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A Review on Abatement of Nickel(II) from Aqueous Solution by Agricultural Biomass

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Levels of toxins has increased in water due to the spurge of industries. Nickel (II) is mostly used in industries because of its anticorrosion behaviour. Nickel (II) is present in the effluent of electroplating, plastics manufacturing, fertilizers and mining industries. It causes detrimental effect on the human health as well as environment because of its toxicity, non-biodegradability and bioaccumulation. Adsorption technique has been investigated in many researches as an effective method for not only detoxifying but also recovering precious heavy metal ions from aqueous solution. In this review various agricultural biomass based adsorbents used for removing Ni(II) from aqueous solution, optimum parameters employed and their removal efficiency from wastewater have been explored.

Keywords: Ni(II); aqueous solution; adsorption; agricultural biomass.

1. INTRODUCTION

Heavy metals are the elements having atomic weights between 63.5 and 200.6, and a specific gravity greater than 5.0. The heavy metal ions are transported by runoff water and contaminate water sources downstream from the industrial site. All living things including microorganisms, plants and animals depend on water for life [1]. Some of the heavy metal ions are arsenic (III), lead(II), cadmium(II), nickel(II), mercury(II), chromium(VI) etc.

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Nickel is a silvery white, hard, malleable and ductile metal. It has an atomic number of 28. Nickel has several oxidation states i.e. -1 to +4 but +2 is most stable. Nickel was first isolated from mineral nicolite by Swedish Chemist Axel Crostedt in 1751 and the name “nickel” was derived from the term “Kupfenickel” which means ‘Old Nick’s Copper’ that the German miners gave to nicolite because of emission of toxic fumes when heated. In elemental form metallic nickel is a hard and lustrous, silvery white metal with high electrical and thermal conductivity, used in coatings prepared by electro plating and in manufacturing stainless steels and coins. In powder form nickel is reactive in air and ignites spontaneously [2].

During washing of the electroplating tanks, considerable amounts of the nickel(II) find their way into the effluent. Ni(II) is also present in the effluents of silver refineries, zinc base casting and storage battery industries etc. It enters in the food chain and progressively larger accumulation of nickel compounds takes place in humans and animals. Higher concentration of nickel(II) causes lungs, nose and bone cancers. Dermatitis(Ni itch) is the most frequent effect of exposure to nickel(II). Acute poisoning of Ni(II) causes headache, dizziness, nausea and vomiting, chest pain, tightness of the chest, dry cough and shortness of breath, rapid respiration, cyanosis and extreme weakness [3].

World Health Organization (W.H.O) has prescribed standards for desirable nickel concentration in drinking water as 0.1 mg/L and industrial effluents as 3.0 mg/L [4]. Removal of toxic metal ions is necessary when the heavy metal ions level exceeds the permissible discharge level in industrial effluents. Many techniques and materials are used to remove contaminants and eliminate or reduce the hazardous nature of industrial wastewater, including chemical precipitation, ion exchange, adsorption, reverse osmosis, membrane processes, solvent extraction, evaporation, biosorption, etc [5]. However, the method that has been described by numerous researchers to be highly selective, efficient, easy to operate and cost effective is adsorption. Adsorption has been an alternative technique for heavy metal ions removal at low concentrations, and it depends on the adsorbent surface area, surface morphology, pore size distribution, polarity and functional groups attached to the adsorbent surface. The high cost of activated carbon in the markets has motivated researches to use inexpensive biomass as adsorbents for the removal of heavy metal ions from wastewater [6]. Agricultural biomasses are agriculture and plant based wastes like the fruit peels, seeds, pods, barks and leaves of trees etc. Agricultural biomasses mainly consist of lignin, cellulose, hemicelluloses and some proteins which make them effective adsorbents for heavy metal cations [7]. Various naturally occurring materials having characteristics of an adsorbent are available in large quantities. The abundance of these materials are used in many continents of the world and their low cost make them suitable as adsorbents for the removal of various heavy metals from water bodies [8]. Treatment of waste by using agricultural biomass waste has become modern day philosophy in environmental research. Adsorption adopts this philosophy to a great effect. In this paper feasibility of various agricultural biomass adsorbents for nickel(II) removal from aqueous solution has been reviewed from the available literature and comparative study has been done.

