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Review

Adsorptive removal of nickel(II) ions from aqueous environment: A review

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A B S T R A C T

Among various methods adsorption can be efficiently employed for the treatment of heavy metal ions contaminated wastewater. In this context the authors reviewed variety of adsorbents used by various researchers for the removal of **nickel(II) ions** from aqueous environment. One of the objectives of this review article is to assemble the scattered available enlightenment on a wide range of potentially effective adsorbents for **nickel(II) ions** removal. This work critically assessed existing knowledge and research on the uptake of nickel by various adsorbents such as activated carbon, non-conventional low-cost materials, nanomaterials, composites and nanocomposites. The system's performance is evaluated with respect to the overall metal removal and the adsorption capacity. In addition, the equilibrium adsorption isotherms, kinetics and thermodynamics data as well as various optimal experimental conditions (solution pH, equilibrium contact time and dosage of adsorbent) of different adsorbents towards **Ni(II) ions** were also analyzed. It is evident from a literature survey of more than 190 published articles that agricultural solid waste materials, natural materials and biosorbents have demonstrated outstanding adsorption capabilities for **Ni(II) ions**.

1. Introduction

The significant increase in the use of heavy metals in different industrial applications as well as the discharge of untreated industrial wastewater to the environment has definitely resulted in an increased amount of metal pollution of various water bodies (Zhao et al., 1999).

The term heavy metal refers to any metallic element that has atomic weights between 63.5 and 200.6, and a specific gravity greater than 5.0 (Fu and Wang, 2011). Heavy metals are natural components of the Earth's crust and can enter a water supply by industrial and consumer waste, or even from acidic rain breaking down soils and releasing heavy metals into streams, lakes, rivers, and groundwater (Malkoc, 2006). They cannot be degraded or destroyed but tend to bio-accumulate **and thus causing an increase in** its concentration in a biological organism over time, compared to its amount in the environment. To a small extent they enter our bodies via food, drinking water and air. As trace elements, some heavy metals (e.g. copper, cobalt, iron, manganese, molybdenum, vanadium, strontium, selenium and zinc) are essential to maintain the metabolism of the human body. However, at higher concentrations they can lead to poisoning (Srivastava et al., 2011). Therefore, the Word Heath Organization (WHO) and Environmental Protection Agency (EPA) have regulated the maximum acceptable discharge level into the environment and thereby controlling the water pollution level. According to the U.S. Environmental Protection Agency (EPA), Agency for Toxic Substances and Disease Registry (ATSDR), and World Health Organization (WHO), the maximum acceptable concentrations recommended for nickel, zinc, chromium and copper in drinking water is 0.02, 3.00, 0.05 and 2.00 mg/L, respectively (Acheampong et al., 2012).

Nickel (Ni), a member of the transition series is the 24th most abundant element in the Earth's crust, comprising about 3% of the composition of the earth. Although it can exist in several different oxidation states, the prevalent oxidation state under environmental conditions is Ni(II), nickel in the +**II** valence state (Cempel and Nikel, 2006; Coogan et al., 1989). As a member of the transition metal series, it is resistant to corrosion by air, water and alkali and hence regularly used in the manufacturing of stainless steel, coins, metallic alloys, super alloys, nonferrous metals, batteries, copper

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sulfate, electroplating, forging, porcelain enameling, mineral processing, paint formulation and steam-electric power plants.

The extensive industrial use of nickel means that considerable amounts of nickel can find its way into the aquatic environment. At non-dangerous level nickel may be beneficial as an activator of some enzyme systems and participating in important metabolic reactions. But, the ingestion of nickel beyond permissible levels is associated with the inhibition of oxidative enzyme activity, severe damage to lungs (pulmonary fibrosis, lung cancer) and kidney (renal edema), gastrointestinal distress (nausea, vomiting, diarrhea), skin dermatitis, chest pain, shortness of breath, etc. Dermatitis or nickel-itch is common among workers involved in making Ni containing jewellery and those using nickel-plated watches and Ni containing detergents. It is highly carcinogenic and high levels of nickel induce the reduction of nitrogen and impaired growth. (Cempel and Nikel, 2006; Coogan et al., 1989).

Looking upon its health hazards, several chemical and physical technologies have been developed and used for the removal of **nickel(II) ions** from water and wastewater which includes nanofiltration (Murthy and Chaudhari, 2008); ultrafiltration (Samper et al., 2009); complexation/ultrafiltration (Molinari et al., 2008); complexation/membrane filtration (Borbély and Nagy, 2009); reverse osmosis (Bakalár Tomáš, 2009; Ipek, 2005; Mohsen-Nia et al., 2007); coagulation/flocculation (Beltrán Heredia and Sánchez Martín, 2009); flotation (Sanciolo et al., 1992); electrocoagulation (Dermentzis et al., 2011; Heidmann and Calmano, 2008); electrochemical reduction/oxidation (X. Chen et al., 2013a); electrodeionization [Ion-exchange bed with electrodialysis] (Spoor et al., 2002); electroflocculation/filtration hybridization (Sun et al., 2009); ion−exchange (Dabrowski et al., 2004; Elshazly and Konsowa, 2003; Keränen et al., 2015; Leinonen et al., 1994; Rengaraj et al., 2002; Shaidan et al., 2012); ion−exchange/precipitation (Papadopoulos et al., 2004); photocatalytic removal (Kabra et al., 2008; Siboni et al., 2012, 2011); ion−exchange/electrodialysis (Dzyazko and Belyakov, 2004); electrodialysis/electrodeionization (Dermentzis, 2010); electroflotation (Belkacem et al., 2008) and co−precipitation (Lakshtanov and Stipp, 2007).

