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Biosorption for Nickel Removal with Microbial and Plant-Derived Biomasses: A Review Study

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Abstract

The negative effects of heavy metal discharge caused by various industries on the environment and living organisms have been well-proven. Conventional technologies for removing heavy metals from aqueous solutions are not economically viable and in addition to being ineffective at low concentrations of metal ions, they produce a large amount of chemical sludge. The biological absorption of nickel by non-living and inactive microbial biomass or derived from plants is an alternative and innovative technology to remove this pollution from aqueous solutions while eliminating the problems of the conventional methods mentioned in this article due to the availability of adsorbents It has renewable and high absorption capacity. The present study was a review study to introduce types of microbial and plant-derived bio absorbents to remove nickel from aqueous solution and reveal the absorption capacity of each adsorbent. It suggests the use of these biomasses as bio-adsorbents for the removal of nickel in aqueous solution as a promising and environmentally friendly perspective. According to the studies, in most processes of nickel biological absorption with different adsorbents, a negative value, and a positive value have been reported. It has a negative value due to the spontaneity of the process and a positive value due to the increase of random collisions between solid and solution during the process.

Keywords: Biosorption, Microbial biomass, Plant-derived Biomasses, Nickel

Introduction

With the advancement of technology and the development of economic activities, a large amount of waste containing heavy metals enters the natural environment. Heavy metals are a serious threat to the environment and public health due to their toxicity, accumulation in the food chain, and their indestructibility and stability in nature (Pahlavanzadeh *et al*., 2010; Al-Fakih, 2015; Kaparapu & Krishna Prasad, 2018). The pollution of water sources due to non-degradable heavy metal wastewater has caused great concern in recent decades (Torab-Mostaedi *et al*., 2013; Waqar *et al*., 2023). According to WHO, the most worrying toxic heavy metals in industrial waste include nickel, cadmium, chromium, cobalt, copper, lead, mercury, and zinc (Pahlavanzadeh *et al*., 2010; Boulaiche *et al*., 2019) These metals are introduced as a solution in water and soil, and in addition to polluting surface and underground water and soil, they disturb the ecosystem into which they are introduced. These metals can enter the human food chain after entering the soil. They can also be easily absorbed by marine animals and thus enter the human body system, which will bring a high risk to the health of the consumer (Nuhoglu & Malkoc, 2009; Thaçi & Gashi, 2023).

Nickel is one of the important and indestructible heavy metals, and its concentration exceeding the permissible limit can be dangerous for humans and other living organisms. Although its existence is necessary to carry out some enzymatic reactions and metabolic activities of the human body. Nickel is a hard silvery-white metal that is an abundant element in nature and can be easily combined with metals such as copper, zinc, chromium, and iron to become an alloy (Yalçın *et al*., 2018). This metal is resistant to corrosion by air and water, and for this reason, its use has a special place in various industries. Among its applications, we can mention the production of stainless steel, electroplating, coins, batteries, metal alloys, non-ferrous metals, super alloys, leather making, paper pulp processing, pigments, and chemical processing (Long *et al*., 2018; Anitha *et al*., 2021).

Excessive consumption of nickel metal causes numerous problems for human immune and nervous systems, allergic skin diseases, lung problems, kidney fibrosis, and digestive tract discomfort (Torab-Mostaedi *et al*., 2013; Noormohamadi *et al*., 2019). The maximum allowed amount of nickel in drinking water is 0.07 mg/liter. Therefore, due to the mentioned destructive effects, it is vital to remove them from wastewater and industrial wastes before releasing and discharging them into the environment. Several technologies have been developed over the years to remove heavy metals from aqueous solutions. Conventional methods include ion exchange, electrochemical methods, chemical precipitation, solvent extraction, membrane filtration, reverse osmosis, surface adsorption, evaporation, and flocculation (Noormohamadi *et al*., 2019).