2. LITERATURE REVIEW

2.1 Adsorption

Adsorption is basically a mass transfer process by which a substance is transferred from the liquid phase to the surface of a solid, and becomes bound by physical and/or chemical interactions [9]. Depending upon the types of intermolecular attractive forces adsorption could be of following types [10].

2.2 Characteristics of the Adsorption Process

2.2.1 Types of interaction

2.2.1.1 Physical adsorption

It occurs in any solid/liquid or solid/gas system. Physical adsorption is a process in which binding of adsorbate on the adsorbent surface is caused by Vander Waals forces of attraction. Van der Waals forces originate from the interactions between induced, permanent or transient electric dipoles.

2.2.1.2 Chemical adsorption

It is a kind of adsorption which involves a chemical reaction between the adsorbent and the adsorbate. The strong interaction between the adsorbate and the substrate surface creates new types of electronic bonds (covalent, ionic).

Chemical adsorption is also referred as activated adsorption.

2.2.1.3 Dynamics of the adsorption process

In general, the main steps involved in adsorption of pollutants on solid adsorbent are:

- Transport of the pollutant from bulk solution to external surface of the adsorbent.
- Internal mass transfer by pore diffusion from outer surface of adsorbent to the inner surface of porous structure.
- Adsorption of adsorbate on the active sites of the pores of adsorbent. The overall rate of adsorption is decided by either film formation or intra particle diffusion or both as the last step of adsorption are rapid as compared to the remaining two steps.

3. CHARACTERISTICS OF ADSORBENT

The most important attributes of an adsorbent for any application are adsorption capacity, selectivity, regenerability, kinetics, compatibility and cost [11].

4. FACTORS AFFECTING THE ADSORPTION PROCESS

Adsorption process is mainly influenced by the nature of solution in which the contaminants are dispersed and the nature of adsorbent used. Some of the important parameters that should be considered during the adsorption process between adsorbent and adsorbate are pH of solution, degree of ionization of the adsorbate, particle size, surface area of adsorbent, temperature, effect of adsorbent dose, effect of initial concentration of metal ion, contact time, solubility of solute, effect of agitation time [12].

Adsorption studies include the structural studies of adsorbents, batch and column studies on the parameters that affects the adsorption, adsorption isotherm modeling, kinetics and thermodynamics and enhancement of adsorption capacity through the modification of adsorbent.

4.1 Adsorption on Activated Carbon

Adsorption is one of the widely used technique for wastewater treatment because of its simplicity. Adsorption on activated carbon from agricultural wastes is currently considered to be very suitable for the removal of metal ions from various industrial effluents because of the cost effectiveness. The two commonly used nickel adsorption studies on activated carbon are the batch and the column studies.

4.2 Agricultural and Plant Based Adsorbents for Ni(II) Removal

4.2.1 Barbadensis miller leaves

Shweta Gupta et al (2019) made biosorption studies in batch mode to investigate the adsorption of Ni(II) ions from aqueous solution on A. barbadensis Miller leaves (ABL) residue powder. The effects of Ni(II) ion concentration, pH, biosorbent dose and temperature on removal process were investigated. The five equilibrium adsorption isotherms, namely Freundlich, Langmuir, Temkin, Dubinin–Radushkevich (D–R) and BET, were analysed to ft the equilibrium data. pseudo-frst-order, pseudo-second-order, intraparticle difusion and Elovich and Bangham kinetics models were studied. Concentrations of nickel ions were determined by atomic absorption spectrophotometer. The maximum biosorption of 60.2% for an initial Ni(II) ion concentration of 100 ppm was achieved. Specifc surface area—BET (m^2 /g) 14.62. Results indicated that A. barbadensis Miller leaves could be used as effective adsorbent. Removal reduced to 59.4% when calcium or magnesium ions were present at 40 ppm in the interference study [13].

