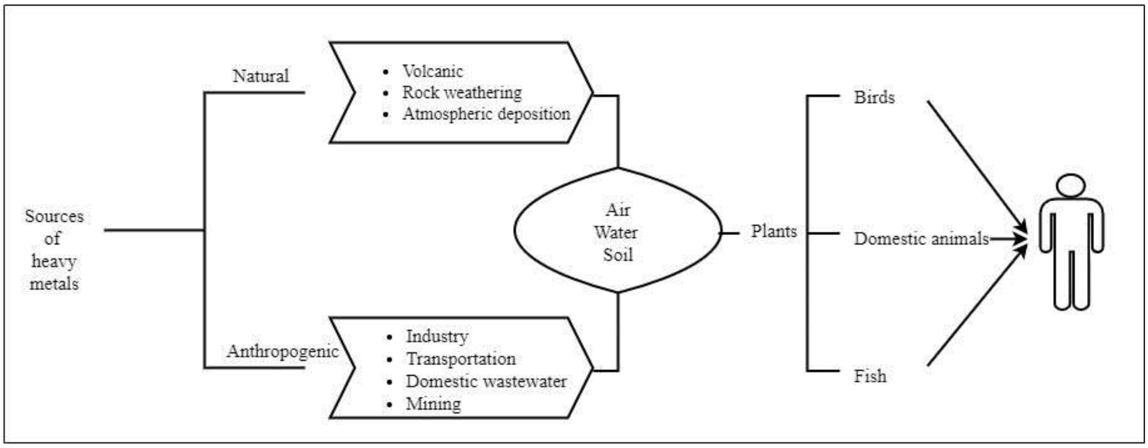


**Fig 1**. Sources of heavy metals along with their associated environmental pathways [8]

Based on Fig 1. Heavy metals such as lead, mercury, cadmium, and arsenic are toxic metals that enter the environment through natural processes and human activities. They pollute air, water and soil, bioaccumulate in plants and accumulate in the food chain. Consumption of contaminated plants or animals will increase heavy metal intake, which can cause nerve damage, kidney disorders, reproductive disorders, and cancer. Monitoring and regulating sources of heavy metal pollution is essential, including reducing industrial waste, using environmentally friendly chemicals, and enforcing strict regulations.

For decades, heavy metals have been removed from industrial effluents by conventional treatment methods such as chemical precipitation [9], ion flotation [10], ion exchange [11], adsorption [12], and electrochemical [13]Low cost-oriented methods have significant drawbacks and disadvantages, some of which are incomplete heavy metal removal, high energy requirements and the production of toxic sludge or waste [14].

This journal aims to provide a comprehensive review of conventional methods for removing heavy metals from industrial and environmental water, such as chemical precipitation, ion exchange, adsorption, membrane filtration, and electrolysis Fig 2. The focus is on comparing the performance, limitations, and costs of each method.

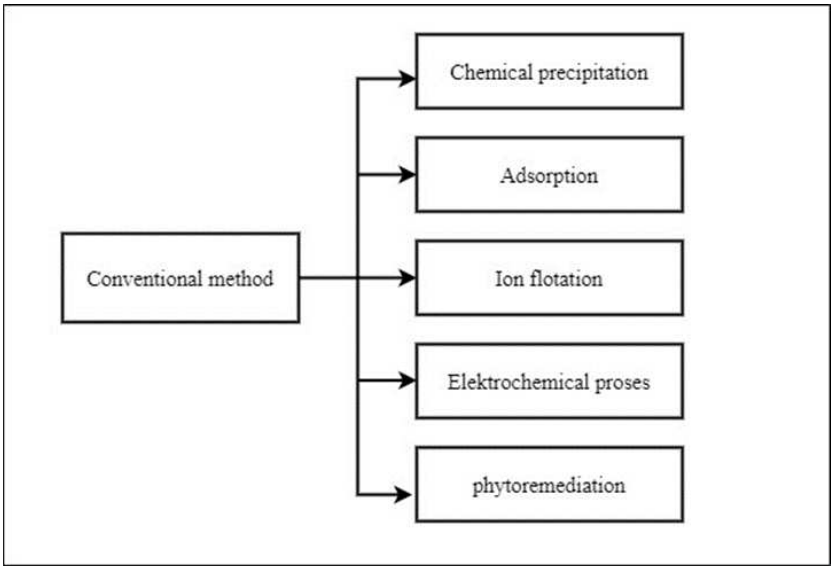


**Fig 2**. conventional method

The above Fig 2. provides five traditional techniques to treat heavy metal pollution in the environment, namely chemical precipitation, adsorption, ion flotation, electrochemical processes and phytoremediation. Chemical precipitation adds chemicals to precipitate metals out of solution, whereas adsorption utilizes absorbent materials like activated carbon. Ion flotation utilizes air bubbles and surfactants, whereas electrochemical processes utilize electric current to remove metals from solution. Phytoremediation is a green technology that utilizes plants to accumulate or immobilize heavy metals.

