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A State of the Art Review For Removing Heavy Metals Resulting from Industrial Waste

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A B S T R A C T

The contamination of heavy metals has become a serious concern for both the government and researchers due to industrial waste. Heavy metals possess toxic properties that can harm the human body if exposed over an extended period. It cannot be denied that toxic heavy metals come in various types, such as Ag (argentum), Cd (cadmium), Cr (chromium), Cu (cuprum), Ni (nickel), and others. In its development, various methods have been implemented to eliminate heavy metal waste, encompassing both conventional and modern approaches. Researchers are actively seeking the most efficient and effective method to address the issue of heavy metal removal. This review focuses on different methods for handling heavy metal waste, measuring the percentage of heavy metal loss to determine which method is the most effective and efficient in heavy metal removal.

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INTRODUCTION

The pollutants generated by the industrial sector are generally categorized into two types, namely organic and inorganic contaminants. One specific type of inorganic pollutant frequently encountered in industrial waste is heavy metals, which have significant adverse effects on human health and the environment. This is attributed to their primary characteristics, namely non-biodegradability and persistence, leading to prolonged and lasting effects (Ngabura et al., 2018). Heavy metals are hazardous compounds, and their specific gravity is at least five times greater than that of water. The contamination process of heavy metals can occur through various means, such as in the fertilizers used in plantations.(et al., 2013). Examples of hazardous heavy metals include Chromium (Cr), Lead (Pb), Copper (Cu), Mercury (Hg), Nickel (Ni), and Manganese (Mn). These aforementioned metals pose significant risks to human health when their levels exceed permissible limits in the body.. The most hazardous heavy metals to health are lead and cadmium. When contaminated with these heavy metals, the worst health outcomes for humans include cardiovascular, kidney, nerve, and bone diseases. Particularly for lead poisoning, individuals may experience ailments such as colic, constipation, and anemia (et al., 2013). Heavy metals such as mercury are also hazardous to human health as they can lead to various diseases such as rheumatoid arthritis, nerve issues, and circulatory problems. Copper, another metal, can result in diseases such as liver damage and insomnia. Additionally, copper has adverse effects on the environment as it inhibits enzyme activities in the soil (Chai et al., 2021).

With the growing awareness of the dangers posed by heavy metals in the environment, many researchers are currently striving to find solutions to reduce or eliminate the presence of heavy metals in waste discharged into the environment. Numerous technologies are available for addressing the issue of heavy metal pollution in wastewater. Established methods commonly employed by researchers encompass chemical precipitation, ion exchange, ultrafiltration, reverse osmosis, nanofiltration, coagulation, flocculation, and flotation. However, these approaches exhibit certain drawbacks, including limited removal efficiency, elevated operational costs, and the generation of solid waste. On the contrary, adsorption methods stand out for their advantages of low energy consumption, operational ease, and enhanced efficiency in removing substances Among the spectrum of cost-effective adsorbents, both natural and bio-based materials can be utilized. Natural substances such as zeolite, clay, chitosan, and red mud find application as adsorbents. Meanwhile, bio-based adsorbents primarily originate from agricultural and animal waste sources.(Chakraborty et al., 2022).

Among the various methods employed for heavy metal removal, the most commonly utilized approach is adsorption due to its operational flexibility, adaptable design processes, significant removal efficiency, and easy availability of raw materials. The adsorption process can be influenced by various variables such as the activator effect, pH influence, activated carbon activation time, adsorption time, pyrolysis temperature, adsorption temperature, initial concentration of heavy metals, activated carbon concentration, and agitation speed. All these variables play a crucial role in the adsorption process. Researchers are actively exploring optimal conditions to achieve maximum removal of heavy metals. (Chai et al., 2021). The purpose of this review is to identify the most efficient and effective method for removing heavy metals among various conventional methods that have been previously employed, through a comparison of success percentages in eliminating heavy metals from waste. Additionally, this review aims to recognize the parameters that influence these methods.

LITERATURE REVIEW

Heavy Metals and Their Impact

Elements with a density exceeding 5 and an atomic weight ranging from 63.5 to 200.6 usually calls heavy metals. Examples include nickel (Ni), manganese (Mn), copper (Cu), nickel (Ni), cadmium (Cd), chromium (Cr), cobalt (Co), and lead (Pb), commonly found in our surroundings. The hazardous characteristics of these metals lie in their tendency to collect in the environment, as well as their stability and toxicity, which can have detrimental effects on all forms of organism life. The rapid growth of industries has led to significant pollution on our planet, especially heavy metal contamination resulting from various industrial activities. The byproducts of industries are waste, containing high levels of heavy metals, toxic chemical compounds, and vivid dyes, contributing to environmental degradation. Due to their ability to accumulate in the human body, heavy metals are considered the most risky, capable of causing severe diseases and physical disorders.(Sharma, 2014).

