

Removal of Nickel from aqueous solution by using low cost adsorbents: A Review

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Abstract

Heavy metal toxicity caused by industrial waste water and other natural sources has become a threat to the environment and ecosystem for the past many decades. Very small concentration of metallic ions present in water increases the health problems to humans and animals. Nickel is one of the non biodegradable, toxic, heavy metal ions present in waste water and ground water. Although there are various conventional treatment methods for removal of heavy metals from water and waste water e.g. chemical precipitation, membrane filtration, ion exchange, coagulation, flocculation, electrochemical technique, adsorption and co-precipitation. Yet various researchers paid their attention towards biosorption which involve adsorption which is a highly effective and economical technique for removal of heavy metals from waste water. Attempts have been made to develop inexpensive adsorbents e.g. agricultural waste material, waste by products of pharmaceutical fermentation, food processing, fruit waste and dead microbial biomass used as low cost adsorbents, is attractive because it reduces the cost of waste disposal, thereby leading to environmental protection. Chemical modification to improve their efficiencies is also discussed. These waste materials pollute our environment or ecosystem and pose the problem of their disposal. So “use the waste to treat the waste” is the concept to avoid the environmental pollution. In this review various agricultural, microbial, synthetic, natural and other adsorbents used for removing Ni(II) from aqueous solution, optimum parameters and their removal efficiency from aqueous solution have been discussed.

Introduction

Water is a basic source of life, energy and thus is essential element to all living things on earth. In purest form water is colorless, odorless, and tasteless in nature. Level of contaminants has increased due to discharge of industrial effluents in aquatic ecosystems which pollute and contaminate the water streams naturally (Akhtar *et al.*, 2013). However millions of people worldwide are suffering from shortage of fresh and clean drinking water. Water pollution raises a great concern now a days due to rapid industrialization e.g. metal mining operations, fertilizers, agricultural wastes, sewage, domestic wastes, alloy and leather industries, metal galvanizations paper industries and pesticides which have largely discharged various types of pollutants into environment and cause disorder into ecosystem (Abas *et al.*, 2013). Chemicals, paper, petroleum and primarily metal sectors cause about 97% of water contamination (Gaballah *et al.*, 1998).

Heavy metal pollution caused by industrial activities and technological development is posing significant threats to the environment and public health because of its toxicity, non-biodegradability, bioaccumulation and persistent tendency through food chain (Reddad *et al.*, 2003; Bahadir *et al.*, 2007; Pérez-Marín *et al.*, 2008).

‘Heavy metals’ refers to any elements with atomic weights between 63.5 and 200.6 with specific gravity greater than 5.0 (Srivastava and Majumder, 2008). Nickel is one of the non biodegradable, toxic, heavy metal ions present in waste water and ground water. 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 (Kotov and Nikitina, 1995). The permissible limit of nickel in drinking water given by U.S. Environmental Protection Agency (EPA) is 0.015 mg/l. (Carrasco-Martin, *et al.*, 1997). Nickel compounds released by industrial activities into the environment will adsorb onto the sediment and soil particles and become immobile. Nickel is more mobile in acidic soils and often leaches out into the groundwater (Sajwan *et al.*, 1996). Concentration of nickel in industrial waste waters ranges from 3.40 to 900 mg/l (Patterson and Passino, 1987).

It is necessary to follow Environmental regulations related to discharge of heavy metals in water streams and develop methods for their removal from waste water and water. The aim and objective of this review paper is to provide fundamental information and literature in adsorption of nickel ions from aqueous solution on various types of low cost adsorbents which include agricultural waste biomass, microbial, synthetic, natural and industrial waste by products etc which are also the sources of pollution. In this article an attempt has been made to review the adsorption process highlighting the applicability of adsorbents, optimum parameters and their adsorption efficiency.

Characteristics of Nickel heavy metal

Heavy metals belong to the group of metals and metalloids with atomic density greater than 4 g/cm³ or 5 times or more and are greater than water (Garbarino *et al.*, 1995; Hawkes, 1997; Jarup, 2003), as Table 1 shows the important properties of Ni (II) ions. In elemental form metallic nickel is a hard and lustrous, silver 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 (ATSDR, 2005). Usually nickel exists in the 0 and +2 oxidation states. Nickel exists less frequently in -1, +1, +3 and +4 oxidation states and due to having electrical and thermal conductivities, nickel is resistant to electrical erosion, oxidation and corrosion at temperature of -20 to +30 (Coogan *et al.*, 1989; WHO, 1991; Chau and Kulikovsky-Cordeiro, 1995; Higgins, 1995).

Table 1: important properties of Ni (II) metal ion.

Property	Ni (II) ion
Atomic weight (gmol ⁻¹)	58.71
Atomic no	28
Solubility @ 20°C (gcm ⁻³)	2.54
Ionic radius	0.69

Pauling electronegativity	1.91
Density	8.9 gcm ⁻³
Melting point	1455°C
Boiling point	2732 °C
Maximum contaminant Level (MCL)	0.2 mg/l by WHO
standards for desirable nickel concentration	in drinking water as 0.01 mg/l (WHO, 1996)
standards for desirable nickel concentration	in industrial effluents as 3.0 mg/l (WHO, 1996)

Sources of nickel

Nickel is released into the environment through natural and anthropogenic sources (Chen and Lin, 1998). Natural source of nickel to the environment are forest fires, vegetation, volcanic emissions and windblown dust. Anthropogenic sources of nickel to the environment are combustion of coal, diesel oil and fuel oil, the incineration of waste and sludge, use of phosphate fertilizers, stainless steel industry, galvanization, smelting, dyeing operation, batteries manufacturing, metal finishing, jewellery manufacturing, coinage, catalyst, nickel mining and processing etc. (Nordberg, et al., 2005; Krishnan et al., 2011). Industrial emissions add more than 100 times more nickel than that from natural sources e.g. in effluents of electroplating industries to the tune of 20-200 ppm (Nriagu, 1990; Revathi, 2005), effluents of silver refineries, zinc base casting and storage battery industries. The main pollution are from nickel plating industry caused by Ni²⁺ heavy metal ion in water. Nickel is present in small quantities (0.1-0.6 ppm) in plants, animals and in small quantities in sea water. All these industries acquire established waste water regulations to minimize the human and environmental exposure to hazardous heavy metals. Some of other industrial processes that contribute to the presence of nickel are bakery (0.43 mg/l), soft drinks and flavoring (0.22 mg/l), ice cream (0.11 mg/l), textile dyeing (0.25 mg/l), laundry (0.1 mg/l), car wash (0.19 mg/l) and miscellaneous foods (0.11 mg/l) (Rao et al., 2001).

Deleterious effect of Ni (II) ions in the ecosystem and environment

Ni(II) is an essential nutrient needed by the body in trace amounts because it takes part in the synthesis of vitamin B12. However increase in the intake of Ni(II) or its compounds can lead to birth defects, embolism, asthma, hard metal related respiratory diseases and chronic bronchitis, etc. (Chen et al., 2008; Chen et al., 2009). Nickel toxicity associated with Ni(II) is mainly due to generation of reactive oxygen species (ROS) with subsequent oxidative deterioration of biological macromolecules. There are two step processes in which nickel can generate free radicals (FR) directly from molecular oxygen to produce superoxide anion and in continued process, produce highly toxic hydroxyl radical (OH[•]). They also inhibit antioxidant enzymes and deplete intracellular glutathione and causes pro-oxidative effects (Das, 2009). Toxicity of nickel causes pulmonary fibrosis and inhibits many enzymatic functions (Liphadzi and Kirkham, 2005) and skin contact with nickel causes a painful, fatal disease called “nickel itch”. The higher concentration of nickel causes harmful health effects like headache, dizziness, nausea, dry cough, tightness of the chest, chest pain, vomiting, shortness of breath, nasopharynx, cyanosis, extreme weakness, renal oedema, skin dermatitis, gastrointestinal disorder and rapid respiration (Parker,

1980; Revathi, 2005; Chen et al., 2008; Chen et al., 2009). Sulphide and oxide form of nickel poses excess risk of lung and nasal cancers (Satpathy, 2002). Due to deleterious effect of nickel WHO (World Health Organization) has prescribed standards for desirable nickel concentration in drinking water given in table 2, therefore it is necessary to bring the nickel concentration in waste water below the prescribed limit.

Table 2. Permissible limit for nickel in different types of water

Type of water	Indian standard (mg/l)	WHO (mg/l)
Surface water	3	1
Marine water	50	-
Drinking water	0.02	0.02
Public water supply	3	-

Methods for the removal of heavy metals from water and waste water

Various methods have been developed to remove heavy metals from water and waste water before discharge into the natural water bodies. These methods can be divided into biological, chemical and physical processes. Conventional methods include coagulation, adsorption, chemical separation, filtration, membrane separation, ion exchange (Bolto et al., 2002), aerobic and anaerobic treatment (Bell et al., 2000), advanced oxidation process (Esplugas et al., 2002), electrolysis, microbial reduction (Shen and Wang, 1994), solvent extraction, electrochemical treatment (Rittmann, 2010; Yu et al., 2000), electro floatation, froth floatation, (Marvos et al., 1994), reduction, chemical precipitation, ion exchange, reverse osmosis, dialysis, activated sludge (Pala and Tokat, 2002) and adsorption by coated carbon (Ajmal, et al., (1998). Most of these methods are expensive and so are not affordable for developing countries. These methods are associated with disadvantages such as use of toxic reagents, incomplete removal of heavy metals, high energy requirements, generation of toxic wastes, non selective, costlier due to operation, maintenance and produces sludge or secondary pollutants which require proper disposal (Eccles, 1999). There is need of safe and economical methods for the removal of heavy metal ions from polluted water so adsorption process is one of the easiest, safest and more cost effective processes for heavy metal removal from industrial effluents (Shah et al., 2009; Rahmani et al., 2009). This has therefore led to the use of adsorbents which have been found significant popularity because of their lower production costs, abundance of their ingredients in nature, low cost of their regeneration and further that they can be simply discharged after expiration.

