Int. J. New. Chem., 2025, Vol. 12, Issue 1, pp. 74-86.

International Journal of New Chemistry

Published online 2025 in http://www.ijnc.ir/.

Open Access

Print ISSN: 2645-7236

Online ISSN: 2383-188x

Review

An Update Comprehensive Review on the Adsorptive Removal of Heavy Metals from Industrial Effluents

Saeedeh Khoshniyat and Saba Abedini*

Department of Applied Sciences, Malek Ashtar University of Technology, Isfahan, Iran.

Received: 2024-06-24 *Accepted: 2024-09-10* *Published: 2024-09-20*

ABSTRACT

This review paper provides an updated and comprehensive overview of the adsorptive removal of heavy metals from industrial effluents. Heavy metal pollution in industrial wastewater poses a significant threat to the environment and human health, making the development of effective treatment technologies crucial. Adsorption has emerged as a promising method for the removal of heavy metals due to its efficiency, cost-effectiveness, and versatility. This paper covers the latest advancements in adsorption technologies, including various adsorbent materials such as activated carbon, zeolites, and biochar, as well as their modification techniques to enhance adsorption capacity. Furthermore, the review discusses the influence of key parameters such as pH, temperature, and initial metal concentration on the adsorption process. Additionally, the paper addresses the challenges and future perspectives in the field of adsorptive removal of heavy metals, aiming to provide valuable insights for researchers, practitioners, and policymakers involved in industrial wastewater treatment.

Keywords: Removal, Heavy metals, Adsorption, Effluents

*Corresponding author email address: sabaabedini6574@gmail.com

Introduction

Heavy metals are a group of metallic elements that have a high density and are toxic or poisonous at low concentrations [1]. Some examples of heavy metals include lead, mercury, cadmium, arsenic, and chromium [2]. These metals are naturally occurring in the earth's crust, but human activities such as mining, industrial processes, and agriculture have led to increased concentrations of heavy metals in the environment [3]. The history of heavy metals dates back to ancient times when they were used for various purposes. For example, lead was used in plumbing and as a component of paint, while mercury was used in medicine and alchemy [4]. However, the toxic effects of these metals were not fully understood, and their widespread use led to various health and environmental problems [5]. In the 20th century, the adverse effects of heavy metals became more evident as industrialization and urbanization led to increased pollution. The Minamata disease in Japan, caused by mercury poisoning, and the lead poisoning crisis in Flint, Michigan, brought global attention to the dangers of heavy metal contamination [6]. As a result, regulations and standards were established to limit the release of heavy metals into the environment and to protect human health. Today, heavy metal contamination remains a significant concern, particularly in developing countries where industrialization is rapidly increasing [7]. Efforts to mitigate heavy metal pollution include the development of cleaner technologies, waste management practices, and remediation techniques. Additionally, research continues to advance our understanding of the sources, transport, and effects of heavy metals in the environment [8]. Heavy metals are naturally occurring elements that have a high atomic weight and density. They can be found in the earth's crust and have become increasingly prevalent in the environment due to human activities such as industrial processes, mining, and agriculture [9]. Heavy metals are known for their potential to cause harm to human health and the environment. The occurrence of heavy metals in the environment is a concern due to their toxicity and potential for bioaccumulation in the food chain [10]. Common heavy metals of concern include lead, mercury, cadmium, arsenic, and chromium. These metals can enter the environment through various pathways, including air and water pollution, soil contamination, and waste disposal [11]. In water, heavy metals can be found in both natural and anthropogenic sources. Natural sources include weathering of rocks and minerals, while anthropogenic sources include industrial discharges, mining activities, and urban runoff [12]. Once in water, heavy metals can accumulate in sediments and aquatic organisms, posing a threat to aquatic ecosystems