One element with a significantly toxic nature is chromium, which contaminates various water sources, soil, and ecosystems comprehensively. The primary sources of chromium waste involve textile industries, leather tanning processes, metal extraction plants, and electrical coating activities. All these industrial sectors contribute to water pollution containing chromium when released into the environment as waste. In various oxidation states, Cr (III) and Cr (VI) emerge as the two most dominant and widely distributed forms. Both forms are highly toxic to various organisms, but Cr (VI) is considered the most hazardous form with higher water solubility compared to Cr (III). Generally, Cr(III) is formed as a result of the oxidation of Cr (VI) due to the presence of oxygen in the environment. Excessive consumption of Cr(III) can be toxic, causing respiratory tract abnormalities and leading to increased lung weight. This element can also affect the immune system and reproductive processes. On the other hand, Cr(VI) has carcinogenic properties for the lungs and stomach, and it can also induce symptoms such as vomiting, headaches, diarrhea, and nausea. According to the World Health Organization (WHO) in 2008, the maximum permissible limit for chromium content in drinking water is set at 50 micrograms per liter (µg/L).(Arora, 2019).

Nickel (Ni) is currently widely used in the production of stainless steel and other anti-corrosion equipment, making the increase in nickel (Ni) concentration in the environment a new health concern. Some diseases resulting from elevated nickel concentrations include dermatitis, encephalopathy, myocarditis, bone cancer, nasal cancer, and lung cancer. Moreover, there are numerous other diseases caused by nickel (Ni) exposure. Heavy metals such as lead (Pb) are discharged into the surroundings due to longstanding industrial practices, for instance, emanations from both the steel and battery sectors. Consequently, the concentration of lead (Pb) has impacted water quality, with approximately half of the total lead emissions to the air estimated to originate from the use of lead-containing gasoline. Pb, fundamentally, has the ability to accumulate in various organs of the body such as the kidneys, brain, muscles, and bones, and can lead to serious effects such as hypertension, kidney failure, and brain damage. Given the very high level of toxicity of Pb, the elimination or reduction of Pb from water environments is imperative. The World Health Organization (WHO) and the Environmental Protection Agency (EPA) have advised limits for lead concentrations in wastewater, set at 0.01 and 0.05 mg/L, respectively. This emphasizes the critical need to oversee and manage lead levels in aquatic environments to safeguard both human health and ecosystems.(Salsabilla et al., 2020).

In addition to the toxic heavy metals mentioned earlier, a novel and highly perilous category is emerging—radionuclides. The continuous progression in nuclear science and technology has led to a substantial rise in environmental contamination caused by radionuclides. Among the radionuclides posing significant concerns, U(VI) stands out due to its extensive application in the nuclear industry, coupled with its elevated levels of toxicity and radioactivity. The ionizing radiation emitted by U(VI) carries the potential to induce permanent harm to cells, tissues, and organ systems, ultimately contributing to the development of cancer and various other ailments. As a result, addressing the elimination of U(VI) ions has become an imperative issue demanding serious attention.(Oktaviani et al., 2020).

Currently, reports indicate that over 1 billion people worldwide face limitations in accessing clean water. Every 15 seconds, somewhere in the world, a child succumbs to diseases transmitted through water. The detrimental effects of swift industrial expansion significantly manifest in the environment, specifically with regard to metal-induced water pollution, posing a grave threat to various life forms, particularly humans, on a global scale.Hence, it is essential to promptly discover efficient remedies for eradicating these hazardous heavy metals to adhere to rigorous standards set by environmental regulations. Scientists have employed diverse purification methodologies in their endeavors to tackle the predicament of heavy metal pollution.

Metode for Removing Heavy Metals

There exist two categories of approaches for the elimination of heavy metals: conventional and contemporary methods. Conventional methods encompass a range of techniques, including chemical precipitation, ion exchange, electrocoagulation, electrodialysis, photocatalysis, solvent extraction, and adsorption.(Soliman & Moustafa, 2020).