Adsorption process: Recently adsorption process has gained great interest as a more promising method because it is more effective and economic process for heavy metal removal. Adsorption is a technique through which some of fluid phase substances are removed by their transmission to the interface between fluid phase and solid (separate) phase and accumulation. Reduction in surface tension occur between the fluid and the solid phase because adsorption of fluid phase substances on the solid surface create required driving force for adsorption process. Adsorption also occurs due to the attractive interaction between a surface and the species being adsorbed at certain level (Monser and Adhoum, 2002). Solid porous material is called adsorbent material or biomass and components of fluid phase that adsorb by solid phase is called adsorbed component

or adsorbate. Movement of fluid phase components (adsorbate) and their accumulation on the solid surface will terminate as soon as the concentration of adsorbate at two phases reach an equilibrium condition. Non living biomass or natural biomass are used widely as metal binding agents because they have the capacity to lower the metal ion concentration to Parts Per Billion (ppb) level due to their affinity for cationic metals (Bailey et al., 1999; Gloaguen and Morvan, 1997). Adsorption can be categorized into two types:

1. Physisorption or Physical adsorption: It is a reversible phenomenon resulting from intermolecular forces of attraction (e.g. weak Vander waals forces of attraction) between molecules of the adsorbent and the adsorbate. It takes place with formation of multilayer of adsorbate on adsorbent.

2. Chemisorption or chemical adsorption: it is an irreversible phenomenon and is also called as activated adsorption (Yadla et al., 2012). It occurs as a result of the chemical interaction or chemical forces of attraction or chemical bond between the solid and the adsorbed substance. It takes place with formation of unilayer of adsorbate on adsorbent. Chemical adsorption occurs at temperatures much higher than the critical temperature. Under certain conditions, both physisorption or chemisorption processes can occur simultaneously or alternately.

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 parameters should be considered during the adsorption process between adsorbent and adsorbate which are given below (Cheremisinoff and Morresi, 1978).

1. pH of solution: pH is determination of adsorption in terms of hydrogen ion concentration. The adsorptive capacity of metal cations increase with increasing pH of the sorption system, but not in linear relationship. Sorption not occurs at highly acidic and alkaline conditions because hydrogen ions and hydroxyl ions compete for active sites on adsorbent surface respectively.

2. Degree of ionization of the adsorbate: More highly ionized molecules are adsorbed to a small degree than neutral molecules. The degree of ionization of a species is affected by the pH.

3. Particle size: It is the size of the molecule with respect to size of the pores. Larger molecules may be too large to enter small pores. This may reduce adsorption independent of other causes. Smaller particle sizes reduce internal diffusion and mass transfer limitation to the penetration of the adsorbate inside the adsorbent i.e. equilibrium is more easily achieved and nearly full adsorption capacity can be attained.

4. Surface area of adsorbent: Large surface area provides greater adsorption capacity. Smaller the particle size and greater the surface area of the adsorbent more is the adsorption.

5. Temperature: Adsorption reactions are normally exothermic, so adsorption capacity increases with decrease of temperature. In the range of 15-40°C, the maximum equilibrium adsorption capacity for Ni (II) ions by the wood ash was reached at temperature of 25°C (Parmar and Thakur, 2013).

6. Effect of adsorbent dose: The percent removal of heavy metals increases rapidly with increase in concentration of adsorbents (Parmar and Thakur, 2013). But after certain concentration of adsorbent further increase in biomass concentration has no effect on removal

percentage because no metal ions left to be adsorbed on the empty active sites after equilibrium point is achieved.

7. Effect of initial concentration of metal ion: The initial concentration of metal ion provides an important driving force to overcome all mass transfer resistance of metal between the aqueous and solid phases. There is a decrease in resistance for the uptake of solute from solution with increase of metal ion concentration (Parmar and Thakur, 2013).

8. Contact time: Longer the contact time or retention, more complete adsorption will be achieved. But after the equilibrium has been achieved there is no increase in percent removal of metal ion.

9. Solubility of solute: Substances slightly soluble in water will be more easily removed from water than substances with high solubility.

10. Effect of agitation rate: Agitation means proper mixing of adsorbate and adsorbent. The adsorption removal efficiency is increased weakly with increasing agitation rate (Parmar and Thakur, 2013).

Functional groups involve in adsorption

Pearson (1963), Nieboer and Richardson (1980) have given the classification of metals which include metal affinity for ligands described in Table 4 (Remacle, 1990). Class A metal ions bind the ligands of Type I through oxygen. Class B metal ions bind with ligands of Type III and also show strong binding with ligands of Types II types of ligands. Borderline metal ions could bind these three types of ligands with different preferences. The symbol R represents an alkyl radical such.

Table 4. Showing the functional groups involve in adsorption (Pearson, 1963; Nieboer and Richardson, 1980; Remacle, 1990).

Ligand class	Ligands	Metal classes
Type I: Ligands, preferred to, Class A	F ⁻ , O ₂ ⁻ , OH ⁻ , H ₂ O, CO ₃ ²⁻ , SO ₄ ⁻ , ROSO ₃ ⁻ , NO ₃ ⁻ , HPO ₄ ²⁻ , PO ₄ ³⁻ , ROH, RCOO ⁻ , ROR	Class A: Li, Be, Na, Mg, K, Ca, Sc, Rb, Sr, Y, Cs, Ba, La, Fr, Ra, Ac, Al, Lanthanides, Actinides
Type II: Other important ligands	Cl ⁻ , Br ⁻ , N ³⁻ , NO ₂ ⁻ , SO ₃ ²⁻ , NH ₃ , N ₂ , RNH ₂ , R ₂ NH, R ₃ N, R, O ₂ , O ₂ ⁻ , O ₂ ²⁻	Borderline ions: Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Cd, In, Sn, Sb, As
Type III: Ligands preferred to Class B	H ⁻ , I ⁻ , R ⁻ , CN ⁻ , CO, S ²⁻ , RS ⁻ , R ₂ S, R ₃ As	Class B: Rh, Pd, Ag, Ir, Pt, Au, Hg, Tl, Pb, Bi

Various low cost adsorbents used for the removal of nickel

Generally an adsorbent can be considered as “low cost” if it requires little processing, abundant in nature and if it is a byproduct or waste from industry. Natural material or certain waste from

industrial or agricultural operation is one of the resources for low cost adsorbents and are locally and easily available in large quantities; therefore they are inexpensive and have little economic value. A vast variety of raw materials originate from industrial and agricultural activities, results in production of chemical and solid wastes. The chemical wastes arise from the use of pesticides, dyes and fertilizers while the solid wastes include bagasse, sawdust, rice husk, peanut shell, coffee husk etc. and it is a concept of “using waste to treat waste”.

Agricultural and plant based adsorbent for Ni(II) removal

Now a day's application of agricultural wastes adsorbents have raised great interest in the field of environmental study, since conventional treatment technologies for removal of toxic heavy metals are not economical and further generate huge quantity of toxic chemical sludge (Sud et al., 2008). According to previous study which reported various materials like crop husks, hulls, fruit fresh or peel azalla, coconut shells etc. used as adsorbents with or without chemical treatment shown in table 5 (Periasamy and Namasivayam, 1995; Zhao and Duncan, 1998; Jiang et al., 2008). Agricultural wastes are characterized by ready availability, affordability, eco friendliness and high uptake capacity for heavy metals due to the presence of functional groups which can bind metals to remove heavy metals from water and waste water (Olayinka et al., 2009). Agricultural waste materials possess unique physical and chemical composition and composed of lignin and cellulose as the main constituents and other components are hemicellulose, lipids, proteins, simple sugar, starches, water and hydrocarbons. Functional groups e.g. hydroxyl and carboxylic groups present on the surface of agricultural waste material have important role in binding processes resulting in high affinity for metal cations (Sud et al., 2008).

Banana pith (*Musacea zingiberales*) used to remove Pb, Cu, Ni, Cr, Zn (Low et al., 1995), carrot pulp removes Pb, Ni, Zn, Fe (Joshi et al., 2003), eucalyptus wood powder removes Pb, Ni, Zn, Fe (Joshi et al., 2003), ground corncobs removes Cd, Cu, Pb Ni, Zn (Vaughan et al. 2001), paper mill sludge removes Pb, Cu, Ag, Cd, Pb, Ni, Zn, Fe (Calace et al., 2003), sawdust removes Zn, Ni, Cd, Cu, Pb (Marin and Ayele, 2002), wheat stem and spent babul bark removes Ni (Verma and Shukla, 2000), waste tea leaves removes Pb, Ni, Zn, Fe (Joshi et al., 2003; Ahluwalia and Goyal, 2005). Grape stalk waste removes Cu and Ni with 15.9mg/g and 18.1mg/g adsorption capacity respectively (Villaescusa et al., 2004). Banana pith (*Musacea zingiberales*) was tested for its ability to adsorb metal ions from electroplating waste water and synthetic solutions under both batch and continuous flow conditions. The adsorption depends on both pH and concentration with optimum pH 4–5 and the equilibrium data followed the Langmuir isotherm model. Waste biomass such as wheat stem and babul bark was used to remove nickel from effluent of an electroplating industry (Verma and Shukla, 2000) and removal of nickel achieved was 2–10% less as compared to synthetic solution under similar conditions. Wheat straw activated carbon could remove 100% Ni(II) from initial nickel concentration of 25 mg/l at pH 4.0 in 4 h at $36 \pm 2^\circ\text{C}$. The uptake capacity of different metals by *Quercus ilex* phytomass (root, stem and leaf) was found to be in the order of roots Ni > Cd > Pb > Cu > Cr; stem Ni > Pb > Cu > Cd > Cr; and leaf Ni > Cd > Cu > Pb > Cr (Prasad and Freitas, 2000). Desorption with 10 mM Na₄ EDTA was effective and there existed the possibility of recycling the phytomass. Biosorption capacity of plant biomass of Indian Saraparilla (*Hemidesmus indicus*) was studied with toxic heavy metals like As, Se, Zn, Fe, Ni, Co, Pb, Mn, Hg, Cr and Cu. The adsorption of activated carbon prepared from apricot stones, to remove Ni(II), Co(II), Cd(II), Cu(II), Pb(II), Cr(III) and Cr(VI) ions from the aqueous solution was studied (Kobyta et al., 2005). Further,

adsorption capacities for these metals were found to in the order of Cr(VI) > Cd(II) > Co(II) > Cr(III) > Ni(II) > Cu(II) > Pb(II), respectively. Modified lignocellulosic fibre/jute was assessed for adsorption of heavy metal ions like Cu(II), Ni(II) and Zn(II) from aqueous solution (Shukla and Pai, 2005). The dye loaded jute fibre showed adsorption capacity of 8.4, 5.26 and 5.95 mg/g for Cu(II), Ni(II) and Zn(II), respectively, the equilibrium data fits well in Langmuir model.