Conventional methods have low efficiency in low concentrations of metal ions, high operating costs, incomplete metal removal, sensitive operating conditions, high energy consumption, high chemical sludge production, and secondary pollution (Villen-Guzman *et al*., 2019). These limitations, together with the

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environmental requirements regarding heavy metals, reveal the need to develop new techniques more and more. The development of technically simple and economically attractive methods for industrial wastewater treatment is one of the most important priorities of the 21st century (Amini *et al*., 2009). As a method based on high absorption efficiency, low investment, and operating costs, ease of management and operation, and low secondary pollution, biological absorption has attracted much attention (Long *et al*., 2018). Bio-adsorption is a low-cost and environmentally friendly technology for the separation of heavy metals using the process of binding metal ions to the adsorbent, the efficiency of which is directly related to the conditions of the adsorbent. These attractants mainly include non-living biomass such as lignin, fruit peel, agricultural waste, algal biomass, and microbial biomass including bacteria, fungi, and yeast. An ideal adsorbent should be economical, environmentally friendly, highly abundant, efficient, and renewable. Agricultural waste materials, which are mainly composed of cellulose and lignin, have been proposed as a suitable option for the treatment of wastewater containing heavy metals (Villen-Guzman *et al*., 2019). The use of live and dead microorganisms and biological materials has been used since 1980 to remove heavy metal ion pollution from wastewater (Beni & Esmaeili, 2020).

During the biosorption process, the metal ions in the aqueous solution are adsorbed on the non-living adsorbent surface. Compared to living organisms, non-living biomasses show more advantages such as high efficiency, no need for additional growth medium and nutrients, low waste sludge, and low cost (Long *et al*., 2018). Recent research has focused on adsorbents with selective metal removal, which usually have a large surface area with various functional groups, as well as fast reaction kinetics suitable for heavy metal removal. To improve the performance of the absorbent when necessary, chemical modification of the surface and modification inside the biological cell are used (Qin *et al*., 2020).

The biological removal of nickel by non-living and inactive microbial biomass or derived from plants is considered an innovative and alternative technology to remove this pollution from aqueous solutions, which, while eliminating the problems of the conventional methods mentioned in this article, has a wide availability of adsorbent combined with renewable and high absorption capacity. This review research was conducted to introduce types of microbial and plant-derived bioabsorbents to remove nickel from aqueous solution and reveal the absorption capacity of each adsorbent.

Biosorption

Biosorption is a special feature of a variety of inactive non-living microbial biomasses and plant-based biomasses to bind and concentrate heavy metals from very dilute aqueous solutions. This process is a fast phenomenon and the binding capacity of certain biomasses is comparable to synthetic cation exchange resins. Biomasses with this property act like an ion exchange chemical, of course, with biological origin. The basis of work in the process of biological absorption is based on the interaction between metal ions with biomass and stabilization on it. This interaction includes surface adsorption, ion exchange reactions with functional groups on the surface of biomass, and surface complex reactions. Binding sites for metal ions placed on the surface of biomass include various groups such as carboxyl, carbonyl, hydroxyl, phosphate, amine, and sulfate from fats, proteins, and polysaccharides that are placed on the surface of biomass (Zafar *et al*., 2007; Amini *et al*., 2009; Long *et al*., 2018).

The structure of the biomass cell wall is responsible for this absorption property. In general, in the biosorption process, three issues should be focused on biological adsorbent (choice of adsorbent with high adsorption capacity, easy availability, and low cost), adsorption mechanism, and testing on a large scale (Long *et al*., 2018).

Biosorption Advantages

Non-living biomass independent of growth is not subject to cell contamination limits. This biomass does not need any nutrients for cell growth in the feed solution, so it is worth considering from an economic point of view, so the problem of disposal of excess nutrients or metabolic products will not be raised. Biomass can be obtained from existing fermentation industries, which are wastes after fermentation. This process does not involve the physiological limitation of living microbial cells.