4.2.2 Fruit peel of artocarpus nobilis

Namal Priyantha et al (2019) studied Fruit peel of Artocarpus nobilis, as biosorbent for Ni(II). Carboxylic acid and its derivatives are the main functional groups present in the biosorbent as structural materials in cell walls to enhance the metal removal efficiency. Further, the negative charge of the biosorbent is an advantage for Ni(II) removal ability. Both these aspects contribute to a high adsorption capacity of 12,048 mg kg^{-1}. Removal efficiency of 50 % was obtained with air-dried particles (0.710 mm<d<1.0mm) of the above waste material under both static and dynamic conditions. It was enhanced to 71% after optimization of shaking time, settling time and processed temperature within a solution pH range of 4.0–7.0. Fixed bed column experiments were carried out and optimization of bed height and flow rate were done. Removal efciency of Ni(II) from synthetic solution is increased up to 93% under dynamic conditions at the optimum values of 10.0 cm for bed height and 8.4 mL min^{-1} for flow rate [14].

4.2.3 Pistachio hull waste

Majid Zamani Beidokhti et al (2019) investigated the adsorption behavior of pistachio hull powder, with respect to nickel(II) ions, in order to consider its application to the purification of metal finishing wastewater. The batch method was employed; parameters such as pH, contact time, adsorbent dose and metal concentration were studied at an ambient temperature 25± 3°C. The kinetics of adsorption were relatively fast, reaching equilibrium for less than 60 min. The maximum Langmuir adsorption capacity was 14 mg/g. The optimum pH required for maximum adsorption was found to be 4-6. The initial concentration of the adsorbate and the concentration of pistachio hull strongly affected the process. A degree of adsorption higher than 75% was achieved for nickel (II) ions. No influence of particle size was evidenced [15].

4.2.4 Longan hull

Xingmei Guo et al (2018) dealt with the adsorptive removal of Ni^{2+} at concentrations of approximately 50 mg/L in wastewater using an agricultural adsorbent, longan hull, and the adsorptive mechanism was characterized. For Ni^{2+} the maximum adsorption capacity of approximately 3.96 mg/ g was obtained at pH 4.7 in approximately 20 min. The longan hull has N–H, C–H, C=O, and C=C functional groups, which serve as the adsorption sites for the metal ions. The adsorption mechanism of the longan hull to Ni^{2+} ions was shown to be a monolayer adsorption of metal ions onto the absorbent surface [16].

4.2.5 Vigna unguiculata (cowpea) pods

Upenyu Guyo et al (2016) examined the potential to remove nickel(II) ions from aqueous solution using a nitric acid pretreated biosorbent prepared from Vigna unguiculata pods in batch experiments. The batch mode experiments were conducted utilising the independent variables of pH (2 to 8), contact time (5 to 120 min), dosage concentration (0.2 to 1.6 g), nickel(II) concentrations (10 to 80 mg L^{-1}) and temperature (20 to 50 ^{0}C). The maximum sorption capacity for nickel(II) was 27.70 mg/g. Using 0.1 M HNO_3 as eluent regenerated the biosorbent successfully up to 10 biosorption–desorption cycles [17].

4.2.6 Fruit peel waste (Orange, banana and Mosambi fruit peel waste)

Sonali R. Dhokpande et al (2016) researched high pectin waste namely orange, banana and mosambi fruit peel waste for their ability to remove nickel(II) from synthetic effluent. They were chopped to finer size of 0.3 to 0.5 cm. Batch studies was carried out. For all three sorbent materials there was initially steep fall in concentration with increase in adsorbent dosages upto 6 grams. The optimum contact time for three biosorbents was observed to be approximately 120 minutes. The removal of nickel was maximum for orange peel biosorbent followed by mosambi peels and banana peels [18].

4.2.7 Doum seed (Hyphaenethebaica) coat

Manal El-Sadaawy et al (2014) investigated the possibility of using agriculture waste doum-palm seed coat for the removal of nickel ions from aqueous solutions. Doum-palm seed coat and two activated carbons were prepared from it, by application of pyrolysis activation, and by application of chemical H_3PO_4 followed by physical activation were used as adsorbents. The process parameters were optimized; initial Ni(II) ion concentration and dose of adsorbent were found to have significant effects on Ni(II) adsorption. Concentrations of nickel ions were determined by Atomic Absorption Spectrophotometer. Activated carbon got by chemical activation followed by physical activation was found to have the maximum adsorption capacity. 1 g of the adsorbent removed around 13.51 g of Ni(II) ions [19].