and human health. In soil, heavy metals can originate from natural processes such as volcanic eruptions and weathering of parent materials [13]. However, human activities such as mining, smelting, and the use of agrochemicals can significantly increase the levels of heavy metals in soil. Contaminated soil can then lead to the uptake of heavy metals by plants, potentially impacting food safety and agricultural productivity [14]. Airborne heavy metals can originate from natural sources such as forest fires and volcanic eruptions, as well as anthropogenic sources including industrial emissions and vehicle exhaust [15]. Once in the atmosphere, heavy metals can be transported over long distances and deposited onto soil and water bodies, contributing to environmental contamination [16]. The presence of heavy metals in the environment poses a significant risk to human health. Exposure to heavy metals can occur through inhalation, ingestion of contaminated food and water, and dermal contact. Chronic exposure to heavy metals has been linked to a range of adverse health effects, including neurological disorders, kidney damage, respiratory problems, and certain types of cancer [17]. In response to the potential risks associated with heavy metal occurrence, regulatory agencies have established guidelines and standards for acceptable levels of heavy metals in the environment. Monitoring programs are in place to assess the levels of heavy metals in air, water, soil, and food products, with the aim of protecting human health and the environment [18]. Efforts to mitigate the occurrence of heavy metals in the environment include pollution prevention measures, remediation of contaminated sites, and the development of cleaner production technologies. Additionally, public awareness and education play a crucial role in promoting sustainable practices and reducing the release of heavy metals into the environment [19]. Heavy metals toxicity refers to the harmful effects of certain metals in the body. These metals, including lead, mercury, arsenic, cadmium, and others, can accumulate in the body over time and cause a wide range of adverse health effects. Exposure to heavy metals can occur through various routes, including ingestion, inhalation, and skin contact [20]. The toxicity of heavy metals is a significant concern due to their persistence in the environment and their ability to bioaccumulate in living organisms. Once absorbed into the body, heavy metals can interfere with normal cellular functions and disrupt essential biochemical processes. This can lead to a variety of health problems, including neurological disorders, organ damage, developmental delays, and even cancer. One of the most well-known examples of heavy metal toxicity is lead poisoning [21]. Lead exposure can occur through contaminated air, water, soil, and consumer products. Children are particularly vulnerable to lead poisoning, as their

developing bodies are more susceptible to the harmful effects of lead. Chronic lead exposure can result in cognitive impairment, behavioral problems, and decreased IQ levels. Mercury is another heavy metal of concern due to its widespread presence in the environment [22]. Mercury exposure can occur through the consumption of contaminated fish and seafood, as well as through dental amalgam fillings and certain industrial processes. Prenatal exposure to mercury can have serious consequences for fetal development, leading to neurodevelopmental disorders and other adverse effects [23]. Arsenic is yet another heavy metal that poses a significant health risk. Arsenic contamination in drinking water is a major concern in many parts of the world, particularly in regions where natural geological processes release arsenic into groundwater. Chronic arsenic exposure has been linked to skin lesions, cardiovascular disease, and an increased risk of certain cancers [24]. Cadmium is a heavy metal commonly found in industrial settings and tobacco smoke. Inhalation of cadmium fumes or consumption of cadmium-contaminated foods can lead to kidney damage, bone demineralization, and an increased risk of lung cancer. In addition to these specific examples, heavy metal toxicity can manifest in a variety of other ways, depending on the type and level of exposure [25]. Symptoms of heavy metal poisoning may include nausea, vomiting, diarrhea, abdominal pain, fatigue, and neurological disturbances. Long-term exposure to heavy metals can have serious and potentially irreversible health consequences. Preventing heavy metal toxicity requires efforts to minimize exposure to these substances in the environment and in consumer products [26]. This may involve implementing regulations to limit industrial emissions, improving water treatment processes to remove heavy metals, and promoting safe practices for handling and disposing of hazardous materials. Additionally, public education and awareness campaigns can help individuals make informed choices to reduce their risk of heavy metal exposure [27]. In cases where individuals have been exposed to high levels of heavy metals, medical treatment may be necessary to address acute poisoning or to manage chronic health effects. Treatment options may include chelation therapy to remove heavy metals from the body, supportive care to alleviate symptoms, and ongoing monitoring to assess the long-term impact of heavy metal exposure [28]. Overall, heavy metal toxicity is a complex and multifaceted issue that requires attention from both public health authorities and individuals. By understanding the sources and health effects of heavy metals, implementing effective prevention strategies, and providing appropriate medical care when needed, it is possible to mitigate the risks associated with heavy metal exposure and protect