Because the non-living biomass acts as an ion exchanger, this process is very fast and takes between minutes and hours. Metal binding to bulk biomass is often so high that it leads to very efficient metal uptake. Since cells are non-living, their process conditions are not limited to cell growth. In other words, a wide range of operating conditions such as temperature, pH, metal concentration, etc. are used, while no aseptic conditions are need for this process. The metal can be easily removed and recovered if the amount of recycled metal is significant. In addition, due to the appropriateness of the price, the use of these absorbents is cheaper.

Biosorption Disadvantages

Premature saturation can be a problem. For example, when metal interaction sites are occupied, regardless of the amount of metal, removal of the metal is necessary before further use. The potential to improve biological processes, for example through genetic engineering, is limited because cells are not metabolizing. Because sorbent production occurs before the growth stage, there is no biological control over sorbent characteristics. This will be especially true when biomass from fermentation waste is used (Ahluwalia & Goyal, 2007).

Bioabsorbent

Bacteria, fungi, yeasts, algae, fruit skin, plant residues, activated sludge, and biopolymers are synthetic bioabsorbents. Researchers classify sorbents extracted from biological sources as biological or biosorbents. Conventional biosorbents should follow the following criteria: high adsorption capacity and appropriate kinetics (Wang *et al*., 2017); Size, appearance, and appropriate physical characteristics (Shi *et al*., 2015); Separation of adsorbent from cheap, fast, and high-efficiency solution (Xin *et al*., 2017); high mechanical strength, temperature stability and favorable chemical resistance (Wang *et al*., 2017a, 2017b); availability of absorbent and efficient preparation methods (Du *et al*., 2016); Ability to revive and reuse (Saha *et al*., 2017).

The general steps of preparation of absorbents are as follows: collection of primary absorbents; washing with distilled water and filtration; drying; improvement of absorbent properties and functional groups; Optimizing the geometry and dimensions of adsorbents such as crushing and placing on a substrate; Maintenance in proper conditions (Beni & Esmaeili, 2020).

For decades, a wide variety of innovative biosorbents have been cultivated and used for the removal of heavy metals. Although a wide range of biological species have been used as an absorbent due to its effectiveness and economic aspect, it has not been able to achieve significant success in practical applications. Therefore, many improved methods based on bio adsorbents emerged. Based on various research and articles, three types of new methods for optimizing bio-adsorbents have been presented: chemical modification of adsorbents, combination of biomass and chemicals, and multi-biomass combined systems. Chemical modification can generally be divided into two categories: internal modification and surface modification of the biological cell. The main aim of surface modification is to remove cell surface impurities, increase the binding sites of heavy metals on the biological cell surface, or alter the charge on the cell surface. Internal modification is much more complex, involving changes in the composition or internal structure of biological cells (Ahmed *et al*., 2023; Binassfour *et al*., 2023; Maneea *et al*., 2023; Pavithra *et al*., 2023).

Stimulating or inhibiting the activity of enzymes that are involved in the transport or accumulation of heavy metals inside the cell has a significant effect on the absorption of heavy metals. Combining biomass with other materials can solve this problem. In addition, the composition of several biological substances has been proven for high absorption of heavy metals and stability against these elements that pollute the environment (Qin *et al*., 2019). Recent research has focused on selective adsorbents, which usually have a large surface area with different functional groups, as well as fast reaction kinetics suitable for the recovery of heavy metal ions. These cases lead to better use of the capacity of these absorbents and a low residual concentration of metal ions (Al-Mubarak *et al*., 2023; Ismikhanov *et al*., 2023; Kushkhova *et al*., 2023; Maskurova *et al*., 2023; Sakaliene *et al*., 2023).