Peat- Peat is successfully used to remove nickel from aqueous solution studied at different pH values in static condition (Babel and Kurniawan, 2003). Equilibrium data fits well in Langmuir isotherm model correlated at different temperatures and first order kinetic model.

Cellulose-Cellulose is a linear polymer chain formed by joining the anhydroglucose units into glucose chains bound together by -(1,4)-glucosidic linkages. Based on this linkage cellulose is established as repeat unit for cellulose chains (O’Connel et al., 2008; Tang et al., 2008; Balat, 2008). The modification of cellulose have been achieved by adding amine, amide, amidoxime, carboxyl, hydroxyl and imidazole type binding ligands to cellulose backbone through chemical modification. The adsorption of heavy metal on cellulose adsorbent is pH dependent (pH 4-6 that is narrow pH range). The equilibrium data fits well in the Langmuir isotherm model and in some cases by Freundlich isotherm model (O’Connel et al., 2008; Tang et al., 2008).

Coir Pith: Coir pith is an agricultural solid waste adsorbent used for adsorption of Ni (II) ion from single and multi ion solution investigated by various researchers. This metal ion removal capacity is due to the presence of lignin (36%) and cellulose (44%) (Namasivayam et al., 2001; Redded et al., 2002; Shukla and Pai, 2005; Pino et al., 2006). Lignin and holo-cellulose are the main components in coir pith that play the major role in nickel adsorption. Hydroxyl and methoxyl are the main functional groups that are involved in nickel adsorption. Oxidation species of nickel involved in nickel adsorption by coir and modified coir pith (NaOH increased metal binding site that is free o⁻) are confirmed by X-ray adsorption spectroscopy (XAS) (Shukla and Pai, 2005; Li et al., 2007).

Table 5. Summary of agricultural waste biomass for the removal of Ni(II) heavy metal ion

Adsorbent	Optimized conditions	% removal or uptake (mg/g)	E/K model	References
Hazelnut shell activated carbon	pH-3, IMC- 15 to 20 mg/l, T-20 to 30°C	10.11 mg/g	L, Ps	Demirbas et al. (2002)
Orange peel	pH-6, T-50	158 mg/g		Ajmal et al. (2000)
Activated carbon from coirpith	pH-5, T-30	62.5 mg/g	L & F	Kadirvelu et al. (2001)
Bagasse, fly ash (FA) and powdered activated carbon (PAC)	pH-8	PAC>FA>bagasse		Shivakant and Shivarajappa, (2009)
Rambai stem (<i>Baccaureamotleyana</i>)	pH-4 to 5, AD-0.1 mg, IMC-30 mg/l,	51%	F	Noor et al, (2011)
Coconut leaves	pH-8, AD-1.0 gm/50ml, IMC-26.81mg/l, T-25 to 32,	93.2%	F, Pf	Gowda et al, (2011)
Peanut hulls	pH- 4 to 5	53.65 mg/g		Periasamy and Namasivayam, (1995)
Carbon derived from	pH-4 to 6	85 % and 58.6%		Kannan, and

Palmyra Palm fruit seeds and commercial activated carbon				Thambidurai, (2008)
<i>Moringa oleifera</i> seeds	pH- 4 to 6, AD- 2.0 gm, IMC-4.0 mg/l	>90%		Marques et al, (2012)
Tamarind fruit shell		90%		Pandharipande and Rohit, (2013)
Coconut husk (CH) and Teak tree Bark (TTB)	pH- 7 to 8, AD-0.6 g	(CH)-81.4%, (TTB)-80.9%	F, Ps	Olayinka et al., (2009)
Activated carbon from grain rice and walnut shell	pH- walnut shell-5.7, grain rice-3.45, AD- 2gm (10 gm/l), CT-60 min	Grain rice-96.73% Walnut shell-75.6%		Chamanchi et al., (2012)
Babul Bark powder	pH-7.0 to 8.0, AD-5.0 gm, IMC-10 mg/l, CT- 120 min, T-30°C	83.4%		Patil et al., 2006
Activated carbon from <i>Thespesia Populnea</i> bark (TPC)	pH-6.5, AD-50 mg/50ml, IMC-50 mg/l, CT-60 min	91%		Prabakaran and Arivoli, 2012
Fruit peel of orange	pH-6, T-50°C, IMC-50mg/l	96%		Ajmal et al., 2000
Jute fiber	-	3.37 mg/g		Shukla and Pai, 2005 a
<i>Delonix regia</i> bark (Gulmohar)	pH-4, AD-2 to 12 g/l, CT-90 min, IMC-20 mg/l,	72.5%, 4.81 mg/g	F, Ps	Patil and Shrivastava, 2010
Leaf, Bark and Seed of <i>Moringa Stenopetala</i>	pH- 5, 6 & 6, AD- 1.5, 2 & 2.5 g IMC-30, 20 & 50 mg/l, , CT-90, 120 & 90, T-40, 30 & 23, agitation speed-250, 250 & 300 rpm	93.90%, 96.25%, 97.50% for leaf, bark & seed respectively		Aregawi and Mengistie, 2012
Orange peel	pH-5.0, AD-2 gm/l, T-25°C, T-60 min, agitation rate-200 rpm	62.3 mg/g		Gonen and Serin, (2012)
Teak tree bark powder (<i>Tectona grandis</i>)	pH-5, IMC-10 mg/l, CT-30 min, T-303 K, particle size ≥ 120 mesh, agitation speed-230 rpm	9.6 mg/g		Patil et al., (2012)
Bagasse fly ash	pH-6.5, AD-10 g/l, IMC-12 mg/l, CT-80 min	90%		Gupta et al., 2003
Coconut leaves	pH-8.0, AD-2g, IMC-50 mg/l, CT-4 h	93.18%		Gowda et al., 2012
Tea waste	AD-1.5 g, IMC-5 mg/l	85.7%		Kamali, 2010
Tea waste	-	86%		Malkoc and Nuhoglu, 2005
Waste tea leaves	-	92%		Ahluwalia and Goyal, 2005a
Waste tea				
Corn cobe	pH-6, AD-6 g, IMC-25 ppm/100 ml, CT-90 min	71.01 %		Arunkumar et al., 2014
<i>Pongamia pinnata</i> seed shells	Batch study pH-8, AD-3 g/300 ml, IMC-10 mg/300 ml, CT-120 min	98.30 %		Rohini et al., 2014
<i>Pongamia pinnata</i> seed shells	Column study- pH-5, AD-20 gm, IMC-25 to 100 ppm, depth of adsorbent-10 cm, flow rate-3 ml/min, ,	99%		Rohini et al., 2014
Cashew Nut Shell	pH- 5, IMC-20 mg/l, CT-30	73.89%	L, F,	Bailey et al., 1999

(CNS)	min, exothermic reaction		Pf & Ps	
Rice straw	pH-4, AD-12g/100ml, CT-40 min	55%		Prasad et al., 2015
Sugarcane Bagasse Pith (SBP-AC)	pH-6.5, CT-4 h	140.85 mg/g	L, Ps	Krishnan et al., 2011
Coir pith	pH-4-7, AD-5% (w/v), CT-10 min, T-30°C	9.5 mg/g		Shukla and Pai, 2005; Pino et al., 2006; Namasivayam et al., 2001; Redded et al., 2002
<i>Casia fistula</i> biomass	-	100%		Hanif e al., 2007
Maple saw dust	-	75%		Shukla and Pai et al., 2005
Defatted rice bran, chemically treated soybean & cottonseed hulls	-	87%		Marshall and Johns, 1996
saw dust of oak and black locust hard wood	-	70-90%		Sciban et al., 2006
Mustard oil cake	-	Upto 94%		Ajmal et al., 2005
Dye loaded ground nut shells and saw dust	-	Up to 90%		Shukla and Pai et al., 2005
PEP (petiolar felt sheath palm)-peeling from trunk of palm tree	-	>70%		Iqbal et al., 2002
Agro waste of black gram husk	-	Up to 93%		Saeed et al., 2005b
kenaf core, kenaf bast, sugarcane bagasse, cotton, coconut coir, spruce	-	Up to 88%		Sciban et al., 2006
Peat	pH-5	61.27 mg/g		Bartczak et al., 2015
Banana and orange peels	pH-6 to 8	Banana peel-6.88 mg/g Orange peel-6.01 mg/g		Annadural et al., 2002
Wheat Bran		12 mg/g		Farajzadeh and Monji, 2004
Fluted pumpkin waste		12.69 mg/g	L	Horsfall and Spiff, 2005
Coir pith		15.95	L & Ps	Parab et al., 2006
Coir pith activated carbon	pH- 5.3,	62.5	L	Kadirvelu et al., 2001
Cocoa shell		2.63 mg/g	-	Meunier et al., 2003
Bengal gram husk	pH-5	19.56 mg/g	F & L	Saeed et al., 2005
Almond husk activated carbon	pH-5.0	37.17	L	Hasar, 2003
Coconut shell	pH-9, AD-1.05g/l, IMC-1.05	0.21 mg/g		Hamidi et al., (2005)
Waste Tea (<i>Camella cinensis</i>)	pH-5, AD-0.2 gm, IMC-10 g/l	-	Ps, L & F	Aikpokpodion et al., 2010
<i>Limonia acidissima</i>	pH-2, AD-1.5 gm, CT-180	84 %	-	Agarwal and Gupta,