4.2.8 Carica papaya seeds

Chithra et al (2014) used carica papaya seeds as suitable biosorbent for the removal of Ni(II) from aqueous solution. The concentration of Ni(II) in solution before and after biosorption was determined by using an Atomic Absorption Spectrophotometer. The adsorption capacity was 5.58 mg/g for Ni(II). The adsorption parameters for maximum adsorption of Ni (II) was, pH 6 and adsorbent dosage 1.0 g/100 mL. The process was found to be exothermic. Functional groups involved were determined by analyzing through FTIR. For Ni (II), ΔG^{o} become less negative indicating less driving force and hence resulting in lesser adsorption capacity at higher temperatures [20].

4.2.9 Annona squamosa (Custard apple) bark

Seshadri et al (2014) studied the removal of the Ni(II) metal ions from aqueous solution using citric acid modified Annona squamosa bark powder. The modified biosorbent was characterized by Fourier transmission infrared, scanning electron microscope and X-ray difractometer techniques. The effect of solution pH, adsorbent dose, initial concentration of metal solution, contact time was investigated in a systematic manner. Ni(II) concentration was analysed by flame atomic absorption spectroscopy. Desorption and recovery of the adsorbent were carried out using HCl solution by changing its concentration from 0.001 N to 0.25 N. Desorption studies showed that 0.15 N of HCl solution was enough to get 98.5% recovery of the Ni (II) from the adsorbent [21].

4.2.10 Pongamia pinnata seed shell

Rohini. J et al (2014) analysed the Pongamia Pinnata seed shell for the removal of nickel ions from wastewater without requiring any pretreatment. Experimental results showed that maximum removal of nickel ion by Pongamia Pinnata seed shell at optimum parameters were pH 8 with adsorbent dose of 3g/300 ml, contact time of 30 to 60 min and 10 ppm initial metal ion concentration. The study investigated the performance of the column in removing nickel ions from aqueous solutions. The Pongamia Pinnata seed shell adsorbent may reduce the level of nickel upto 99%. The study also investigated the performance of the column in removing nickel ions from aqueous solutions [22].

4.2.11 Pod of pigeon pea (*Cajanus cajan*)

Jeyaseelan Aravind et al (2013) studied pretreated Pod of pigeon pea (Cajanus cajan) produced through chemical activation using NaOH as a novel material to investigate its nickel binding efficiency. Spectrophotometric analysis was adopted to estimate nickel(II) using DMG. The influence of key physicochemical parameters on Ni(II) removal was studied. Optimum Ni(II) removal was obtained with a contact time of 45 min, pH of 8.0, and an adsorbent dose of 0.4g. The removal of Ni(II) decreased from 95% to 85% as the initial metal concentration increased from 20 to 100 mg/L. The negative value of ΔG° indicated the feasibility and spontaneous nature of the adsorption of nickel(II) onto the pigeon pea pod [23].

4.2.12 Orange peel

Ferda Gönen et al (2012) assessed adsorption of nickel(II) ions from aqueous solution onto orange peel and evaluated the effects of pH, initial nickel ion concentration and adsorbent dose on the removal of Ni(II) systematically. The optimal pH value for Ni(II) adsorption onto the orange peel was found to be 5.0. Greater percentage of metal ion was removed with decrease in the initial concentration of metal ion and increase in amount of adsorbent used. The positive values of ∆G° showed the endothermic nature of Ni(II) adosorption. The rate of adsorption of the metal ion was rapid. The nickel-orange peel system attained equilibrium in 14 min [24].