## 2. Technology for Heavy Metal Removal

### 2.1. Electrochemical Proses

The electrochemical process is a chemical reaction that causes or is caused by the movement of an electric current through an aqueous metal-bearing solution with the application of a voltage between insoluble cathode and anode plates. Heavy metals are precipitated as hydroxides in a mildly acidic electrolyte or neutralized during the process [15].

Electrochemical methods are widely used for the treatment of domestic wastewater as well as industrial wastewater. These methods are only used if pretreatment of wastewater is done. And these cannot treat effluents that have large particles such as physical objects. Disinfection, removal of pollutants, harmful ions, heavy metals are the main concerns of removal in electrochemical wastewater treatment methods [16]. Electrochemical processes are known for their high efficiency in removing heavy metals from wastewater. This process has been recognized as a highly efficient method for industrial wastewater treatment, especially in removing heavy metal ions [17]. The following is the efficiency of the electrochemical process in removing heavy metals, can be seen in Table 1.

**Table 1.** Electrochemical Efficiency in Removing Heavy Metals

| Heavy metal | Efisiensi | Ref |
|---|---|---|
| Cd | The removal rate reached 76.60% in 240 minutes at a current density of 7.80 mA/cm2. | [18] |
| Cu, Ni | The efficiency of heavy metal removal reached 97% over 20 hours of operation time. | [19] |
| Cu, Cd, Pb | At high pollution levels in industrial wastewater, AC electrodeposition successfully recovers more than 99.9% of heavy metal ions. | [20] |
| $Cu^{2+}$, $Cr^{6+}$, $Ni^{2+}$ | More than 99% metal reduction was successfully achieved, with final concentrations of copper, chromium, and nickel in the treated water being 0.10–0.13 ppm, 0.19–0.20 ppm, and 0.05–0.13 ppm, respectively. | [21] |
| Pb (II) | capable of removing 99.99% Pb (II) and immediately reaching concentrations acceptable for environmental and drinking water standards, with low energy consumption. | [22] |

### 2.2. Adsorption

Adsorption is a surface phenomenon defined as the adherence of certain compounds to the surface of solid objects by physical forces or chemical bonds [23]. When adsorption occurs in biological systems, the process is called biosorption. Biosorption is a process that combines the removal and recovery of metals. Biosorption is effective due to the low cost of adsorbents and ease of regeneration. Bacteria, fungi, algae, industrial waste, agricultural waste, natural residues, and other biological materials have been widely used to absorb heavy metals from wastewater [24]. Physical adsorption, chemisorption, electrostatic interactions, simple diffusion, intra-particle diffusion, hydrogen bonding, redox interactions, complexation, ion exchange, precipitation, and pore adsorption are mechanisms that enable the adsorption of heavy metal ions into bioadsorbents [25]. the following is the adsorption of heavy metals by various adsorbents as shown in Table 2.

**Table 2.** Adsorption Of Heavy Metals from Various Adsorbents

| Adsorben | Heavy metal | Removal efficiency % | Ref |
|---|---|---|---|
| Yam peel | Pb (II) | 81.24 | [26] |

| | | | |
|---|---|---|---|
| Piceasmithiana sawdust | Pb (II), | 95.2 | [27] |
| | Cr (II), | 87.7 | |
| | Cd (II) | 83.3 | |
| Alkali treated walnut shell | Cd (II) | - | [28] |
| Peanut husk biochar | Cd (II) | 99.9 | [29] |
| Eggshell nano-particle | Hg (II) | - | [30] |
| Coal fly ash | Cu (II) | - | [31] |

The advantages of adsorption for removing heavy metals include: producing high-quality waste, making it more profitable compared to other processes. Low cost and environmentally friendly. Reversibility and regeneration. Adsorption is often a reversible process, allowing for regeneration and potential profit [32]. The disadvantages of adsorption for removing heavy metals include: low efficiency, which can impact its effectiveness in removing heavy metals from wastewater, high energy requirements, and the precipitation of toxic substances. In some cases, the adsorption process can lead to the precipitation of toxic substances, which can be a disadvantage for the overall treatment process [32].

### 2.3. Ion Flotation

Ion flotation is a separation technology used to recover and remove heavy metals from dilute solutions. This process is based on imparting hydrophobic properties to ionic heavy metals in wastewater using surfactants and then removing these hydrophobic species with air bubbles [33]. The use of surfactants is generally applied in efforts to remove contaminants from water. There are three types of surfactants that can be used, namely synthetic chemical surfactants, green surfactants, and biosurfactants. Each type of surfactant has specific characteristics and advantages in the process of cleaning water from various contaminants [34]. Here is one example of the ion flotation process in removing cadmium, which can be seen in Table 3.