(Apple wood) (Activated carbon)				2015
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AD-adsorbent dose; CT-contact time; IMC-initial metal concentration; T-temperature; E/K, Equilibrium/Kinetics; F-Freundlich; L-Langmuir; La-Lagergren; PF-pseudo first order; Ps-Pseudo second order; UM-unmodified; M-modified

Chemical modification of agricultural and plant waste adsorbents:

Pre treatment of agricultural and plant wastes can extract soluble organic compounds and enhance chelating efficiency. Different types of modifying agents e.g. (1) base solutions (sodium hydroxide, calcium hydroxide, sodium carbonate) (2) mineral and organic solutions (HCl, HNO₃, H₂SO₄, tartaric acid, citric acid, thioglycolic) (3) organic compounds (ethylenediamine, formaldehyde, epichlorohydrin, methanol), (4) oxidizing agent (H₂O₂), dye (reactive orange 13) etc. have been used for removing coloration of aqueous solutions, increasing efficiency of metal adsorption and removing soluble organic compounds have by many researchers (Rehman et al., 2006; Hanafiah et al., 2006). The type of chemical used for the modification and their maximum adsorption capacities/%removal is given in table 6.

Table 6. Summary of chemically modified agricultural wastes for the removal of Ni(II) heavy metal ion from aqueous solution

Adsorbent	Modifying agent	Optimized conditions	% removal or uptake (mg/g)	E/K model	References
Rice straw	NaOH	pH-4, AD-8g/100ml, CT-50 min	85%	-	Prasad et al., 2015
Walnut shell	NaOH	pH-7.0-9.0, AD-10 gm/l, IMC-10 to 82.5 mg/l, T-25°C	8.57 mg/g	L, Ps	Karimi-Jashini and Saadat, (2014)
Peat soil, cow dung and digested paddy husk	Ethanol	pH-5.14, CT-120 min, T-30°C	86.23%		Zhang and Ismail, 2012
<i>Pouteria sapota</i> seed	H ₂ SO ₄	pH-3, AD-100mg/100 ml, CT-3 to 4 h	80 %		Rani et al., 2012
Pine saw dust	Citric acid	pH-3.9, AD-2gm, IMC-2.625 mg/l	65.9x10 ⁻³ mg/gm	F	Moodley et al., 2011
Holly sawdust	Chemically modified	pH-7	22.47 mg/g		Samarghandi et al., 2011
<i>Ficus Religiosa</i> (peepal) leaves	HNO ₃	pH-7, AD-10 g/l, IMC-100 mg/l, T-33 ± 1°C, CT-60 min	6.35 mg/g ± 0.54 mg/g	F, Ps	Aslam et al., 2010
Coconut husk (CH) and Teak tree Bark (TTB)	HCl	pH- 7 to 8, AD-0.6 g	CH- 24.1%, TTB-29.9%	F, Ps	Olayinka et al., (2009)
Cellulose	Chemically modified	pH-4.0-6.0,		L,	O'Connel et al., 2008; Tang et a., 2008; Balat, 2008
Orange peel cellulose	acid and alkali	CT- 60 min	95%	L, F, Pf	Tang et al., 2008; Li et al., 2007; Li et al., 2007

Sawdust (oak tree)	HCl	-	3.37 mg/g	-	Argun et al., 2007
<i>Calotropis procera</i> leached biomass (LBM)	Chemically modified	pH-3, AD-1 to 25g/l, IMC-5-500mg/l, CT-30 min	85%	F	Pandey et al., 2007
Coir fibers	H ₂ O ₂		4.33 mg/g	L	Shukla et al., 2006
Hazelnut shell, orange peel, maize cob, peanut hulls, soyabean hulls & jack fruit	NaOH		High metal adsorption		Kurniawan et al., 2006
15.Babul bark (PBB)	NaOH	pH-7.0 to 8.0	PBB-80%		Patil et al., 2006
Sawdust (<i>Dalbergia sissoo</i>)	NaOH	T-50°C	10.7 mg/g	L & F	Rehman et al., 2006
Jute fiber	Reactive Orange 13	-	5.26 mg/g		Shukla and Pai, 2005 a
Jute fiber	H ₂ O ₂	-	5.57 mg/g		Shukla and Pai, 2005 a
Sawdust	Reactive Orange 13	-	9.87 mg/g		Shukla and Pai, 2005 b
Coir fibre	H ₂ O ₂		>70%		Shukla and Pai et al., 2005
Fluted pumpkin waste	0.5 N 2-mercaptoethanoic acid		40 mg/g	L	Horsfall and Spiff, 2005
Fluted pumpkin waste	1 N 2-mercaptoethanoic acid		42.19 mg/g	L	Horsfall and Spiff, 2005
Coir pith	NaOH	pH-4 to 7, AD-5% (w/v), CT-10 min, T-30°C	38.9%		Shukla and Pai, 2005; Pino et al., 2006; Namasivayam et al., 2001; Redded et al., 2002
Activated carbon from almond husk	H ₂ SO ₄	pH-5, carbonization temp-700°C, CT-50 min, AD-5 g/l, IMC- 25 mg/l	37.17 mg/g	L	Hasar, (2003)
Walnut sawdust	Formaldehyde in H ₂ SO ₄	CT-60 min,	6.43 mg/g	Ps	Bulut and Tez (2003)
Activated carbon prepared (900°C) from waste apricot	K ₂ CO ₃	pH-5, AD-0.7/10ml, IMC -10mg/l, CT-60 min,	40-100% or 101.01 mg/g	L	Fernandez-Lahore et al., 1999

AD-adsorbent dose; CT-contact time; IMC-initial metal concentration; T-temperature; E/K, Equilibrium/Kinetics; F-Freundlich; L-Langmuir; La-Lagergren; Pf-pseudo first order; Ps-Pseudo second order; UM-unmodified; M-modified

Removal of Ni (II) by microorganisms

Fungal biomass

Mucor rouxii removes Ni with adsorption capacity of 5.24 mg/g (Yan and Viraraghavan (2003). *Rhizopus nigricans* removes Ni with 5mg/g efficiency (Fourest and Roux (1992; Holan and

Volesky 1995), *Rhizopus arrhizus* removes Ni the uptake capacity of 18 mg/g (Fourest and Roux (1992). Alkali treated biomass of *Aspergillus niger* was used to remove Cd^{2+} , Cu^{2+} , Zn^{2+} , Ni^{2+} and Co^{2+} with uptake capacity of up to 10% of its weight (w/w) and show higher metal binding capacity as compared to *Neurospora*, *Fusarium* and *Penicillium* (Akthar et al., 1996). The kinetics of metal binding by showed that it is a rapid process and about 70–80% of the metal is removed from solution in 5 min followed by further slower rate.

Algal biomass

Ascophyllum nodosum removes Ni(II) with uptake capacity of 30 mg/g, (Holan and Volesky 1995). *Fucus vesiculosus* removes Ni with adsorption capacity of 17 mg/g (Holan and Volesky 1995). *Lyngbya taylorii* algae removes Cd, Pb, Ni, Zn (Klimmek et al., 2001), *Phormidium laminosum* removes Cu, Ni, Zn (Blanco et al., 1998), *Pilayella littoralis* algae removes Al, Cd, Co, Cr, Ni, Zn (Carrilho and Gilbert, 2000), *Scenedesmus obliquus* removes Cr, Cu, Ni (Donmez et al., 1999). *Chlorella vulgaris* also removes nickel reported by Donmez et al. (1999). *Sargassum natans* removes Ni with adsorption capacity of 24-44 mg/g (Holan and Volesky (1995). Biosorption of Cu(II), Fe(II), Ni(II) and Zn(II) by dead biomass of the cyanobacterium *Phormidium laminosum* from single and binary metal solution was extremely rapid and consisted of a single phase (Blanco et al., 1998). The presence of a second metal in solution decreased the binding of Fe(II), Ni(II) and Zn(II) due to chemical blocking of the carboxyl groups of biomass but this had no effect on the binding of Cu(II). Washing with dilute acids was much faster and effective than NaOH, NaCl, $CaCl_2$ and ultra pure water reaching equilibrium within 30 min and the efficiency was independent of the concentration of desorbent. Biosorption of Cu(II), Ni(II) and Cr(VI) from aqueous solution by dried algae *Chlorella vulgaris*, *Scenedesmus obliquus* and *Synechocystis* sp. was tested under laboratory conditions as a function of pH, initial metal ion and biomass concentration (Donmez et al., 1999) followed both Freundlich and Langmuir adsorption models. Microorganisms used as adsorbent for removal of Ni(II) from aqueous solution shown in table 7.

Bacterial biomass

Mattuschka and Straube (1993) reported that *Streptomyces noursei* removes nickel with adsorption capacity of 0.8 mg/g.