4.2.13 Pouteria sapota seed

Amala Fatima Rani et al (2012) examined the capacity of sulphuric acid treated Pouteria sapota seeds carbon for the removal of Nickel from aqueous solution. The influence of various parameters such as effect of equilibration time, pH, and carbon dosage for the removal of nickel was studied using batch process. The adsorption behavior of the activated carbon was explained on the basis of its chemical nature. Desorption study was carried out using HCl solution. A concentration of 0.1N HCl was required to recover 79% of the adsorbent [25].

4.2.14 Pine saw dust

Krishnie Moodley et al (2011) analysed Pine sawdust to remove nickel (II) ions from multi-component aqueous solutions. Assessment of the interactive effects of process variables (dose, pH and initial concentration) revealed that the system was sensitive to the tested process variables and the process was technically feasible. Analysis was carried out with Atomic Absorption Spectrophotometer. A combination of low adsorbent dose (2 g), high initial concentration (2.625 mg/ℓ) and pH (3.9) resulted in the highest adsorption capacity of 65.9 x 10^{-3} mg/g. Removal of nickel (II) ions from multi-component aqueous solutions (Ni(II), Co(II), Fe(III) was determined [26].

Table 1. The summary of the above literature

Adsorbent	Optimized conditions	Removal%/ Adsorption capacity	Best isotherm model fit	Best Kinetic model fit	Adsorbent –characterization
A. barbadensis Miller leaves	Batch study Initial conc. = 100 mg / L Contact Time = 180 min. pH = 7 rpm = 150 , dose = 1 g Temp=303K	60.2%	Freundlich	Pseudo second order	SEM-surface morphology, Zeta potential-point of zero charge, specific surface area-BET calculated
Fruit peel of Artocarpus nobilis	Batch study pH 4-7, Temp= 175 °C	71%	Langmuir	Pseudo first order	FT-IR studies-Functional groups, surface charge density calculated to determine point of zero charge
Pistachio Hull Waste	Batch study pH=4-6,	14mg/g	Freundlich	Pseudo second order	FT-IR studies
Longan hull	Batch study pH=4.7, Time=20 min, Initial conc=50mg/L	3.96 mg/g	Langmuir	Pseudo second order	SEM, FT-IR, BET surface area
Vigna unguiculata (cowpea) pods	Batch study pH =5.5, Temp=25^{0}C Dose=0.2g	27.70 mg /g.	Freundlich	Pseudo second order	Physico-chemical characteristics , FT-IR
Orange, banana and Mosambi fruit peel waste	Batch study contact Time = 120 min dose = upto 6 g	Max adsorption capacity for orange peel followed by mosambi and banana	Freundlich	Pseudo first and Pseudo second order	-
Doum seed (Hyphaenethebaica) coat	Batch study pH=7,Adsorbent dose =1 g	13.51mg/g	Freundlich	Pseudo second order	Micrograph photo of the surface, FT-IR
Carica papaya seeds	Batch study pH=6 dose=1.0 g/100 mL	5.58 mg/g	Freundlich	Pseudo second order	FT-IR analysis
Annona squamosa (Custard Apple) Bark	Batch study pH=6 Dose=0.4 g	40.29 mg/g	Langmuir	Pseudo second order	FT-IR, XRD-phases, SEM
Pongamia Pinnata seed shell	For Batch study pH =8 Dose =3g/300mL, Contact time =30 - 60min Initial metal ion conc=10 ppm	99%	Langmuir	-	-
Pod of pigeon pea (Cajanus cajan)	Batch study contact time = 45 min, pH = 8.0 dose =0.4g	19.23 mg/g	Freundlich	Second order	FT-IR, SEM
Orange peel	Batch study pH=5, T = 25°C rpm= 200	62.3 mg/g	Freundlich	Pseudo second order	-
Pouteria sapota seed	Batch study pH=3-10 Dose= 100mg/100mL Time=3 h	80%	Freundlich	-	Carbon characteristics such as moisture content, ash content, apparent density etc
Pine saw dust	Batch study Initial conc=2.625 mg/L, dose-2 g, pH=3.9	65.9 x 10^{-3} mg/g	Freundlich	Second order	FT-IR
(*Eriobotrya japonica*) loquat bark	Batch study pH=6 Dose =0.4 g	27.548 mg/g	Langmuir and Temkin	Pseudo second order	FT-IR analysis