public health. Heavy metals removal techniques are an essential aspect of environmental protection and public health. These techniques are employed to eliminate or reduce the concentration of heavy metals in various environmental matrices such as water, soil, and air. Heavy metals, including lead, mercury, cadmium, and arsenic, are known for their toxicity and potential to cause serious health problems in humans and other living organisms. Therefore, it is crucial to develop and implement effective removal techniques to mitigate the adverse effects of heavy metal contamination [29].

Heavy Metals Removal Techniques

Several techniques are used for the removal of heavy metals from different environmental compartments. These techniques can be broadly categorized into physical, chemical, and biological methods. Physical methods include processes such as precipitation, filtration, and adsorption, which involve the physical separation of heavy metal ions from the contaminated media. Chemical methods, on the other hand, utilize chemical agents such as chelating agents, ion exchange resins, and oxidation-reduction reactions to precipitate or transform heavy metals into less toxic forms [30]. Biological methods employ microorganisms, plants, or enzymes to sequester or metabolize heavy metals, thereby reducing their concentration in the environment. One of the commonly used physical methods for heavy metals removal is precipitation. This process involves the addition of chemicals such as lime or sodium hydroxide to the contaminated water or wastewater to form insoluble metal hydroxides, which can then be separated from the solution by sedimentation or filtration [31]. Another physical method, adsorption, relies on the use of adsorbent materials such as activated carbon or zeolites to attract and retain heavy metal ions from aqueous solutions through surface interactions. Chemical methods play a significant role in heavy metals removal, with ion exchange being a widely employed technique [32]. Ion exchange resins are used to selectively remove heavy metal ions from solution by exchanging them with less toxic ions immobilized on the resin matrix [33]. Chelation is another chemical method that involves the use of chelating agents such as ethylenediaminetetraacetic acid (EDTA) or citric acid to form stable complexes with heavy metal ions, thereby preventing their reactivity and facilitating their removal from the environment. Biological methods offer a sustainable and eco-friendly approach to heavy metals removal [34]. Phytoremediation, for instance, utilizes plants to uptake and accumulate heavy metals from soil or water, thereby reducing their

bioavailability and potential for harm. Microbial bioremediation involves the use of microorganisms such as bacteria or fungi to immobilize or transform heavy metals through processes such as biosorption, bioprecipitation, or enzymatic degradation. In addition to these primary removal techniques, advanced treatment technologies such as electrochemical remediation, membrane filtration, and nanotechnology-based approaches have emerged as promising strategies for addressing complex heavy metal contamination scenarios. Electrochemical methods utilize electrodes to induce redox reactions that facilitate the removal or transformation of heavy metals in contaminated water or soil. Membrane filtration techniques, including reverse osmosis and ultrafiltration, offer selective separation of heavy metal ions from aqueous solutions based on their size and charge. Nanotechnology-based approaches involve the use of engineered nanomaterials such as nanoparticles or nanocomposites for targeted removal of heavy metals through adsorption, catalysis, or membrane-based processes [35].