Table 7: Microorganisms used as adsorbent for removal of Ni(II) from aqueous solution shown in tabulated form.

Adsorbent	Optimized conditions	% removal or uptake (mg/g)	E/K model	References
<i>Cyanobacteria oscillatoria -virens</i>	pH-5.0, CT-60 to 75	84 mg/g	L, Ps	Das, 2012
<i>Aspergillus flavus</i>	AD-10 mg/l, IMC-10 mg/l	-		Pandey et al., 2013
<i>Aspergillus niger</i>	pH-5 to 8, 0.5 N NaOH	50-60%		Rao and Bhargavi, 2013
Column filled with sulfate reducing bacteria (SRB) and silica	Column study- pH-4.5 to 7.0	>97.5%		Jong and parry, 2003
<i>Aspergillus niger</i> and <i>Rhizopus stolonifer</i> (living cells)	pH-6.8 to 8.9, T-30 ± 2°C, incubation time-60 days	47.1%, 1.0%, 38.2%, 52.7% and 35.4%		Onianwah et al., 2013

AD-adsorbent dose; CT-contact time; IMC-initial metal concentration; T-temperature; E/K, Equilibrium/Kinetics; F-Freundlich; L-Langmuir; La-Lagergren; PF-pseudo first order; Ps-Pseudo second order; UM-unmodified; M-modified

Synthetic material and other adsorbents used for Ni (II) ion removal shown in table 8.

Table 8. The synthetic, natural and other wastes used as adsorbents for the removal of Ni(II) ions from aqueous solution.

By product	Optimized condition	% removal or uptake	Reference
Red mud	pH-9, metal ion conc-400mg/l,	160 mg/g	Zoubulis et al.,1993
Red mud	pH-5, adsorbent dose 10 g/l	13.69 mg/g	Hannachi et al., 2010
Iron/steel slag	pH-1.5-9.0, metal ion conc-20 to 100 mg/l,	Effective metal removal	-
Calcined phosphate	pH-5.0, adsorbent dose-10g/l	15.53 mg/g	Hannachi et al., 2010
Clarified sludge	pH-5.0, adsorbent dose-10g/l	14.30 mg/g	Hannachi et al., 2010
Activated slag	pH-4.0, adsorbent dose-10g/l	30 mg/g	Feng et al., 2004
Carbon anode	pH-4.5, adsorbent dose-15g/l	8.64 mg/g	Strkalj et al., 2011
Fly ash	pH-8, adsorbent dose-20g/l	0.99 mg/g	Bayat, 2002
Fly ash (power plant)	pH-6, adsorbent dose-12 gm/100 ppm, cotact time-90 min	76.84%	Narayanan et al., 2014
Magnite	pH-5.5 to 6, adsorbent dose-1g/l	18.43 mg/g	Ortiz et al., 2001
Anode dust	pH-4.5	-	Strkalj et al., 2011;
Sewage sludge using chemical pyrolysis	pH-5.5 to 6.0, AD-10 g/l, IMC-30 mg/l, CT-60 min, L & F	16.9 mg/g	Ocampo-Perez et al., 2012
Clay Mixture containing Boron Impurity (BC)	Batch study - higher pH, CT-90 min, exothermic reaction, L, Ps	81.86%	Olgun, 2012; Tan et al., 2008
Starch, activated charcoal, wood charcoal and clay (type bleaching earth)	Batch study -pH-7.5 and 6.5, endothermic reaction, Pf	-	Choksi and Joshi, 2007
Fixed activated sludge reactor (FAS)	-	87%	Hassani et al., 2010
Basic chelating anion exchange resin	pH-4 to 6, IMC-5-30 mg/l, resin dose-25 to 700 mg/l,		Dave et al., 2010
Ceralite IR 120 cationic exchange resin (CXR)-ion exchange	Batch study - pH-5, F, Pf & L	28.57 mg/g	Kumar et al., 2010
Perlite	pH- 6, AD-8 g/l, F, Ps	93%	Mostaedi et al., 2010
Khulays activated clay (bentonite)	pH-2 to 9, CT-40 min, L, F,& Ps	70-100%	Al-Shahrani, (2012)
Cow Bone Charcoal	pH-5.1, AD-0.01-0.03 gm/100 ml, IMC-20 mg/l, , CT-60 min, T-298 K, L	32.54 mg/g	Moreno et al., 2010
Powdered cow hooves (an inedible spare part of cows)	pH-7, AD-1g, CT-20 min, T-298 K	78.5%	Osasona et al., 2014

Conclusion

In recent years, increasing cost and environmental considerations associated with the use of commercial adsorbents, has led to development of low cost adsorbents derived from renewable resources. A review of various low cost adsorbents presented in this paper shows the effectiveness and potential of adsorption process by using low cost adsorbents derived from agro-industrial, dead microorganisms, fermentation, food processing and municipal wastes etc. The adsorption capacity is dependent on the type of adsorbent used and the nature of waste water treated. 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. The use of waste materials as low cost adsorbents for removing various pollutants from water and waste water presents many features especially their contribution in the reduction of cost for waste disposal, therefore contributing to environmental protection. Although the amount of available literature data on the use of low cost adsorbents in water and waste water treatment is increasing at a tremendous pace, there are still several gaps which need to be filled.

References

Abas Siti Nur Aeisyah, Mohd Halim Shah Ismail, Md Lias Kamal and Shamsul Izhar (2013). Adsorption process of heavy metals by low cost adsorbents: A review. *World Applied Sciences Journal*, 28 (11): 1518-1530, ISSN 1818-4952.

Agarwal A and Gupta PK (2015). Removal of Ni from its aqueous solution by using low cost adsorbent prepared from wood apple shell. *International Journal of Advanced Research*, Volume 3, Issue 1, 412-416 . ISSN 2320-5407.

Ajmal, Ali. Mohd, Rehana Yousuf and Anees Ahmad (1998). Adsorption behaviour of cadmium, nickel and lead from aqueous solutions by *Magnifera Indica* seed shell. *Indian Journal of Environmental Health*. 40 (1), 1-15.

Ahluwalia S. S. and D. Goyal (2005a). *Eng. Life Sci.*, 5, 158.

Ahluwalia, S.S., Goyal, D., (2005). Removal of heavy metals by waste tealeaves from aqueous solution. *Engineering in life Sciences* 5, 158–162.).

Ajmal M., R. A. K. Rao and M. A., Khan, (2005) . *J. Hazard. Mater.*,122 177.

Ajmal Mohammad, Rifaqat Ali Khan Rao, Rais Ahmad, Jameel Ahmad (2000). Adsorption studies on *Citrus reticulata* (fruit peel of orange): Removal and recovery of Ni (II) from electroplating wastewater. *Journal of Hazardous Materials*. Vol 79, Issues 1-2, P 117-131.

Akhtar, S.M., Chali, B. and Azam, T. (2013). Bioremediation of arsenic and lead by plants and microbes from contaminated Soil. *Research in Plant Sciences*. 1(3): 68-73.

Akhtar, M., Sastry, K., Mohan, P., (1996). Mechanism of metal ion biosorption by Fungal biomass. *Biometals* 9, 21–28.).

- Aikpokpodion P.E., Ipinmoroti, R.R. and Omotoso, S.M. (2010). Biosorption of Ni (II) from aqueous solution using waste Tea (*camella cinencis*) materials. *The American-Eurasian Journal of Toxicological Sciences*. Vol.2, No.2, pp.72-82.
- Al-Shahrani S. S. (2012). Treatment of Wastewater Contaminated with Nickel Using Khulays Activated Bentonite . *International Journal of Engineering & Technology IJET-IJENS* Vol:12 No:04 pp 14-18.
- Annadural, G., Juang, R.S., and Lee, D.J. (2002). Adsorption of heavy metals from water using Banana and orange peels. *Water Science and Technology* Vol 47 No 1, pp 185-190.
- Aregawi Beyene Hagos and Mengistie Alemayehu Abebaw (2013). Removal of Ni (II) from aqueous solution using Leaf, Bark and Seed of Moringa *Stenopetala* Adsorbents. *Bull.Chem. Soc. Ethiop.* 27 (1), 35-47. ISSN 1011-3924.
- Argun M E., Dursun, S, Ozdemir, C., Karatas, M., (2007). Heavy metal adsorption by modified oak sawdust: thermodynamics and kinetics. *J.Hazardous Mater.* B 141, 77-85.
- Arunkumar, C., Perumal, R., Lakshmi Narayanan, S. and Arunkumar, J. (2014). Use of corn cob as low cost adsorbent for the removal of Nickel (II) from aqueous solution. *Internation Journal of Advanced Biotechnology and Research (IJBR)*. Vol. 5, Issue 3, pp325-330.
- Aslam Muhammad Zaheer, Ramzan Naveed, Shahid Naveed, Feroze Nadeem. (2010). Ni (II) removal by biosorption using *Ficus Religiosa* (Peepal) leaves. *Journal of the Chilean Chemical Society (J. Chil. Chem. Soc.,* Vol 55, No 1, PP 81-84. ISSN)717-9707.
- ATSDR (2005). Toxicological profile of nickel. Atlanta, GA: Agency for Toxic substances and disease Registry.
- Balat M,. (2008). *Energy source Part A.* 30, 620.
- Bailey, E., Trudy, J., Olin, R., Bricka, M., and Adrian, D.D. (1999). A review of potentially low cost sorbents for heavy metals. *Water Research.*33: 2469-2479.
- Babel, S. and T.A. Kurniawan, (2004). Cr (VI) removal from synthetic waste water using coconut shell, charcoal and commercial activated carbon modified with oxidizing agents and /or chitosan. *Chemosphere*, 5(7): 951-967.
- Bayat B., *J. Hazard*(2002). *Mater. B*, 95 251-273.
- Bahadir, T., Bakan, G., Altas, L., Buykgungar, H. (2007). The investigation of lead removal by biosorption. An application at storage battery industry wastewaters. *Enzyme Microbiology Technolyog.* 41: 98–102.
- Bartczak , P., Norman, M., Klapiszewski, L., Karwanska, N., Malgorzata, Kawalec, Baczynska, M., Wysokowski, M., Zdarta, J., Ciesielczyk, F., Jesionowski, T. (2015). Removal of Ni(II) ions from aqueous solution using peat as a low cost adsorbent: A kinetic and equilibrium study. *Arabian Journal of Chemistry*, <http://dx.doi.org/10.1016/j.arabjc.2015.07.018>. Article in press.