4.2.15 (*Eriobotrya japonica*) loquat bark

Nida´ M. Salem et al (2011) produced modified loquat bark waste with NaOH and investigated the removal of Nickel(II) from aqueous solutions in a batch biosorption process. The biosorbent was characterized by FTIR analysis. The extent of biosorption of Ni(II) ions was found to be dependent on solution pH, initial nickel ions concentration, biosorbent dose, contact time, and temperature. 0.01 M HCl appeared as the most efficient and practical eluting agent releasing nickel sequestered on the biosorbent. Removal of Ni(II) from electroplating wastewater was found to be 92.4%. From the experimental results, sulfate and chloride ions had no effect on Ni(II) removal [27].

5. CONCLUSION

This review article has showed several types of agricultural wastes used as efficient adsorbents for the treatment of Ni(II) ions from aqueous media. Researchers have shown effective results based on removal percentage or adsorption capacity. The adsorption capacity is dependent on the type of adsorbent used and the nature of wastewater treated. The use of waste materials contributes in the reduction of cost for water treatment, thereby contributing to environmental protection. Many agricultural biomass adsorbents are modified to increase its adsorption efficiency but still to know the complete adsorption mechanism. Thus, there is good research scope in this direction.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Srivastava, NK Majumder, CB. Novel biofilteration methods for the treatment of heavy metals from industrial waste water. Journal of Hazardous Materials. 2008;151(1):1-8.
2. Jyoti Shah, Sanjeev Kumar, Sudha Sharma, Rajeev Sharma, Rupinder Sharma. Removal of Nickel from aqueous solution by using low cost adsorbents: A Review. International Journal of Scientific Engineering and Applied Science. 2016;2(7):48-70.
3. Parmar M, Thakur LS. Adsorption of heavy metals [Cu (II), Ni (II), and Zn (II)] from synthetic waste water by tea waste adsorbent. International journal of chemical and physical sciences. 2013;2(6):6-19.
4. Patil SJ, Bhole AG, Natarajan GS. Scavenging of Ni(II) Metal Ions by Adsorption on PAC and Babhul Bark. Journal of Environmental Science and Engineering. 2006;48(3):203-208.
5. Flores R, Espinoza S. Kinetics Studies on the Process of Zn Removal from Wastewater Using Ultrasonically Activated Sorbents. Chemical and Biochemical Engineering Q. 2017;31(1):123–130.
6. Mustapha S, Shuaib DT, Ndamitso MM, Etsuyankpa MB, Sumaila A, Mohammed UM, Nasirudeen MB. Adsorption isotherm, kinetic and thermodynamic studies for the removal of Pb(II), Cd(II), Zn(II) and Cu(II) ions from aqueous solutions using Albizia lebbeck pods. Applied Water Science. 2019;9:142.
7. Garg U, Kaur MP, Jawa GK, Sud D and Garg VK. Removal of cadmium (II) from aqueous solutions by adsorption on agricultural waste biomass. Journal of Hazardous Material. 2008;154(1-3):1149-1157.
8. Manjuladevi M, Anitha R, Manonmani S. Kinetic study on adsorption of Cr(VI), Ni(II), Cd(II) and Pb(II) ions from aqueous solutions using activated carbon prepared from Cucumis melo peel. Applied Water Science. 2018;8:36.
9. Babel S, Kurniawan TA. Various treatment technologies to remove arsenic and mercury from contaminated groundwater: an overview. In: Proceedings of the First International Symposium on Southeast Asian Water Environment, Bangkok, Thailand, 24-25 October. 2003;433-440.
10. Tripathi A,Ranjan MR. Heavy Metal Removal from Wastewater Using Low Cost Adsorbents. Journal of Bioremediation and Biodegradation.2015;6:315.
11. Yasmin Regina M, Saraswathy S, Kamal B, Karthik V, Muthukumaran K. Removal of nickel (II) ions from waste water using low cost adsorbents:A review. Journal of chemical and pharmaceutical research. 2015;8(1):1-6.
12. Cheremisinoff, PN, Morresi AC. Carbon adsorption Handbook. An Arbor Science Publishers, Borought Green. 1978;1-57.
13. Shweta Gupta, Arinjay Kumar. Removal of nickel (II) from aqueous solution by biosorption on A. barbadensis Miller