Due to the high surface-to-volume ratio and the large number of functional groups on their surface, microorganisms can create very suitable and efficient conditions for interaction with heavy metals. Compared to living microorganisms, non-living biomasses show more advantages due to high efficiency, no need for additional growth medium and nutrients, low waste sludge, and low cost. The use of agricultural wastes and fruit peels as bioabsorbents is very promising due to their low cost. They are also environmentally friendly. There are some limitations in the use of fruit peels, such as low absorption capacity, which can be compensated by various chemical modifications, such as placing adsorbents in acid, alkali, organic solvent, and other reagents (Villen-Guzman *et al*., 2019). They showed a 2.5 times increase in nickel absorption by lemon peel by using NaoH to modify the absorbent surface. The improvement of the alkali-modified surface can be due to the transformation of the lignin structure into a negative charge and the increase of anionic sites more interested in the absorption of metal cations. In addition, the increase in absorption capacity can also be due to metal hydroxide precipitation. Modification of Aspergillus niger with NaOH has also increased the absorption capacity according to reports (Amini *et al*., 2009). The positive results of biological absorption by mango peel absorbent modified with sulfuric acid have shown the appropriate performance of rice husk modified with humic acid (Basu *et al*., 2019).

Seaweeds are considered an important adsorbent because of their high metal absorption, low renewable cost, and abundance in many areas of the world. Brown algae have attracted a must attention because of their high absorption capacity, which is mainly due to the polysaccharides present in their cell walls. These polysaccharides are mainly responsible for the function of carboxyl and sulfonic acid functional groups, which are active in the ion exchange process (Barquilha *et al*., 2019).

In the investigation of the nickel ion removal process by discontinuous method, effective parameters such as initial pH of solution, adsorbent amount, initial concentration of solution, contact time, and temperature were evaluated. The laboratory data were analyzed with the Friendly and Langmuir isotherm model and it was observed that the results are in better agreement with the Langmuir isotherm than the Friendly isotherm. Based on the Langmuir model, the maximum absorption capacity of the adsorbent for Butnickel is 18.09 (mg/g). Pseudo-second-order and pseudo-first-order models were used for the traditional investigations of the process. The results of kinetic studies also show that the pseudo-second-order model is more suitable than the pseudo-first-order model in the absorption process of nickel ions. Because of the investigations of thermodynamic parameters, it was observed that nickel ion absorption is a spontaneous and endothermic process. The results of the studies showed that natural zeolite with its high capabilities can be used as an effective adsorbent to remove heavy metals from aqueous solutions (Sadat Hosseini *et al*., 2015). Gholami *et al*. (2013) conducted a study to remove nickel and cadmium from polluted water using bagasse nanoparticles. In this research, bagasse (sugarcane bagasse) nanometer adsorbent was used to remove nickel and cadmium ions from polluted water through continuous experiments. At first, pH tests were performed on aqueous solutions with a concentration of five mg/liter, an adsorbent amount of 10 g/liter, a contact time of 12 hours, and a pH range of three to eight for the studied adsorbent. The optimum pH for the adsorbent of bagasse nanoparticles for nickel and cadmium metals was 6 and the equilibrium time for both metals was 15 minutes. Adsorption isotherm experiments were performed at laboratory temperature, optimal pH, and optimal equilibrium time. Adsorption efficiency was determined for initial concentrations of 2, 5, 10, 15, and 20 mg/liter of metal solutions. Then Langmuir-Freundlich-Riedlich-Peterson and Langmuir-Freundlich isotherm models were fitted on the experimental equilibrium data, and in all experiments, the Ridlich-Peterson model described the experimental data better.

To determine the optimal adsorption conditions, the effect of important parameters such as adsorbent weight, contact time, pH, and initial concentration were studied. In addition, thermodynamic studies (changes in standard Gibbs free energy, entropy, and enthalpy), isotherm studies (adsorption capacity), and kinetic studies (adsorbent sensitivity or time) were studied

Conclusion

Heavy metals, including nickel, are a serious threat to the environment and public health because of their toxicity, accumulation in the human body and other living organisms, stability, and non-degradability. The old conventional methods of separating heavy metals from wastewater and aqueous solutions are expensive and inefficient at low concentrations of metal ions. Biosorption with non-living microorganisms and biological materials has more benefits than living adsorbents. The abundance and low value of biological adsorbents justify their use from an economic point of view. The use of physical and chemical methods to modify the surface of the bio-absorber, the internal modification of the cell, and the combination of biomass with other materials have an effect.