Chemical Precipitation

Chemical deposition stands out as a commonly utilized method for addressing heavy metals in wastewater, primarily due to its procedural simplicity. In this method, the precipitation of heavy metal ions occurs by introducing Introducing coagulating agents such as alum, iron salts, lime, or polymers into the solution. These chemical coagulants interact with heavy metal ions, transforming them into insoluble forms. precipitates such as hydroxides, sulfides, carbonates, and phosphates. Separation of solid precipitates from the heavy metal ion solution is achieved through processes like filtration, sedimentation, or gravity settling. The adjustment of pH emerges as a critical parameter that significantly enhances the effectiveness of eliminating heavy metals using this method. Alkaline conditions with a pH of 11 are preferred to enhance the efficiency of heavy metal removal. Lime and limestone are the most commonly employed coagulants due to their simplicity, safe operational characteristics, and cost-effectiveness. A study conducted by Quanyuan and collaborators demonstrated removal efficiencies reaching up to 99.3% for Zn(II), Pb(II), Cu(II), and Cr(III) from wastewater using CaO as a precipitating ion within the optimal pH range of 7–11.(Soliman & Moustafa, 2020).

Ion Exchange

This technique is widely utilized in various industries to combat heavy metal contamination in wastewater. In this method, a reversible ion exchange occurs between the solid and liquid phases. An insoluble substance, commonly known as resin, facilitates the removal of heavy metal ions from the solution and releases ions with similar charges without altering the internal structure of the resin. In the physical absorption of heavy metal ions, a complex is formed between functional groups and counter ions. Ion exchange resins can exist as either synthetic organic resins or naturally occurring inorganic zeolites. These resins exhibit insolubility in water and have the capacity to absorb either negatively or positively charged ions from electrolytes. They subsequently release ions with similar charges in equivalent amounts into their surroundings. For instance, positively charged ions like sodium and hydrogen in cationic resin can be substituted by positively charged ions such as copper, zinc, and nickel ions present in heavy metal solutions. Moreover, negatively charged ions in resins, such as chloride and hydroxide ions, can be exchanged with negatively charged ions such as sulfate, chromate, nitrate, and cyanide, alongside soluble organic carbon.

Electrocoagulation

One of the techniques in electrochemichal is electrocoagulation technique employed in industries for small-scale wastewater treatment. In the electrocoagulation process, an electric current is passed through the wastewater solution to remove soluble metals, precipitate solids, colorants, and tannins. The electrocoagulation reactor constitutes an electrolytic cell with both an anode and a cathode. For the treatment of wastewater, electrodes, typically constructed from Fe or Al plates, are employed. Hydrogen gas is liberated at the cathode, while heavy metal ions are produced at the anode. These heavy metal ions are neutralized and combine to form small aggregates called flocs. Filtration can be employed to remove these flocs. Electrocoagulation has become an environmentally friendly technique as it does not require the addition of chemicals.

Electrodialisys

Electrodialysis (ED) is a technique that involves the application of an electric potential across semi-permeable ion-exchange membranes to segregate metal ions within a solution. These membranes consist of thin sheets of plastic material possessing either anionic or cationic properties. Positioned between two electrodes within an electrolytic cell, these ion-exchange semi-permeable membranes, when subjected to an electric current, prompt the movement of relevant metal ions, facilitating the extraction of heavy metals from the solution. There are two primary categories of ion-exchange semi-permeable membranes: Cation exchange, wherein positive ions (cations) migrate toward the cathode, and Anion exchange, wherein negative ions (anions) move toward the anode, traversing the ion-exchange semi-permeable membrane.

Photocatalysis

Photocatalysis is called as the hastening of a chemical reaction facilitated by a catalyst when exposed to light. When a photocatalyst captures light waves possessing energy surpassing the semiconductor bandgap, it results in two of electrons and gaps in the conduction and valence bands of the semiconductor. Electrons from the valence band of the photocatalyst become stimulated upon exposure to light, and the surplus energy from these stimulated electrons promotes electron transfer to the photocatalyst's conduction band, generating pairs of electrons with a negative charge and positively charged holes. These pairs are transferred to the semiconductor surface, generating powerful oxidative free radicals like OH- and O2-. These charge carriers, migrating to the semiconductor surface, can reduce or oxidize species in the solution with corresponding redox potentials.

Solvent extraction

Solvent extraction depends on the utilization of organic reagents with the ability to differentially isolate metal ions. Method of Solvent extraction encompasses various application fields, ranging from pharmaceutical and biochemistry industries, inorganic chemistry, analytics, to large-scale industrial separations, including waste management. In the realm of In the realm of separation technology, extraction techniques have become commonplace steps applied. Moreover, it stands out as one of the most favored techniques for separating metals in the process of recovery processes due to its , simplicity, and wide ranging applications. Through the use of relatively simple equipment and shorter implementation times, solvent extraction procedures offer several advantages for researchers. However, the importance of highly selective extraction solvents to separate metals, such as cobalt, becomes a crucial factor. The creation and introduction of novel selective innovations. extraction agents require substantial investment and time. To address In these challenges, a blend of readily accessible solutions. solvent agents or collaborative solvent extraction approaches is undertaken, aiming to enhance metal selectivity and the potential for developing new applications.