waste leaves powder. Applied Water Science. 2019;9:96.
14. Namal Priyantha, Kotabewatta PA. Biosorption of heavy metal ions on peel of Artocarpus nobilis fruit: 1—Ni(II) sorption under static and dynamic conditions. Applied Water Science. 2019;9:37.
15. Majid Zamani Beidokhti, Seyed Taghi (Omid) Naeeni, Mohammad Sajjad Abdi Ghahroudi. Biosorption of Nickel (II) from Aqueous Solutions onto Pistachio Hull Waste as a Low-Cost Biosorbent.Civil Engineering Journal. 2019;5(2):447-457.
16. Xingmei Guo, Sihan Tang, Yan Song, Junmin Nan. Adsorptive removal of Ni^{2+} and Cd^{2+} from wastewater using a green longan hull adsorbent. Adsorption Science and Technology. 2018;36(1–2):762–773.
17. Upenyu Guyo, Kudakwashe Sibanda, Edith Sebata, Fidelis Chigondo, Mambo Moyo. Removal of nickel(II) from aqueous solution by Vigna unguiculata (cowpea) pods biomass. Water Science and Technology. 2016;73:10.
18. Sonali R. Dhokpande, Jayant P. Kaware. Biosorptive Nickel Removal by Fruit Peel Waste: Batch, Kinetic and Isotherm Studies. International Journal of Research in Chemistry and Environment. 2017;7(1):1-6.
19. Manal El-Sadaawy, Ola Abdelwahab. Adsorptive removal of nickel from aqueous solutions by activated carbons from doum seed (Hyphaenethebaica) coat. Alexandria Engineering Journal. 2014;20(53):399-408.
20. Chithra K, Shweta Lakshmi, Abhishek Jain. Carica Papaya Seed as a Biosorbent for Removal of Cr (VI) and Ni (II) Ions from Aqueous Solution: Thermodynamics and Kinetic Analysis of Experimental Data. International Journal of Chemical Reactor Engineering. 2014;12(1):1–12.
21. Seshadri N, Ramesh Naik B, Sandeep Kumar NV, Venkata Ramana DK, Seshaiah K. Application of Citric Acid Modified Annona squamosa (Custard Apple) Bark Powder as Biosorbent to Remove Ni (II) from Waste Water. Indian Journal of Advances in Chemical Science. (2014);3:1-10.
22. Rohini. J, Nagarajappa DP, Mamatha M. Removal of Nickel from Simulated Wastewater using Pongamia Pinnata Seed Shell as Adsorbent. International Journal of Engineering Research and Technology. (2014);3(6):1080-1086.
23. Jeyaseelan Aravind, Shanmugaprakash Muthusamy Sangeetha Hubbathalai Sunderraj, Lenin Chandran, Kanmani Palanisamy. Pigeon pea (Cajanus cajan) pod as a novel eco-friendly biosorbent: a study on equilibrium and kinetics of Ni(II) biosorption. International Journal of Industrial Chemistry. 2013;4:25.
24. Ferda Gönen, Selen Serin D. Adsorption study on orange peel: Removal of Ni(II) ions from aqueous solution. African Journal of Biotechnology. 2012;11(5):1250-1258.
25. Amala Fatima Rani S, Rosaline Vimala J, Bhuvana T. Studies on the removal of nickel(II) using chemically activated pouteria sapota seed and commercially available carbon, Der Chemica Sinica. 2012;3(3):613-620.
26. Krishnie Moodley, Ruella Singh, Evans T Musapatika, Maurice S Onyango, Aoyi Ochieng. Removal of nickel from wastewater using an agricultural adsorbent.Water SA. 2011;37(1).
27. Nida M, Salem, Akl M, Awwad. Biosorption of Ni(II) from electroplating wastewater by modified (*Eriobotrya japonica*) loquat bark. Journal of Saudi Chemical Society. 2011;18:379-386.

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