On an industrial scale, the design of an inexpensive reactor or biological adsorbent and, if needed, chemical modifications, along with taking into account the optimal operating conditions according to experimental data, can bring acceptable results. Although it is desirable to maintain all factors at similar levels in each stage of scaling up, it is not possible. During the upgrade of the scale, due to the dissimilarity of the conditions of the production line devices with the laboratory equipment, we usually face a decrease in performance, which is a big challenge for the industrialization of the biosorption process. Based on thermodynamic studies, negative ΔG values, and positive ΔS values have been reported in most nickel biological absorption processes with different adsorbents. The negative value of AG is due to the spontaneity of the process and the positive value of AS is due to the increase of random collisions between solid and solution during the process.

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References

Ahluwalia, S. S., & Goyal, D. (2007). Microbial and plant derived biomass for removal of heavy metals from wastewater. *Bioresource Technology*, *98*(12), 2243-2257.

Ahmed, S., Algarni, T., Alshareef, M., Alhussain, A., Alrashidi, K., & Alahmari, S. (2023). Prevalence of oral mucosal lesions among patients visiting private university dental hospital, Riyadh, Saudi Arabia. *Annals of Dental Specialty*, *11*(1), 83-87. doi:10.51847/qvnfdOmZPj

Al-Fakih, A. A. (2015). Biosorption of Ni2+ and Cd2+ from aqueous solutions using NaOH-treated biomass of Eupenicillium ludwigii: Equilibrium and mechanistic studies. *Open Journal of Applied Sciences*, *5*(07), 376. doi:10.4236/ojapps.2015.57038

Al-Mubarak, A. M., Alkhaldi, F. A., Alghamdi, A. A., Almahmoud, M. A., & Alghamdi, F. A. (2023). Dental students and interns' clinical knowledge toward crown lengthening; a cross-sectional study. *Annals of Dental Specialty*, *11*(2), 75-83. doi:10.51847/2cisEzAkOG

Amini, M., Younesi, H., & Bahramifar, N. (2009). Biosorption of nickel (II) from aqueous solution by Aspergillus niger: Response surface methodology and isotherm study. *Chemosphere*, *75*(11), 1483-1491.

Anitha, D., Ramadevi, A., & Seetharaman, R. (2021). Biosorptive removal of Nickel (II) from aqueous solution by Mangosteen shell activated carbon. *Materials Today: Proceedings*, *45*(2), 718-722.

Barquilha, C. E. R., Cossich, E. S., Tavares, C. R. G., & Silva, E. A. (2019). Biosorption of nickel (II) and copper (II) ions by Sargassum sp. in nature and alginate extraction products. *Bioresource Technology Reports*, *5*, 43-50.

Basu, H., Saha, S., Mahadevan, I. A., Pimple, M. V., & Singhal, R. K. (2019). Humic acid coated cellulose derived from rice husk: A novel biosorbent for the removal of Ni and Cr. *Journal of Water Process Engineering*, *32*(1-3), 100892.

Beni, A. A., & Esmaeili, A. (2020). Biosorption, an efficient method for removing heavy metals from industrial effluents: a review. *Environmental Technology & Innovation*, *17*(1), 100503.

Binassfour, A., Alamri, A., bushnaq, Y., Almutairi, R., Alyaqoub, B., & Alamri, N. (2023). Management of anterior resin bonded cantilever: a review of recent literature. *Annals of Dental Specialty*, *11*(1), 88-94. doi:10.51847/7chQHKcYSH

Boulaiche, W., Belhamdi, B., Hamdi, B., & Trari, M. (2019). Kinetic and equilibrium studies of biosorption of M (II)(M= Cu, Pb, Ni, Zn and Cd) onto seaweed Posidonia oceanica fibers. *Applied Water Science*, *9*(8), 173. doi:10.1007/s13201-019-1062-1

Du, Z., Zheng, T., Wang, P., Hao, L., & Wang, Y. (2016). Fast microwave-assisted preparation of a low-cost and recyclable carboxyl modified lignocellulose-biomass jute fiber for enhanced heavy metal removal from water. *Bioresource Technology*, *201*, 41-49.