Adsorption

Adsorption is the process by which molecules or particles adhere to the surface of a solid or liquid. This phenomenon occurs due to the attractive forces between the adsorbate (the substance being adsorbed) and the adsorbent (the surface to which the adsorbate adheres). Adsorption is a crucial process in various industrial, environmental, and biological applications. In industrial settings, adsorption is used for purification, separation, and catalysis [36]. For example, activated carbon is widely employed as an adsorbent to remove impurities from gases and liquids in the purification of drinking water, treatment of wastewater, and air filtration. Additionally, adsorption plays a vital role in gas separation processes, such as the removal of carbon dioxide from natural gas or the purification of hydrogen for fuel cell applications [37]. Furthermore, adsorption is utilized in catalytic processes to enhance the efficiency of chemical reactions by providing a surface for reactant molecules to adsorb and undergo transformation. In environmental applications, adsorption is instrumental in remediation efforts to clean up contaminated soil and water. Adsorbent materials are deployed to capture and remove pollutants, including heavy metals, organic compounds, and dyes, from industrial effluents and hazardous waste sites [37]. This helps mitigate the adverse effects of pollution on ecosystems and human health. In biological systems, adsorption plays a crucial role in processes such as drug delivery, protein purification, and the removal of toxins from the body. Adsorbent materials are designed

to selectively bind specific molecules, facilitating their targeted delivery or removal from biological fluids. This has significant implications for pharmaceutical formulations, biomedical devices, and therapeutic interventions [38]. The mechanisms of adsorption can vary depending on the nature of the adsorbate and adsorbent, as well as the prevailing conditions such as temperature, pressure, and concentration. Physical adsorption involves non-specific interactions, such as van der Waals forces and electrostatic attractions, between the adsorbate and adsorbent. In contrast, chemisorption entails the formation of chemical bonds or interactions between the adsorbate and adsorbent surface. Understanding these mechanisms is essential for optimizing adsorption processes and developing tailored adsorbent materials for specific applications. Overall, adsorption is a versatile and indispensable phenomenon with widespread implications across diverse fields. Its fundamental principles continue to drive advancements in materials science, environmental engineering, chemical processing, and biomedical research. As researchers continue to explore the intricacies of adsorption phenomena, new opportunities for innovation and problem-solving are likely to emerge, further expanding the impact of this fundamental process on society and the natural world [39].

Adsorptive Removal of Heavy Metals

Adsorptive removal of heavy metals from effluents is a critical process in environmental remediation. Heavy metals such as lead, cadmium, mercury, and arsenic are known to be highly toxic and can cause serious health and environmental issues if not properly managed. Adsorption is a widely used method for removing heavy metals from effluents due to its effectiveness and cost-efficiency [1]. The process of adsorption involves the attachment of heavy metal ions to the surface of a solid material, known as an adsorbent. Commonly used adsorbents include activated carbon, zeolites, and various types of clays. These materials have high surface areas and specific chemical properties that make them effective at capturing heavy metal ions from water or wastewater. One of the key advantages of adsorptive removal is its ability to selectively target specific heavy metal ions. This allows for the removal of multiple contaminants from effluents in a single treatment step [2]. Additionally, adsorption can be easily integrated into existing water treatment processes, making it a versatile and practical solution for heavy metal removal. The effectiveness of adsorptive removal is influenced by several factors, including the characteristics of the adsorbent material, the concentration of heavy metal ions in the effluent, and the pH of the

solution. Proper selection of adsorbent materials and optimization of operating conditions are critical for achieving high removal efficiencies. In recent years, significant research efforts have been focused on developing novel adsorbent materials with enhanced adsorption capacities and selectivity for heavy metals [3-6]. Nanomaterials, such as graphene oxide and carbon nanotubes, have shown great potential for use in adsorptive removal due to their unique structural and chemical properties. Furthermore, the application of functionalized adsorbent materials, such as ion-exchange resins and chelating polymers, has expanded the range of heavy metal ions that can be effectively removed from effluents [7-9]. These advancements in adsorbent technology have the potential to significantly improve the efficiency and sustainability of heavy metal removal processes. Overall, adsorptive removal of heavy metals from effluents plays a crucial role in mitigating the environmental and health risks associated with heavy metal contamination. Continued research and development in this field are essential for advancing the effectiveness and applicability of adsorption-based treatment technologies. By addressing the challenges associated with heavy metal pollution, adsorptive removal offers a promising solution for ensuring the safety and quality of water resources [10].