However, these traditional techniques have their own internal limitations such as less removal efficiency, sensitive operating conditions, high operational cost and production of secondary sludge **which requires an additional treatment**. Among the various physico chemical processes, adsorption has advantages such as flexibility in term of operation, feasibility in term of production of high quality product, economically viability in the context of initial capital cost and chemicals requirement as well as effectiveness in term of treating pollutants at low concentrations.

There was a number of review articles summarize the work conducted on the removal of heavy metals by different adsorbents such as: A review of potentially low-cost sorbents for heavy metals by Bailey et al. (1999); Low-cost adsorbents for heavy metals uptake from contaminated water: a review by Babel and Kurniawan (2003); Removal of heavy metal ions from wastewaters: A review by Fu and Wang (2011); Adsorption of heavy metal ions on soils and soils constituents by Bradl (2004); Biosorption of heavy metal ions using wheat based biosorbents − A review of the recent literature by Farooq et al. (2010); Sorption of Heavy Metals by Inorganic and Organic Components of Solid Wastes: Significance to Use of Wastes as Low-Cost Adsorbents and Immobilizing Agents by Zhou and Haynes (2010); Application of Chitosan for the Removal of Metals From Wastewaters by Adsorption—Mechanisms and Models Review by Gerente et al. (2007). Nevertheless, none of them has given complete enlightenment on one specific heavy metal ion.

Therefore, the present work aims to critically review the various adsorbents studied by researchers for the removal of **nickel(II) ions** from aqueous environment. As a result by reading this review, the young researchers can get complete idea that in which direction they have to start and further move their research. All the optimized parameters for the removal of nickel by various reported adsorbents were also specified, still authors encourage the readers to refer to the original research articles for information regarding the experimental conditions.

2. Literature review on various adsorbents used for the removal of nickel ions

2.1. Activated carbon adsorbents

Activated carbon is a crude form of graphite having a random or amorphous highly porous structure with a variety of pore sizes ranging from visible cracks and crevices to crevices of molecular dimensions (Hamerlinck et al., 1994). Activated carbons are appealing adsorbents for the removal of heavy metal contaminants mainly because of their extended surface area, high adsorption capacity, availability from renewable sources, reusability, microporous structure and special surface reactivity (Anoop Krishnan et al., 2011). Activated carbon is classified into four different types i.e. Powder (PAC), Granular (GAC), Fibrous (ACF) and Cloth (ACC) based on its size and shape.

Commercial activated carbon is one of the best adsorbent for effluent treatment containing heavy metal ions (Gupta et al., 2009) but their use is sometimes restricted due to higher cost. In addition, the CACs after their use become exhausted and are no longer capable of further adsorbing the pollutants. Once CAC has been exhausted, it has to be regenerated by any one of the methods, like thermal, chemical, oxidation, electrochemical, of regeneration but again this whole process of regeneration adds additional cost, furthermore, any regeneration process results in reduction of adsorption capacity (Zhou and Lei, 2006). To overcome these limitations the use of activated carbon sorbents derived from various natural materials have received increasing attention in the purification of wastewater over the last several years because they are plentiful, inexpensive and locally available (Pehlivan and Arslan, 2007).

In 2009, Ewecharoen et al. (2009) found that grafted activated carbon showed higher efficiency (55.7 mg/g) compare to the ungrafted activated carbon (44.1 mg/g) at the pH of 8.0, with the dosage of 0.1 g/10 mL and within the contact time of 120 min. Sudha et al. (2015) also carried out research in which they stated that activated carbon has been derived from various agricultural waste products and among all that Seed Carbon, which was prepared from waste material such as Citrus Limettioides peel and seed, had Ni(II) ions removal capacity around 35.54 mg/g, at the pH of 6.5 with the dosage of **1.5 g/L**, within 240 min of contact time. The process was spontaneous and well fitted to the Langmuir isotherm. Activated carbon prepared by Pehlivan and Arslan (2007) studied adsorption of nickel onto Lignite and activated carbon which was prepared from brown and black young coals. In that research study Lignite had efficiency 13.0 mg/g compare to the Beysehir lignite 12.0 mg/g and Activated carbon 5.4 mg/g. This process was well fitted with the Langmuir isotherm and the process was exothermic and gets the optimum adsorption capacity at between the pH 4.5−5.5 with the dosage of 0.1 g/L.

Keränen et al. (2015) removed nickel and vanadium from real ammoniacal industrial wastewater which was obtained from a synthesis gas scrubber. Activated carbons had efficiency of 4.36 mg/g at the pH of 5.5 with the dosage of 5.0 g/L and reach the equilibrium within 24 h.

Kadirvelu et al. (2001) prepared coir-pith carbon for the adsorption of heavy metal ions from waste water which had 62.5 mg/g efficiency within 120 min of contact time for Nickel ion at