Gholami, Z., Houshmand, A., Naseri, A., & Pourreza, N. (2013). Removal of nickel and cadmium from polluted water using bagasse nanoparticles. *Journal of Irrigation Engineering Sciences (Agricultural Scientific Journal)*, *36*(2), 107-197.

Ismikhanov, A. G., Dadaeva, G. T., Dzhabrailov, S. M., Maysigova, J. B., Semenov, M. R., & Dzagurova, L. A. (2023). Prospects for the use of selenium-containing drugs in dentistry. *Annals of Dental Specialty*, *11*(2), 88-93. doi:10.51847/2Z0fZ4rAoM

Kaparapu, J., & Krishna Prasad, M. (2018). Equilibrium, kinetics and thermodynamic studies of cadmium (II) biosorption on Nannochloropsis oculata. *Applied Water Science*, *8*(6), 1-9. doi:10.1007/s13201-018-0810-y

Kushkhova, D. K., Kozyreva, A. A., Valiev, D. G., Kallagova, A. R., Elzhurkaeva, S. S., & Kakaeva, K. A. (2023). The process of formation of tooth enamel by the method of elemental dispersion spectral analysis. *Annals of Dental*

Specialty, 11(2), 84-87. doi:10.51847/9NwEe582ow

Long, J., Gao, X., Su, M., Li, H., Chen, D., & Zhou, S. (2018). Performance and mechanism of biosorption of nickel (II) from aqueous solution by non-living Streptomyces roseorubens SY. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *548*(5), 125-133.

Maneea, A. S. B., Alqahtani, A. D., Alhazzaa, A. K., Albalawi, A. O., Alotaibi, A. K., & Alanazi, T. F. (2023). Microbiological effect of various concentrations of sodium hypochlorite (NaOCL) during endodontic treatment: a systematic review. *Annals of Dental Specialty*, *11*(1), 95-101. doi:10.51847/7CZTguksH9

Maskurova, Y. V., Kokoev, V. A., Gusengadzhiev, K. A., Megrikyan, A. A., Alieva, K. M., & Serov, N. G. (2023). Structural and mechanical assessment of dental implants based on TiO_2 and ZrO_2. *Annals of Dental Specialty, 11*(2), 94-98. doi:10.51847/gFHZM9fdj8

Noormohamadi, H. R., Fat'hi, M. R., Ghaedi, M., & Ghezelbash, G. R. (2019). Potentiality of white-rot fungi in biosorption of nickel and cadmium: Modeling optimization and kinetics study. *Chemosphere*, *216*, 124-130.

Nuhoglu, Y., & Malkoc, E. (2009). Thermodynamic and kinetic studies for environmentaly friendly Ni (II) biosorption using waste pomace of olive oil factory. *Bioresource Technology*, *100*(8), 2375-2380.

Pahlavanzadeh, H., Keshtkar, A.R., Safdari, J., & Abadi, Z. (2010). Biosorption of nicke l(II) from aqueous solution by brown algae: Equilibrium, dynamic and thermodynamic studies. *Journal of Hazardous Materials, 175*(1-3), 304-310.

Pavithra, A. S., Paulraj, J., Rajeshkumar, S., & Maiti, S. (2023). Comparative evaluation of antimicrobial activity and compressive strength of conventional and thyme-modified glass ionomer cement. *Annals of Dental Specialty*, *11*(1), 70-77. doi:10.51847/FrmCSw6TqP

Qin, H., Hu, T., Zhai, Y., Lu, N., & Aliyeva, J. (2020). The improved methods of heavy metals removal by biosorbents: A review. *Environmental Pollution*, *258*, 113777.