Advantages

Adsorptive removal of heavy metals offers several advantages over other methods. Firstly, adsorption is a cost-effective and efficient process for removing heavy metals from wastewater. It requires relatively simple equipment and can be easily integrated into existing water treatment systems. Additionally, adsorption can effectively remove a wide range of heavy metal contaminants, including lead, cadmium, mercury, and arsenic, making it a versatile solution for various industrial and environmental applications. Moreover, adsorption processes can be easily tailored to specific heavy metal contaminants and operating conditions, allowing for greater flexibility and control [11-13]. This level of customization ensures that adsorptive removal can achieve high removal efficiencies and meet stringent discharge regulations. In contrast, other methods such as precipitation or ion exchange may be less effective for certain heavy metal contaminants or require more complex operational parameters. Furthermore, adsorption is a non-destructive process, meaning that the heavy metal contaminants can be recovered and potentially reused, minimizing waste and reducing environmental impact [14-17]. This aspect aligns with sustainable practices and circular economy principles, making adsorptive removal an attractive

option for industries seeking to minimize their environmental footprint. Another advantage of adsorptive removal is its ability to operate over a wide range of pH levels, temperatures, and concentrations, providing greater adaptability to diverse wastewater streams [18-20]. This flexibility is particularly beneficial for treating complex industrial effluents with fluctuating compositions and characteristics. In addition, adsorption processes can be easily combined with other treatment technologies such as coagulation, filtration, or membrane separation to create multi-stage treatment systems that offer enhanced removal efficiencies and overall performance. This integrated approach can provide a comprehensive solution for addressing complex wastewater challenges and achieving regulatory compliance [21-23]. Overall, the advantages of adsorptive removal of heavy metals over other methods make it a compelling choice for industries and municipalities seeking effective, efficient, and sustainable solutions for managing heavy metal contamination in water resources. Its cost-effectiveness, versatility, customization potential, non-destructive nature, operational flexibility, and compatibility with other treatment processes position adsorption as a valuable tool in the pursuit of clean water and environmental stewardship.

Challenges

The challenges of adsorptive removal of heavy metals present significant obstacles in the field of environmental remediation. One of the primary challenges is the selection of an adsorbent material that effectively and efficiently removes heavy metals from contaminated water or soil. The adsorbent material must have high affinity and selectivity for the target heavy metals, while also being cost-effective and environmentally friendly [24]. Additionally, the regeneration and reusability of the adsorbent material is a critical consideration, as it directly impacts the overall cost and sustainability of the removal process. Another challenge is the optimization of adsorption conditions, including factors such as pH, temperature, contact time, and initial concentration of heavy metals. These parameters can significantly influence the adsorption capacity and efficiency of the process, making it essential to carefully control and optimize these conditions for practical application [25-28]. Furthermore, the presence of competing ions and complex matrices in real-world wastewater or soil can interfere with the adsorption process, reducing its effectiveness. Overcoming this challenge requires thorough understanding of the interactions between the adsorbent material and various components in the contaminated

medium, as well as the development of strategies to mitigate these interferences. In addition, scaling up adsorptive removal processes from laboratory-scale to industrial-scale presents its own set of challenges. Factors such as mass transfer limitations, reactor design, and cost considerations need to be carefully evaluated and optimized to ensure the practicality and efficiency of large-scale implementation [29]. Moreover, the long-term stability and durability of adsorbent materials in continuous operation under varying environmental conditions is a crucial challenge. The potential for leaching of adsorbed heavy metals back into the environment, as well as the physical and chemical degradation of the adsorbent material over time, must be addressed to ensure the overall effectiveness and safety of the removal process. Finally, the disposal or regeneration of spent adsorbent materials and the management of concentrated heavy metal-laden waste streams generated during the removal process pose significant challenges in terms of environmental impact and cost-effectiveness. In conclusion, addressing these challenges requires multidisciplinary approaches that integrate materials science, chemistry, engineering, and environmental science to develop efficient, cost-effective, and sustainable adsorptive removal technologies for heavy metals [30-39]. Despite these challenges, continued research and innovation in this field are essential for mitigating the environmental and human health risks associated with heavy metal contamination.