Adsorption

Adsorption is the phenomenon of the accumulation of molecules of one substance on the surface of another substance due to imbalances and attractive forces between atoms or molecules on the solid substance's surface. This process is divided into chemical and physical adsorption, with differences based on the uniformity of the adsorbent and adsorbate, adsorption energy, reversibility, and the thickness of the layer. Aspect influencing adsorption include levels, extent, heat, granule dimensions, acidity level, and duration of interaction. Adsorption is selective, allowing only the adsorption of dissolved substances or solutes. The amount of absorbed substance relies on the solute's level of concentration and this dependence on equilibrium concentration is referred to as the adsorption isotherm.

In general, adsorption is a process in which specific components are separated from a solution in a fluid phase and transferred to the surface of a solid substance capable of adsorption, known as the adsorbent. This or the division process happens because of variations in molecular mass porosity, causing some molecules to bind more strongly to the surface than others. For adsorption to occur, the conditions include the presence of both adsorbent and adsorbate, along with sufficient shaking time to reach equilibrium. Adsorption can be categorized into two types: chemical adsorption (chemisorption) involving chemical forces and reactions, and physical adsorption (physisorption) occurring due to physical forces without the formation of strong chemical bonds.(Alamsyah et al., 2017).

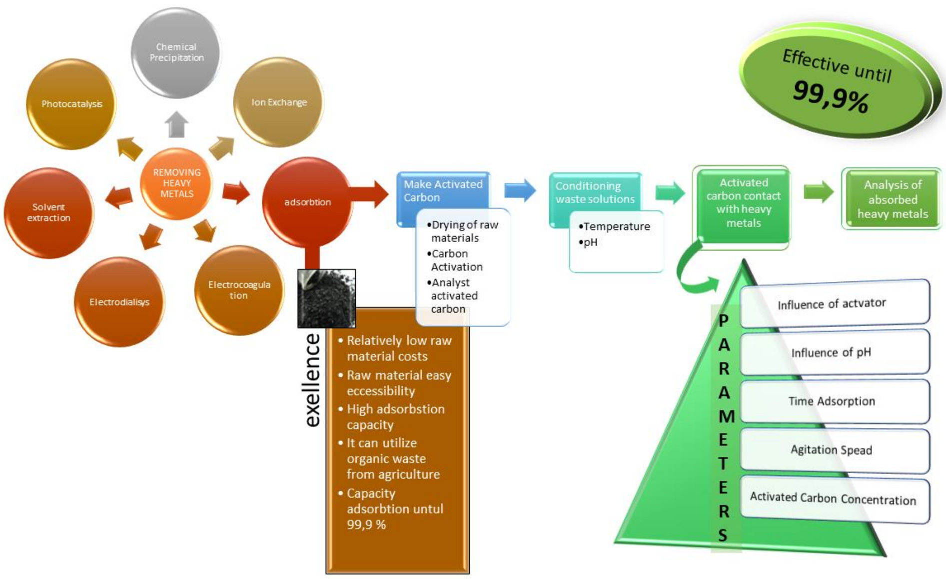

Figure.1 Scope Adsorption from Removing Heavy Metals

METHODOLOGY

The method used is a qualitative method because it is more about understanding and evaluating literature regarding types of methods for absorbing heavy metal waste through in-depth analysis of the text and research context. This approach is different from quantitative reviews which focus more on collecting and analyzing numerical data. Qualitative reviews emphasize interpretive, holistic, and contextual understanding of the studies analyzed.

RESEARCH RESULT

The following presents a comparison of several methods for removing heavy metals from industrial waste can be seen in Table 1 :

Table 1. Comparison of Several Methods for Removing Heavy Metals From Industrial Waste

No	Metode for Removing Heavy Metals	Heavy Metals Remove	% Efficiency	Refference
1.	Chemical Precipitation	Ar (Arsen)	≥ 99%	(Harper & Kingham, 1992)
2.	Ion Exchange	Cu (Cuprum)	90%	(Wang & Peng, 2010)
3.	Ion Exchange	Zn	90%	(Wang & Peng, 2010)
4.	Ion Exchange	Ni	75%	(Papadopoulos et al., 2004)
5.	Electrocoagula tion	Ar	98,8%	(Ali et al., 2012)
6.	Electrocoagula tion	Cd	80-90%	(Park et al., 2002)
7.	Electrodialisys	Cd	67-70%	(Jakobsen et al., 2004)
8.	Photocatalysis	Ag	46,62% (UV100), 99,7%(P25)	(Chen & Ray, 2001)
9.	Solvent Extraction	Cr	89,8%	(Mcdonald & Bajwa, 1977)
10	Solvent Extraction	Zn	98,8%	(Mcdonald & Bajwa, 1977)
11	Solvent Extraction	Cd	89%	(Mcdonald & Bajwa, 1977)
12	Adsorption	Pb	99,9%	(Bobade et al., 2015)
13	Adsorption	Cd	99,9%	(Bobade et al., 2015)
14	Adsorption	Cu	99,9%	(Bobade et al., 2015)
15	Adsorption	Ni	99,8%	(Bobade et al., 2015)