Sadat Hosseini, S., Asm Hosseini, M., Khezri, S., Qanbari Talouki, F., & Khosravi, A. (2015). Removal of nickel ion from aqueous solutions using natural zeolite along with a case study. *Journal of Applied Chemistry*, *11*(41), 48-39.

Saha, G. C., Hoque, M. I. U., Miah, M. A. M., Holze, R., Chowdhury, D. A., Khandaker, S., & Chowdhury, S. (2017). Biosorptive removal of lead from aqueous solutions onto Taro (Colocasiaesculenta (L.) Schott) as a low cost bioadsorbent: Characterization, equilibria, kinetics and biosorption-mechanism studies. *Journal of Environmental Chemical Engineering*, *5*(3), 2151-2162.

Sakaliene, G., & Zaroviene, A. (2023). A survey of oral hygienists regarding orthodontic patients and cooperating with an orthodontists. *Annals of Dental Specialty*, *11*(2), 70-74. doi:10.51847/fHfNOWlBqS

Shi, L., Wei, D., Ngo, H. H., Guo, W., Du, B., & Wei, Q. (2015). Application of anaerobic granular sludge for competitive biosorption of methylene blue and Pb (II): Fluorescence and response surface methodology. *Bioresource Technology*, *194*, 297-304.

Thaçi, B., & Gashi, S. (2023). Study of Cd (II) ions biosorption from aqueous solution by wheat bran. *Water and Environmental Sustainability*, *3*(2), 32-42. doi:10.52293/WES.3.2.3242

Torab-Mostaedi, M., Asadollahzadeh, M., Hemmati, A., & Khosravi, A. (2013). Equilibrium, kinetic, and thermodynamic studies for biosorption of cadmium and nickel on grapefruit peel. *Journal of the Taiwan Institute of Chemical Engineers*, *44*(2), 295-302.

Villen-Guzman, M., Gutierrez-Pinilla, D., Gomez-Lahoz, C., Vereda-Alonso, C., Rodriguez-Maroto, J. M., & Arhoun, B. (2019). Optimization of Ni (II) biosorption from aqueous solution on modified lemon peel. *Environmental Research*, *179*(Pt B), 108849.

Wang, B., Xuan, J., Bai, Z., & Luque, R. (2017a). Chitosan biosorbents with designable performance for wastewater treatment. *Chemical Engineering Journal*, *325*, 350-359.

Wang, Z., Shen, D., Shen, F., Wu, C., & Gu, S. (2017b). Kinetics, equilibrium and thermodynamics studies on biosorption of Rhodamine B from aqueous solution by earthworm manure derived biochar. *International Biodeterioration & Biodegradation*, *120*, 104-114.

Waqar, R., Kaleem, M., Iqbal, J., Minhas, L. A., Haris, M., Chalgham, W., Ahmad, A., & Mumtaz, A. S. (2023). Kinetic and equilibrium studies on the adsorption of lead and cadmium from aqueous solution using scenedesmus sp. *Sustainability*, *15*(7), 6024. doi:10.3390/su15076024

Xin, S., Zeng, Z., Zhou, X., Luo, W., Shi, X., Wang, Q., Deng, H., & Du, Y. (2017). Recyclable Saccharomyces cerevisiae loaded nanofibrous mats with sandwich structure constructing via bio-electrospraying for heavy metal removal. *Journal of Hazardous Materials*, *324*(Pt B), 365-372.

Yalçın, M. S., Özdemir, S., & Kılınç, E. (2018). Preconcentrations of Ni (II) and Co (II) by using immobilized thermophilic Geobacillus stearothermophilus SO-20 before ICP-OES determinations. *Food Chemistry*, *266*, 126-132.

Zafar, M. N., Nadeem, R., & Hanif, M. A. (2007). Biosorption of nickel from protonated rice bran. *Journal of Hazardous Materials*, *143*(1-2), 478-485.