Conclusions and Future Perspectives

In conclusion, the adsorptive removal of heavy metals from effluents offers a promising solution for addressing environmental pollution and protecting human health. Various adsorbent materials, including natural and modified substances, have demonstrated efficient metal removal capabilities through mechanisms such as ion exchange, complexation, and surface precipitation. The effectiveness of adsorption processes is influenced by factors such as pH, temperature, contact time, and initial metal concentration, which should be carefully considered in the design and operation of treatment systems. Despite the progress made in adsorption technology, several challenges and opportunities for future research and application should be noted. Firstly, the development of cost-effective and sustainable adsorbent materials with high selectivity and capacity for heavy metals is essential for practical implementation. This requires further exploration of novel materials, such as bio-based adsorbents, nanomaterials, and composite structures, as well as the optimization of synthesis methods to enhance their performance.

Furthermore, the integration of adsorption processes with other treatment methods, such as membrane filtration, electrochemical techniques, or biological remediation, could offer synergistic effects and improve overall treatment efficiency. The potential for regeneration and reuse of adsorbent materials should also be investigated to minimize waste generation and operational costs. In addition, the scale-up of adsorption technologies for industrial applications requires consideration of engineering aspects, including reactor design, flow dynamics, and process control strategies. Pilot-scale studies and field trials are needed to validate the performance and feasibility of adsorption systems under real-world conditions and to assess their economic and environmental impacts. Moreover, the assessment of potential risks associated with the disposal or utilization of spent adsorbent materials, as well as the fate of adsorbed metals during regeneration or disposal processes, is crucial for ensuring overall environmental sustainability. In conclusion, the adsorptive removal of heavy metals from effluents holds great potential for mitigating metal pollution and advancing sustainable water management practices. Continued research efforts and interdisciplinary collaborations are essential to address current limitations, optimize adsorption technologies, and facilitate their practical implementation in diverse industrial and environmental settings. By doing so, we can work towards a cleaner and healthier environment for present and future generations.

References

1. M. Y. Pamukoglu and F. Kargi, Enzyme Microbiol. Tech. **42**, 76 (2007).
2. M. Y. Pamukoglu and F. Kargi, J. Hazard. Mater. **138**, 479 (2006).
3. A. Denizli, B. Garipcan, A. Karabakan, et al., Sep. Purif. Technol. **30**, 3 (2003).
4. A. C. Gonçalves, H. Nacke, D. Schwantes, et al., Environ. Sci. Pollut. Res. **24**, 21778 (2017).
5. F. Karipcin, B. Dede, and M. Cengiz, Russ. J. Inorg. Chem. **55**, 530 (2010).
6. K. G. Bhattacharyya and S. Sen Gupta, Adsorption **12**, 185 (2006).
7. M. M. H. Khalil, K. Z. Al-Wakeel, S. S. A. E. Rehim, et al., J. Dispers. Sci. Technol. **35**, 1691 (2014).
8. A. A. Hussain, S. R. Mohammed, M. Nallu, et al., J. Chem. Pharm. Res. **4**, 2325 (2012).
9. M. N. Ehssan, Int. J. Eng. Sci. Technol. **4**, 4480 (2012).