Blanco, A., Sanz, B., Llama, M.J., Serra, J.L., 1998. Reutilization of nonviable biomass of *Phormidium laminosum* for metal biosorption. *Biotechnology and Applied Biochemistry* 27, 167–174.).

Bulut Y and Z Tez, (2003). Removal of heavy metal ions by modified sawdust of walnut. *Fresenius Environmental Bulletin*, 12(12):1499-1504.

Bolto B, Dixon R, Eldridge S, King and K. Linge (2002). *Water Res.*, 36, 5057

Bell J., J J. Buckley C A and Stuckey D C. J. (2000). *Environ. Eng, ASCE* 126, 1026.

Calace, N., Nardi, E., Petronio, B.M., Pietroletti, M., Tosti, G., 2003. Metal ion removal from water by sorption on paper mill sludge. *Chemosphere* 51 (8), 797–803.).

Carrasco-Martin F., A. Mueden, T. A. Centeno, F. Stoeckli, C. Moreno Castilla, J. *Chem Soc. Faraday Trans.*, 93 (1997) 2211-2215.

Carrilho, E.N., Gilbert, T.R., 2000. Assessing metal sorption on the marine alga *Pilayella littoralis*. *Journal of Environmental Monitoring* 2 (5), 410–415.).

Choksi P. M. and V. Y. Joshi *Desalination*, 208 (2007) 216.

Chau YK, Kulikovskiy-Cordeiro OTR (1995). Occurrence of nickel in Canadian Environment. *Environ Rev.*, 3: 95-120.

Chamanchi M., Vaferi, B., and Jalili Isaac, (2012). A comparative experimental study of removal of heavy metals using low cost natural adsorbents and commercial activated carbon. *International Journal of Chemical and Environmental Engineering*, Vol 3 No 1.

Chen C. Y. and Lin, T.H., *J. Toxicol. Environ. Health Part A.* (1998), 54,37-47 (Cross Ref).

Chen H, Liu S C. Chen C Y, Chen C Y. (2008). *J. Hazard Mater.* 154, 184.

Chen H, Yang C Y, Chen C Y, Chen C Y, Chen C W. (2009). *J. Hazard Mater.* 163, 1068.

Cheremisinoff, P.N. and A.C. Morresi, 1978. *Carbon adsorption Handbook*. An Arbor Science Publishers, Borought Green, pp: 1-57.

Coogan TP, Latta DM, Snow, ET, Costa M (1989). Toxicity and carcinogenicity of nickel compounds. *Crit. Rev. Toxicol.*, 19(4): 341-384.

Das S. Biosorption of chromium and nickel by dried biomass of cyanobacterium *Oscillatoria laete-virens*. *INTERNATIONAL JOURNAL OF ENVIRONMENTAL SCIENCES* Volume 3, No 1, 2012 . ISSN 0976 – 4402 .

Demirbas, E., M. Kobyas, S. Oncel, S. Sencan, *Biores. Tech.*, 84 (2002), 291-293.

Dave R.S., G.B. Dave and V.P. Mishra. Removal of Nickel from electroplating waste water by weakly basic chelating anion exchange resins. Dowex50x4, Dowex 50x2 and Dowex M-4195. *Journal of Applied Sciences in Environmental Sanitation*. Vol 6, pp. 39-44, 2010.

Donmez, G.C., Aksu, Z., Ozturk, A., Kutsal, T., 1999. A comparative study on heavy metal biosorption characteristics of some algae. *Process Biochemistry* 34, 885–892.).

Eccles, H, 1999. Treatment of metal contaminated wastes: why select a biological process? *Trends in Biotechnology*, 17:462-465.

Esplugas S, Gimenez J. Contreas S, Pascual E, and Rodriguez M. (2002). *Water Res.*, 36, 1034.

Farkas, V., 1980. Biosynthesis of cell wall of fungi. *Microbiological Reviews* 44, 117–141.)

Farajzadeh MA, Monjii AB. (2004). Adsorption characteristics of wheat bran towards heavy metal cations. *Sep. Puri. Technol.* Vol 38, pp.555-562.

Feng D., Van Deventer J. S. J., Aldrich C. (2004). *Sep. Purif. Technol.*, 40 61-67.

Fernandez-Lahore H. M., R. Kleef, M.R. Kula and J. (1999). Thoemmes., *Biotechnol. Bioeng.*, 64 484.

Fourest, E., Roux, J.C., (1992). Heavy metal biosorption by fungal mycelia by-products: mechanism and influence of pH. *Applied Microbiology Biotechnology* 37, 399–403.

Garbarino, J.R., H. Hayes, D.Roth, R. Antweider, T.I. Brinton and H. Tailor, (1995). Contaminants in the Mississippi River, U.S. Geological Survey Circular 1133, Virginia, U.S.A.

Gaballah I., G. J. Kilbertus (1998). *Geochem. Explor.* 62 241-286.

Gloaguen V and Morvan H, Removal of heavy metal ions from aqueous solution by modified barks. *Journal of Environmental Sci Health A*, 32 (1997) 901-912.

Gonen, Ferda and Serin D. Selen (2012). Adsorption study on orange peel: Removal of Ni (II) ions from aqueous solution. *African Journal of Biotechnology*. Vol. 11 (5), pp1250-1258. ISSN 1684-5315.

Gowda R, A.G.Nataraj and N.Manamohan Rao (2012). “Coconut leaves as a low cost adsorbent for the removal of Nickel from Electroplating effluents” *International Journal of Scientific & Engineering Research*, Volume 2, pp. 1- 5.

Gupta VK., Jain CK., Ali I., Sharma M., Saini VK (2003). Removal of Cadmium and Nickel from waste water using bagsse fly ash-A suger industry waste” *Water Res.*, Vol. 37, pp 403-44,.

Hassani A.H., Hossenzadeh, B. Torabifar. Investigation of using Fixed Activated Sludge System for removing heavy metals (Cr, Ni and Pb) from industrial waste water. *Journa of Environmental studies*. Vol. 36, No. 53, pp.22-24, 2010.

Hawkes J.S., (1997). Heavy Metals. *Journal of Chemical Education*. 74(11):1374.

Hamadi N. K., S. Swaminathan and X. D. (2004). Chen, *J. Hazard. Mater.*, 112 133.

Hamidi AA, Mohd NA, Chieng SH, Zahari and Hameed BH, (2005). Removal of Ni, Cd, Pb, Zn and colour from aqueous solutions using potential low cost adsorbents, *Indian Journal of engineering and material sciences*, 248-258.

Hannachi Y, Shapovalov NA, Hannachi A. (2010). Adsorption of nickel from aqueous solution by the use of low-cost adsorbents. *Korean Journal of Chemistry Engineering*, 27:152-158.

Hanafiah MAK, Ibrahim SC, Yahaya MZA (2006). Equilibrium adsorption study of lead ions onto sodium hydroxide modified Lalang (*Imperata cylindrica*) leaf powder. *Journal of Applied Science Research*, 2: 1169-1174.

Hanif M. A., R. Nadeem, M. N. Zafar, K. Akhtar and H. N. Bhatti., *J. Hazard. Mater.*, 139 (2007) 345.

Hasar H (2003). Adsorption of Ni (II) from aqueous solution onto activated carbon prepared from almond husk. *J. Hazard. Mater.* 97: 49-57.

Higgins SJ (1995). Nickel 1993. *Coordination Chemistry Reviews*. 146:115-201.

Holan, Z.R., Volesky, B., (1995). Accumulation of cadmium, lead and nickel by fungal and wood biosorbents. *Applied Biochemistry Biotechnology* 53, 133–146.

Horsfall Jr., Spiff, A.I., 2005. Effect of metal ion concentration on the biosorption of Pb²⁺ and Cd²⁺ by *Caladium bicolor* (wild cocoyam). *Afr. J. Biotechnol.* 4, 191–196.

Iqbal M., A. Saeed and N. Akhtar, *Bioresource Technol.*, 81 (2002) 151. Jarup, L., 2003. Hazards of Heavy Metals Contamination, *British Medical Bulletin*, 68:167-182.

Jiang Y., Huang C.J., Pang H., Liao B., (2008). Progress in cellulose based Adsorbents. *Chemistry*. 71 (12).

Jong Tony, David L., Parry (2003). Removal of Sulfae and Heavy Metals by sulfate reducing Bacteria in short term Bench scale up flow Anaerobic packed bed reactor runs. *Water Research*. Vol. 37, pp.3379-3389.

Joshi, N., Ahluwalia, S.S., Goyal, D., (2003). Removal of heavy metals from aqueous solution by different bio-waste materials. *Research Journal Chemistry & Environment* 7 (4), 26–30.



Kadirvelu K., Thamaraiselv K. K., Namasivayam C. C., Sep. Purif. Technol. 24 (2001). 497-505.

Karimi-Jashni, A. and Saddat, S., (2014). Investigation of factors affecting removal of nickel by pre-treated walnut shell using factorial design and univariate studies. IJST, Transactions of Civil Engineering, Vol. 38, No. CI⁺, pp 309-324.