Based on the above data, it can be concluded that, on average, the most effective and efficient method for removing heavy metals from industrial waste is through adsorption. This is evident from the percentage of heavy metal adsorption that approaches 100%. Additionally, the adsorption process has many advantages, such as relatively low raw material costs and easy accessibility, as it can utilize organic waste from agriculture.

DISCUSSION

From the results it was found that the best method for removing heavy metal waste is adsorption. Several things must be paid attention to regarding adsorption so that the absorption of heavy metal waste can be maximized. In the implementation of the adsorption process, several parameters play a crucial role in ensuring that adsorption occurs optimally, allowing heavy metals to be absorbed to the maximum extent possible. Some of these parameters include:

Influence of Activator

There are two types of activators: acid and base. The impact of acid and base on the percentage difference in adsorption capacity is not very significant, but acid tends to outperform base, albeit with an advantage of around >10%. When comparing similar acids or bases, the stronger acid or base tends to adsorb more heavy metal waste than the weaker acid or base.(Raninga et al., 2023)

Influence of pH

pH significantly affects the adsorption process. Adsorption capacity increases with rising pH. This is because, under low pH conditions, protons predominantly occupy the active carbon surface, resulting in diminished adsorption capacity.Conversely, a decrease in behavior is observed at pH above 8, as noted in several studies. This may be attributed to the formation of soluble hydroxylated complexes.(Ngabura et al., 2018).

Tima Adsorption

Time Initially, the unsaturated adsorbent surface results in suboptimal binding of heavy metals. However, with prolonged contact time, the adsorbent surface becomes saturated, leading to better absorption of heavy metals.(Ngabura et al., 2018).

Temperature Pyrolysis

Pyrolysis temperature also influences the quality of activated carbon. The temperature affects the surface area, total pore volume Temperature, and micropore volume, all of which increase with higher pyrolysis temperatures. This is because activated carbon loses volatile substances, and the decomposition of its main compounds occurs at elevated pyrolysis temperatures.(Bouchelta et al., 2012).

Initial Concentration of Heavy Metals

Adsorption capacity increases with the growing concentration of the adsorbate. As the absorbed adsorbate increases, the efficiency of absorption on the adsorbent decreases due to a lack of absorption sites. The rise in the initial adsorbate concentration will provide a driving force, often referred to as the concentration gradient, and it will overcome the mass transfer resistance between the solid phase and the solution. The initial concentration plays a crucial role; therefore, it is highly recommended to dilute waste containing an excess of metal ions initially.(Ngabura et al., 2018).

Activated Carbon Concentration

It is evident that using a higher dose of the adsorbent in the adsorption process will increase the surface area and also affect the amount of heavy metals adsorbed.(Ngabura et al., 2018).

Agitation Speed

The stirring speed will impact the rate of contact between the adsorbent and its adsorbate. This is as a result of an increase in the degree of agitation enhances system mobility. Additionally, increasing agitation with stirrer speed will reduce the effect of external mass transfer.(Dotto & Pinto, 2011).

CONCLUSIONS AND RECOMMENDATIONS

Regardless of everything, it cannot be denied that heavy metals indeed have the potential to pose a threat to human health. Even minimal exposure can have serious impacts on health, especially in the case of continuous exposure and the deposition of heavy metals within the body. The volume of industrial waste in the form of heavy metals has spurred the development of various methods to address this pollution issue in the environment. Among the various available methods for both large and small-scale applications, adsorption stands out as the most optimal choice due to its low energy consumption, operational simplicity, and high efficiency in metal removal. Associated with the mentioned energy cost is the relatively inexpensive production of activated carbon, making this method the most commonly employed approach.

ADVANCED RESEARCH

Over time, the evolution of technology brings advancements toward more sophisticated and efficient methods. These changes are expected to serve as benchmarks or refinements for adsorption methods in absorbing heavy metals. The emergence of new methods is anticipated to be more economical and effective for application, both on a laboratory and industrial scale.

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