**Table 3**. The Ion Flotation Process Removes Cadmium

| Parameters | Optimal Condition | Cadmium Removal Efficiency (%) |
|---|---|---|
| Metal collection ratio | 3:1 | 84 |
| Flow rate | 150 ml\min | - |
| Ethanol concentration | 0.4 % | 92.1 |

In the flotation process, surfactants are used to concentrate inorganic ions from an aqueous solution. This type of surfactant is widely applied in the industry because its molecular structure can be designed according to needs. Some commonly used types of surfactants include alkane sulfonates, alkylamines, disodium alkyl malonate, xanthates, sodium oleate, and sodium dodecyl sulfate (SDS).These surfactants have been widely applied in the ion flotation process [35]. In Table 4, it can be seen how ion flotation works in removing cadmium, in the process, optimization is carried out on the reaction between $Cd_2^+$ and the collector sodium dodecyl sulfate (SDS) followed by flotation with ethanol as the frother. The test solution was prepared by combining the required amounts of cadmium ions, SDS, and frother or the required sodium sulfate solution [35].

**Table 4**. Ion Flotation Process in Removing Heavy Metal Ions

| Type of surfactant | Removed ions | Removal Efficiency (%) | Ref |
|---|---|---|---|
| Octanoyl-Cysteine (Octanoyl-Cys) | Merkuri (Hg) | 99.9 | [36] |
| | Arsenik (As), | 99.1 - 99.7 | |

| | | | |
|---|---|---|---|
| | Timbal (Pb),<br>Kadmium (Cd),<br>Kromium | | |
| Sodium Dodecyl Sulphate (SDS) | Zn (II), Mn (II), Cu (II) | 90.5, 99.8, 73.4 | [37] |
| Sodium Dodecyl Sulphate (SDS) | Cd (II) | 94 | [38] |

The efficiency of ion flotation in removing heavy metals is affected by various factors, such as Chemical Variables: Although chemical variables play an important role in flotation performance, other factors such as hydrodynamic variables also affect the efficiency of ion flotation for heavy metal removal [39]. Operating Conditions such as critical operating conditions, including pH, collector/froth type and concentration, gas type, gas flow rate, and energy input, have been identified as factors that affect ion flotation performance and process efficiency [40]. The removal mechanism by metal ion removal mechanism in ion flotation is mainly due to electrostatic attraction, ion exchange, and surface complexation between surfactants and target ions. These mechanisms can affect the efficiency of the ion flotation process [41].

### 2.4. Chemical Precipitation

Chemical precipitation involves the formation of an insoluble substance that allows precipitating it. This method involves the addition of precipitating reagents to the waste product which results in a chemical reaction that produces insoluble substances. The insoluble substance forms particles, which are agglomerated by chemical coagulation and removed by filtration or sedimentation [42]. Typical chemical precipitation methods using lime, soda ash and sodium sulfide to remove heavy metals from aqueous solutions are compared. A removal of 99.9% from aqueous solutions with the three precipitants was achieved for copper and zinc at an initial concentration of 100 mg L-1, and lead was efficiently removed (99.8%) by sodium sulfide. These precipitants showed good removal efficiency for heavy metals [43]. The following process demonstrates chemical precipitation in removing heavy metal ions can be seen in Fig 3.

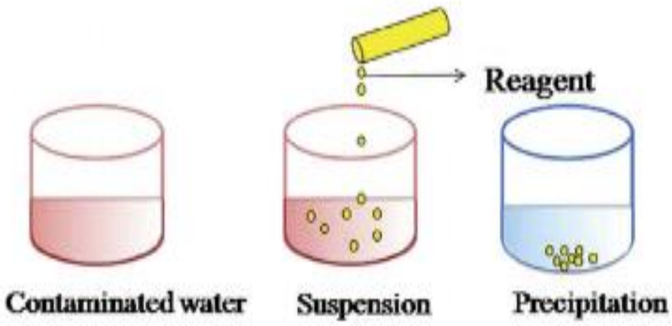


**Fig 3.** The Chemical Precipitation Process in the Removal of Heavy Metal Ions [44]

Some advantages of using chemical precipitation in removing heavy metals, as supported by the following references: Lower solubility of metal compounds, sulfur-containing precipitating agents, such as sulfides, have been reported to have lower solubility of metal compounds than hydroxide precipitates, making them a favorable choice for removing heavy metals (Pohl, 2020).