Kamali MohdAriff Bin. Removal of Heavy Metal from industrial waste water using Ultrasonic Assisted by Tea waste as adsorbent. Brazilian Journal of chemical Engineering. Vol. 27, pp299-308, 2010.

Kannan, A. and S. Thambidurai, (2008). Comparative studies on the removal of Nickel(II) from aqueous solution by using carbon derived from Palmyra Palm fruit seeds and commercial activated carbon. International journal of science and technology. Vol. 1, No 1, 93-107, 2008.

Klimmek, S., Stan, H.J., Wilke, A., Bunke, G., Buchholz, R., 2001. Comparative analysis of the biosorption of cadmium, lead, nickel, and zinc by algae. Environmental Science and Technology 35, 4283–4288.

Krishnan A K. Sreejalekshmi K G, Baiju R S. (2011). Bioresource Technol. 102, 10239.

Kotov V, Nikitiana E (1996). Norilsk: Russia Wrestles with an old polluter. Environment, 38: 6-11.

Kobyas, M., Demirbas, E., Senturk, E., Ince, M., (2005). Adsorption of heavy metal ions from aqueous solution by activated carbon prepared from apricot stone. Bioresource Technology 96, 1518–1521.).

Kumar P. Senthil, K. Ramakrishnan, R. Gayathri (2010). Removal of Nickel (II) from aqueous solution by Ceralite Ir 120 cationic Exchange Resins. Journal of Engineering Science and Technology. Vol. 5, pp. 232-243.

Kurniawan T. A., G. Y. S. Chan, W. H. Lo and S. Babel, *Sci. Total Environ.*, 366 (2006) 409.

Liphadzi MS and Kirkham MB (2005). Phytoremediation of soil contaminated with heavy metals, a technology, a technology for rehabilitation of the environments. South African Journal of Botany., 71:24-37.

Li X, Tang Y, Xuan Z, Liu Y, Luo F, 2007. Study on the preparation of orange peel cellulose adsorbents and biosorption of Cd²⁺ from aqueous solution. Sep. Puri, Technol., vol, 55, pp. 69-75.

Low, K.S., Lee, C.K., Leo, A.C., 1995. Removal of metals from electroplating waste using banana pith. Bioresource Technology 51 (2-3), 227–231.).

Mattuschka, B., Straube, G., 1993. Biosorption of metals by waste biomass. Journal of Chemical Technology Biotechnology 58, 57– 63.).

Malkoc E, Nughoglu Y (2005). Investigation of Ni (II) removal from aqueous using tea factory waste. *J Hazard Mater B127*:120-128.

Marques T. L., Alves, V. N., Coelho, L. M., Coelho N. M. (2012). Removal of Ni (II) from aqueous solution using *Moringa oleifera* seeds as a biosorbent. *Water Science Technology*. 65 (8): doi:10.2166/wst.2012.026.

Marshall W. E. and M. M. Johns (1996). *J. Chem. Tech. Biotechnol.*, 66, 192.

Marin, J., Ayele, J., (2002). Removal of some heavy metal cations from aqueous solutions by spruce sawdust. I. Study of the binding mechanism through batch experiments. *Environment Technology* 23 (10), 1157–1173.

Meunier, N. J Laroulandie, JF. Blais and RD tyagi, (2003). Cocoa shells for heavy metal removal from acidic solutions. *Bioresource Technology*, 90 (3). 255-63.

Monser, L., and N. Adhoum, (2002). Modified Activated Carbon for the removal of copper, Zinc, Chromium and Cyanide from waste water. *Separation and Purification Technology*, 26 (2/3):137-146.

Moreno, Juan Carlos, Rigoberto Gomez and Liliana Giraldo. (2010). Removal of Mn, Fe, Ni and Cu ions from Wastewater using Cow Bone Charcoal. *Materials*, 3, 452-466, ISSN 1996-1944.

Mostaedi Torab M., H.Ghassbzadeh, M. Ghannadi-Maragheh, S.J. Ahmadil and H. Taheri (2010). Removal of cadmium and nickel from aqueous solution using expanded Perlite. *Brazilian Journal of chemical Engineering*. Vol. 27, pp299-308.

Moodley Krishnie, Ruella Singh, Evnas T Musapatika, Maurice S Onyango and Aoyi Ochieng (2011) Removal of nickel from wastewater using an agricultural adsorbent. *Water SA* vol 37 No 1. ISSN 0378-4738 (Print), 1816-7950 (on-line).

Muzzarelli, R.A., Tanfari, F., 1982. The chelating ability of chitinous material from *Aspergillus niger*, *Streptomyces*, *Mucor rouxii*, *Phycomyces blakesleanus* and *Choamephora curcurnitium* in Chitin and Chitosan. S.Mirano, S. Tokura (Eds.), *Japanese Society of Chitin and Chitosan*, pp. 183–186).

Narayanan LS, Arunkumar C, Perumal R, Saravanan PK, and Arun Prasad AS (2014). A batch study on the removal of nickel (II) using low cost adsorbent fly ash. *Int. Jour. Chem and Petrochem Tech.* 31-36.

Namasivayam M D, Kumar K, Selvi R A, Begum T, Vanathi and Yamuna (2001). *Biomass Bioenerg.* 21, 477.

Nordberg G. F. Fowler B. A , M. Nordberg, L. Friberg, (2005). *Handbook of Toxicology of metals*, European Environmental Agency, Copenhagen,.

Nieboer E, Richardson DHS (1980). The replacement of the no-descript term 'heavy metals' by a biologically and chemically significant classification of metal ions. *Environ Pollut Series B*;1:3-26.)

Nriagu, J.O. 1989. A Global Assessment of Natural sources of Atmospheric Trace Metals., *Nature*, 338:47-49.

Noor K., Nour Usama M, and MaitraSaikat (2011). "Removal of nickel from aqueous solution using Rambai stem (*Baccaureamotleyana*) Adsorbent". *Journal of Environmental Science and Engineering*. Vol. 53 (3): 257-262.

Ocampo-Pérez R., J. Rivera-Utrilla, C. Gómez-Pacheco, M. Sánchez-Polo, J. J. López-Peñalver, *Chem. Eng. J.*, 213 (2012) 88.

O'Connell D W, Birkinshaw C, O'Dwyer T F. (2008). *Bioresource Technol.* 99, 6709.

Olgun, N. Atar, *J. Indust. Eng. Chem.*, 18 (2012) 1751.

Olayinka Kehinde, O. Adetunde Oluwatoyin, T., and Olayinka Aderonke O. (2009). Comparative analysis of the efficiencies of two low cost adsorbents in removal of Cr (VI) and Ni (II) from aqueous solution. *African Journal of Environmental Science and Technology*. Vol. 3 (11), pp. 360-369. ISSN 1991-637X@2009 Academic Journals.

Onianwah, I.F., Stanley, H.O., and Stanley C.N. (2013). Bioremoval of cadmium, nickel and zinc from leachate sample collected from refuse dump on Obiri Ikwerre/ Air Port Link road using living cells of *Aspergillus Niger* and *Rhizopus Stolonifer*. *International Research Journal of Environment Sciences*. Vol. 2 (11), 1-8..

Ortiz N., M. A. F. Pires, J. C. Bressiani, *Waste Manage.*, 21 (2001) 631-635.

Osasona I., Ajayi, O.O. and Adebayo, A.O. Equilibrium, Kinetics and Thermodynamics of the removal of Nickel (II) from aqueous solution using cow hooves. *Advances in Physical Chemistry*. Vol. 2014, Article ID 863173, pp.8. Hindawi Publishing Corporation. <http://dx.doi.org/10.1155/2014/863173>.

Pala and ToKat E. (2002). *Water Res.* 36, 2920.

Patil, S.J. Bhole, A. G. and Natrajan G.S. (2006). Scavenging of Ni (II) metal ions by adsorption on PAC and Babhul Bark. *Journal of environmental Science and Engineering*. Vol. 48, No 3, Page 203-208. July 2006.

Patil AK., and Shrivastava, VS. (2010). Adsorption of Ni (II) from aqueous solution on *Delonix regia* (Gulmohar) tree bark. *Archives of Applied Science Research*. 2 (2): 404-413.

Patil Satish, Renukdas Sameer, Patel Naseema (2012). Kinetic and yhermodynamic study of removal of Ni (II) ions from aqueous solution using low cost adsorbents. *International Journal of Environmental Sciences*, Vol 3, No 1, ISSN 0976-4402.

Pandharipande, S. L., and Rohit P. K. (2013). Tamarind fruit shell adsorbent synthesis, characterization and adsorption studies for removal of Cr (VI) and Ni (II) ions from aqueous solution. *International journal of Engineering Sciences and Emerging Technologies*. Vol 4, Issue 2, pp: 83-89 @IJESET.

Parker P. *Encyclopaedia of Environmental Science* (2nd edn). McGraw Hill, New York. (1980).

Patterson J., R. Passino, *Metal Speciation, Separation and recovery*, Lewis Publishers. Inc., Chelsea, (1987).

Periasamy, K. and Namasivayam C. (1995). Removal of Nickel (II) from aqueous solution and nickel plating industry wastewater using an agricultural wastes: peanut hulls. *Waste Management*. 15 (1), 63-68.

Pérez-Marín, A.B., Ballester, A., González, F., Blázquez, M.L., Muñoz, J.A., Sáez, J., Meseguer Zapata, V., (2008). Study of cadmium, zinc and lead biosorption by orange wastes using the subsequent addition method. *Bioresource Technology*. 99: 8101-8106.