10. E. Erdem, N. Karapinar, and R. Donat, J. Colloid Interface Sci. **280**, 309 (2004).

11. G. Sun and W. Shi, Ind. Eng. Chem. Res **37**, 1324 (1998).

12. I. A. Katsoyiannis and A. I. Zouboulis, Water Res. **38**, 17 (2004).

13. X. H. Wang, L. Yang, J. Zhang, et al., Chem. Eng. J. **251**, 404 (2014).

14. J. Abdi, M. Vossoughi, N. M. Mahmoodi, et al., Ultrason. Sonochem. **39**, 550 (2017).

15. S. A. Sallam et al., Catal. Lett. **12**, 3701 (2018).

16. El-Subruiti, G. M. Eltaweil, A. S. Sallam, et al., Nano: Brief Rep. Rev. **14** (10) (2019).

17. Y. Y. Ling and F. M. Suah, J. Environ. Chem. Eng. **5**, 785 (2017).

18. L. Huang, W. Y. Chen, Y. S. Wan, et al., Environ. Sci., No. **7**, 2604 (2015).

19. B. Fda, B. Ls, B. Zh, et al., Chemosphere **239**, 124764 (2020).

20. Z. Bekçi, C. Özveri, Y. Seki, and K. Yurdakoç, Hazard Mater. **154,** 254 (2008).

21. J. Vila, M. Tauler, and M. Grifoll, Curr. Opin. Biotechnol. **33**, 95 (2015).

22. F. X. Zhu, S. Storey, M. M. Ashaari, N. Clipson, and E. Doyle, Environ. Sci. Pollut. Res. **24**, 5404 (2017).

23. G. D. Sayles, C. M. Acheson, M. J. Kupferle, Y. Shan, Q. Zhou, J. R. Meier, L. Chang, and R. C. Brenner, Environ. Sci. Technol. **33**, 4310 (1999).

24. J. W. Talley, U. Ghosh, S. G. Tucker, J. S. Furey, and R. G. Luthy, Environ. Sci. Technol. **36**, 477 (2002).

25. S. N. Chen, H. Yin, and J. Chang, J. Hazard. Mater. **321**, 9 (2017).

26. S. N. Chen, H. Yin, S. Y. Tang, H. Peng, and Z. Dang, Bioresour. Technol. **24**, 26 (2016).

27. N. Nader, R. Bikas, M. Emami, M. Siczek, and T. Lis, Polyhedron **111**, 167 (2016).

28. Y. Xie, J. Wang, M. Wang, and X. Ge, J. Hazard. Mater. **297**, 66 (2015).

29. Q. Wang, W. Gao, Y. Liu, J. Yuan, Z. Xu, Q. Zeng, Y. Li, and M. Schröder, Chem. Eng. J. **250**, 55 (2014).

30. O. M. M. Freitas, R. J. E. Martins, C. M. Delerue-Matos, and R. A. R. Boaventura, J. Hazard. Mater. **153**, 493 (2008).

31. A. T. Paulino, L. B. Santos, and J. Nozaki, React. Funct. Polym. **68**, 634 (2008).

32. . Pérez-Quintanilla, A. Sánchez, I. del Hierro, M. Fajardo, and I. Sierra, J. Colloid Interface Sci. **313**, 551 (2007).

33. M. Amini, H. Younesi, and N. Bahramifar, Colloids Surf. A **337**, 67 (2009).

34. A. Bhatnagar and M. Sillanpää, Chem. Eng. J. **168**, 493 (2011).

35. B. Ajdari, T. Madrakian, A. Afkhami, Int. J. New. Chem., 11, 270 (2024)

36. F. Akbari Lasboo, M. Karimian, F. Movahed, N. Ghoreishi Amin, Int. J. New. Chem., 11, 1 (2024).

37. P. Niknam Rad, F. Ashtari Mahini, Int. J. New. Chem., 11, 424 (2024).

38. S. Abrahi Vahed, F. Hemmati Tirabadi, Int. J. New. Chem., 10, 288 (2023).

39. M. Akbar, M. Manoochehri, A. Alihosseini, 10, 53 (2023).

HOW TO CITE THIS ARTICLE

Saeedeh Khoshniyat and Saba Abedini, "**An Update Comprehensive Review on the Adsorptive Removal of Heavy Metals from Industrial Effluents**" International Journal of New Chemistry., 2025; 12(1), 74-86. DOI: 10.22034/ijnc.2024.715829