### 2.5. Phytoremediation

Phytoremediation exploits metal-accumulating plants to restore primary sources contaminated with soil and water (Muthusaravanan et al., 2018). Plants have the ability to absorb ionic compounds in the soil even at low concentrations through their root systems. Plants extend their root systems into the soil matrix and form a rhizosphere ecosystem to accumulate heavy metals and modulate their bioavailability, thereby reclaiming contaminated soil and stabilizing soil fertility [46].

Are a viable option for phytoremediation due to their physiological capacity to withstand and accumulate heavy metals as well as their ability to adapt to various environmental conditions. Moreover, the use of certain plant species for phytoremediation can be tailored to the type of heavy metal pollution, as different plant species have varying abilities to accumulate specific heavy metals [47].The process of removing heavy metals from waste using phytoremediation plants can be seen in Table 5.

**Table 5**. Phytoremediation Process of Plants Blocking Heavy Metal Contaminants

| No | Plant Species | Contaminants Removed | Ref |
|---|---|---|---|
| 1 | Brassica juncea L. | Cd, Cu, Zn | [48] |
| 2 | Helianthus annuus | Zn | [49] |
| 3 | Medicago sativa, Brassica nigra | Pb | [50] |
| 4 | Lemna minor | Pb, Cd, Ni, Cr | [51] |
| 5 | Brassica rapa L. | U | [52] |
| 6 | Azolla filiculoides | Hg (II), Pb (II) | [53] |
| 7 | Oryza sativa | Cd, Zn, Fe, Cu, Pb, Cr, Mn | [54] |

Some advantages of applying phytoremediation include: (i) a feasible economic aspect - phytoremediation is an autonomous system that uses solar energy as a resource, making it easy to manage with low installation and maintenance costs;(ii) environmentally friendly and capable of reducing pollutant exposure to the environment and ecosystems; (iii) easy to implement and can be applied on a large scale and easily disposed of; (iv) effective in preventing erosion and leaching of heavy metals by stabilizing them, reducing the risk of contaminant spread; (v) contributes to soil fertility improvement through the release of various organic materials into the soil [55].

### 2.6. Comparative study analysis

Evaluation of five technologies for heavy metal removal, Table 6 presents a comparison of the efficiency, advantages, disadvantages, and application guidelines of each technology. The comparison is made in terms of effluent type, industry size, cost, and secondary environmental effects to provide reasonable guidance for technology selection.

**Table 6.** Comparison of Major Metal Removal Technologies and Application Recommendations

| Technology | Efficiency (%) | Advantages | Limitations | Recommended Conditions |
|---|---|---|---|---|
| Electrochemical | 76.6–99.9% | High efficiency | High energy cost, requires pre-treatment, not suitable for large particles | Industries with high-concentration heavy metal waste (e.g., electroplating, mining) |
| Adsorption | 81–99.9% | Low cost, environmentally friendly (bio-adsorbents), adsorbent regeneration | Limited capacity, generates saturated adsorbent waste | Small to medium-scale industries with low-concentration waste (e.g., textiles, agro-industry) |
| Ion Flotation | 73.4–99.9% | Effective for diluted waste, selective for specific metal ions | Depends on surfactants, additional chemical costs, operational complexity | Waste with low dissolved metal content (e.g., laboratory wastewater, chemical industry) |
| Chemical Precipitation | 99.8–99.9% | High efficiency, fast process, suitable for large scale | Produces toxic sludge, costly secondary waste management | Large-scale industries with sludge handling capacity (e.g., battery, metal industries) |

| | | | | |
|---|---|---|---|---|
| Phytoremediation | Varies | Environmentally friendly, low operational cost, improves soil fertility | Slow process, climate and plant dependent, not suitable for acute contamination | Large contaminated areas (e.g., agricultural land, mining sites, or former industrial areas) |

Based on Table 6. The type of metal, waste concentration, industry size, operational costs, and secondary environmental impact need to be considered when selecting technology. A combination of methods (precipitation and chemical adsorption) can also be used to enhance efficiency and sustainability.

## 3. Conclusion

Heavy metal pollution originating from industrial waste, particularly from the chemical industry, is a serious environmental issue given the toxic, persistent, and bioaccumulative nature of these metals. Conventional methods such as chemical precipitation and electrochemical processes have proven effective under certain conditions, but they often lead to problems such as the production of toxic sludge and high energy consumption, whereas adsorption and ion flotation offer a more environmentally friendly and economical approach, especially with the use of natural materials or agricultural waste as adsorbent media. Additionally, phytoremediation has become one of the promising methods because it is sustainable, low-cost, and has minimal ecological impact. Based on the type of waste to be processed, we can adjust it with the appropriate conventional methods to achieve optimal conditions in the waste processing process. Therefore, the integration of several methods or the implementation of an integrated processing system becomes a relevant strategy to enhance the efficiency of heavy metal removal effectively, sustainably, and environmentally friendly.

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