Parab H, Joshi S, Shenoy N, Lali A, Sarma US, Sudersanan M (2006). Determination of kinetic and equilibrium parameters of the batch adsorption of Co(II), Cr(II) and Ni(II) on to coir pith. *Process Biochem* 41:609-615.

Pandey AK, Jamaluddin, Awasthi AK, and Amit Pandey. (2013). Biosorption characteristics of *Aspergillus Flavus* in removal of Nickel from an aqueous solution". *International Journal of Green and Herbal Chemistry*. Vol.2, pp47-51.

Pandey PK, Choubey S, Verma Y, Pandey M, Kamal SSK, Chandrashekhar. (2007). Biosorptive removal of Ni (II) from waste water and Industrial effluent". *Int J. Environ. Res. Public Health*. Vol. 332 to 339.

Pérez-Marín, A.B., Ballester, A., González, F., Blázquez, M.L., Muñoz, J.A., Sáez, J., Meseguer Zapata, V., (2008). Study of cadmium, zinc and lead biosorption by orange wastes using the subsequent addition method. *Bioresource Technology*. 99: 8101-8106.

Parmar M and Thakur LS (2013). Adsorption of heavy metals [Cu (II), Ni (II), and Zn (II)] from synthetic waste water by tea waste adsorbent. *IJCPS*, 2(6), 6-19.

Pearson RG. Hard and soft acids and bases. *J Am Chem Soc* 1963;85:3533–9. 1963).

Prasad, M.N.V., Freitas, H., 2000. Removal of toxic metals from solution by leaf, stem and root phytomass of *Quercus ilex* L. (holly oak). *Environmental Pollution* 110, 277–283.).

Pino GH, Mesquita L M S, Torem M L & Pinto G A S, Biosorption of Cd (II) by green coconut shell powder, *Minerals Eng*, 19 (2006) 380-387.

Periasamy, K. Namasivayam, *Waste Manage.*, 15 (1995). 63-68.

Prabakaran, R., and Arivoli, S., (2012). Adsorption kinetics, equilibrium and thermodynamic studies of Nickel adsorption onto *Thespesia Populnea* bark as biosorbent from aqueous solutions. *European Journal of Applied Engineering and Scientific Research*. 1(4):134-142.

Prasad, K.S.S., Brahmaiah, T., Spurthi, L., Chandrika, K. and Ramanaiah, (2015). S.Kinetic of Heavy Metal (Cr & Ni) Removal from the waste water by using low cost adsorbent. *World Journal of Pharmacy and Pharmaceutical Sciences*. Vol. 4, Issue 11, pp.1600-1610.

Rahmani, K., A.H. Mahvi, F. Vaezi, A.R. Mesdaghinia, R. Nabizade and S. Nazmara, 2009. Bioremoval of lead by use of waste activated sludge. *International Journal of Environmental Research*. 3(3):471-476.

Rehman, H., Shakirullah, M., Ahmad, I., Shah, S. and Hameedullah, H. Sorption studies of Nickel ions on to saw dust of *Dalbergia sissoo*. *Journal of the Chinese chemical Society*. Vol. 53, no. 5, pp. 1045-1052, 2006.

Remacle J. The cell wall and metal binding. In: Volesky B, editor. *Biosorption of heavy metals*. Boca Raton: CRC Press; 1990. p. 83–92.).

Rani S. Amala Fatima, J. Rosaline Vimala and T. Bhuvana. Studies on the removal of nickel (II) using chemically activated *Pouteria Sapota* seed and commercially available Carbon. *Pelagia Research Library*, Vol. 3, pp. 613-620, 2012.

Rittmann, B.E., *Journal of Environmental Engineering*, Vol. 136, No.4, 2010, pp.348-353.

Rao P.R. and Bhargavi Ch (2013). Studies on Biosorption of Heavy Metals Using Pretreated Biomass of Fungal Species. *International Journal of Chemistry and Chemical Engineering*. ISSN 2248-9924 Volume 3, Number 3, pp. 171-180.

Rao, M., Parwate, A.V. and A.G. Bhole (2001). Uptake of nickel from aqueous solution using low cost adsorbent, *Enviromedia*, 20 (4), 669-675.

Reddad, Z., Gérente, C., Andrès, Y., Thibault, J.F., Le Cloirec, P. (2003). Cadmium and lead adsorption by a natural polysaccharide in MF membrane reactor: experimental analysis and modelling. *Water Research*. 37: 3983-3991.

Revathi M (2005). *Journal of Environmental & Engg.*, 47,1.

Rittmann, B.E., *Journal of Environmental Engineering*, Vol. 136, No.4, 2010, pp.348-353.

Rohini, J.S., Dr D.P.Nagarajappa, M. Mamatha, (2014). Removal of Nickel from simulated wastewater using *Pongamia Pinnata* seed shell as adsorbent. *International Journal of Engineering Research & Technology (IJERT)*. Vol. 3 Issue 6, pp1080-1089. june. ISSN: 2278-0181.

Samarghandi, R., S. Azizian, M. Shirzad Siboni, S.J. Jafari, S. Rahimi. Removal of Divalent Nickel from aqueous solution by adsorption on to modified holly saw dust: Equilibrium and Kinetics. *Iran Journal Environ. Health Science Engineering*, Vol. 8, pp 181-188, 2011.

Satpathy D, (2002). Optimisation of recovery processes of metal ions using granular activated carbon, ph.D thesis, Nagpur University, India.

Saeed A, MWaheed Akhter and M Iqbal, (2005). Removal and recovery of heavy metals from aqueous solution using Papaya wood as a new biosorbent. Separation and purification technology.45:25-31.

Sajwan K. S., W. H. Ornes, T. V. Youngblood, A. K. Alva. (1996). Wat. Air Soil Polution., A. K. Alva, Wat. Air Soil pollution. 91 209-217.

Sciban M., M. Klasnja and B. Skrbic. *Wood Sci. Technol.*, 40 (2006) 217.

Shukla, S.R., Pai, R.S., 2005a. Adsorption of Cu(II), Ni(II) and Zn(II) on modified jute fibres. *Bioresour. Technol.* 96, 1430–1438.

Shukla, S.R., Pai, R.S., (2005b). Adsorption of Cu(II), Ni(II) and Zn(II) on dye loaded groundnut shells and sawdust. *Sep. Purif. Technol.* 43, 1–8.

Shah B.A., A.V. Shah and R.R. Singh, (2009). Sorption isotherm and kinetics of chromium uptake from waste water using natural sorbent material. *International Journal of Environmental Science and Technology*, 6(1):77-90.

Štrkalj A., Rađenović A., J. Malina, *Can. Metall. Q.*, 50 (2011) 3-9.

Srivastava, N.K. and Majumder, C.B., (2008). Novel biofiltration methods for the treatment of heavy metals from industrial waste water. *Journal of Hazardous Materials*, 151(1):1-8.

Sud D , Garima Mahajan, M.P. Kaur (2008). Agricultural waste material as potential adsorbent for sequestering heavy metal ions from aqueous solutions – A review *Bioresource Technology* 99 6017–6027.

Shukla, S.R., Pai, R.S., 2005. Adsorption of Cu(II), Ni(II) and Zn(II) on modified jute fibres. *Bioresource Technology* 96, 1430–1438.).

Shukla, S.R., Pai, R.S., 2005. Adsorption of Cu(II), Ni(II) and Zn(II) on modified jute fibres. *Bioresource Technology* 96, 1430–1438.).

Shivakant M R. and Shivarajjapa (2009). “Adsorption studies of Cr (VI) on activated carbon derived from phoenix *Dactylifera* (date palm) seeds”. *Journal of IPHE, India*, Vol. 2009-10 (1):5-13.

Tang P L, Lee CK, Low K S, and Zainal Z, (2003). Sorption of Cr (IV) and Cu (II) in aqueous solution by ethylenediamine modified rice hull, *Environ Technol*, 24 1243-1251.

Tsezos, M., Deutschmann, A.A., (1990). The use of mathematical model for the study of important parameter in immobilized biomass biosorption. *Journal of Chemical Technology & Biotechnology* 53, 1–12.

Vaughan, T., Seo, C.W., Marshall, W.E., (2001). Removal of selected metal ions from aqueous solution using modified corncobs. *Bioresource Technology* 78 (2), 133–139.

Verma, B., Shukla, N.P., (2000). Removal of nickel(II) from electroplating industry by agrowaste carbons. *Indian Journal of Environmental Health* 42 (4), 145–150.

Villaescusa, I., Fiol, N., Martinez, M., Miralles, N., Poch, J., Serarols, J., 2004. Removal of copper and nickel ions from aqueous solutions by grape stalks wastes. *Water Research* 38, 992–1002.

World Health Organization, WHO (1991). Nickel. *Environmental Health Criteria*. 108, p.383.

Yadla, S.V., V. Sridevei and M.V.V. Chandana Lakshmi, (2012). Adsorption performance of fly ash for the removal of lead. *International Journal of Engineering Research and Technology*, 1(7).

Yu, B., Y. Zhang, A. Shukla, S.S. Shukla and K.L. Dorris, (2000). The removal of Heavy metal from aqueous solution by saw dust adsorption removal of copper. *Journal of Hazardous Materials*, 80:33-42.

Zhao, M and Duncan, J.R. (1998). Removal and recovery of nickel from aqueous solution and electroplating rinse effluent using *Azolla filiculoides*. *Process Biochemistry*. 33 (3), 249-255.

Zhang Xiao Tian and Ismail, MHS. (2012). Adsorption mechanism and properties of mixed agricultural wastes Adsorbent for Nickel (II) removal. *Journal of Purity of, Utility Reaction and Environment* Vol.1, No.2, April, 2012, 80-103.

Zoubulis A. I., K. A. Kydros, (1993). *J. Chem. Technol. Biotechnol.*, 38: 95-101.