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ORIGINAL RESEARCH PAPER

Nickel removal from electroplating industry wastewater: A bamboo activated carbon

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ABSTRACT: Water is prime requirement for surviving of any living beings. The existence of surface water and groundwater sources are used for domestic, agriculture and industrial purposes in all over the world. Fresh water from both the water sources is highly contaminated in recent years because of rapid population growth, modern agriculture and industrial growth. Among them, contamination of water sources due to industrialization is high and it requires more attention to protect those water sources. In this study, nickel removal from electroplating industry wastewater was done with the help of bamboo activated carbon. The nickel removal from electroplating industry wastewater by bamboo activated carbon was done in this study at various adsorbent dosages (0.5, 1.0, 1.5 and 2.0 g/L), agitation speeds (25, 50, 75 and 100 rpm), particle sizes (2.36, 1.18, 0.6 and 0.3 mm), and concentration dilutions (0, 25, 50, 75 and 100%). The maximum removal percentage of nickel from electroplating industry wastewater using bamboo activated carbon was found to be 98.7 % at an optimum adsorption dosage 1.5 g/L, agitation speed 25 rpm, particle size 0.6 mm and concentration dilution 75 % with 110 min. contact time and 5.5 pH. Functional groups available in a bamboo activated carbon before and after treatment were determined by fourier-transform infrared spectroscopy analysis. Fourier-transform infrared spectroscopy analysis specified that alkanes, carboxylic acids, esters, amides, amines, aromatic compounds, alkyl halides, ethers, alcohols, carboxylic acids, aldehydes functional groups in bamboo activated carbon was contributed for removing nickel from the electroplating industry wastewater. Isotherm models were used to know the adsorption behaviour of bamboo activated carbon for removing nickel from electroplating industry wastewater. Isotherm results revealed that Langmuir model was best suited with the equilibrium data than Freundlich model. Finally, this study concluded that bamboo activated carbon was best suited for removing nickel from electroplating industry wastewater.

KEYWORDS: *Bamboo activated carbon; Nickel removal; Process parameters; Isotherm models; Fourier-transform infrared spectroscopy (FTIR).*

INTRODUCTION

Due to volcanic action and natural weather, heavy metals are releasing to the water environment. The disposal of wastewater from the various metal industries to the water environment also enhanced the concentration of heavy metals in it (Kinhikar, 2012). Heavy metals like cadmium, mercury, lead, copper, zinc, chromium, cobalt, nickel, selenium, thallium and arsenic are in the list highly toxic chemicals provided by World Health Organization (WHO). Those chemical are non-biodegradable, which can accumulate into the biological system (Ijagbemi *et al.,* 2010; Torab-Mostaedi, *et al.,* 2010) and hence, it is necessary to reduce the concentration in a water environment. Human consumes toxic chemicals

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indirectly through both food and water consumption. Nickel availability in the earth crust is about 3 %. The natural and anthropogenic activities are influencing the presence of nickel within the air, water and land environment. Burning of fossil fuels, forest fires and volcanic ash are also contributing nickel into the environment. Among various industries, electroplating industry and stainless steel production industry are contributing more nickel disposal (wastewater) into the environment. Nickel is mainly used to prepare nickel alloys and stainless steel because of its high thermal and corrosive resistance properties. Its salts are highly used in chemical industries in the form $NiCl_2$, $NiSO_4$, $NiCO_3$, $C_4H_6NiO_4$, NiO and $Ni(OH)_2$. Thus, the nickel product industrial wastewater contains more nickel ion and if the concentration of nickel ion exceeds the drinking water and industrial wastewater limit as per WHO standards and BIS standards, it creates health hazard to all living beings. If nickel ion concentration exceeds 0.02 mg/L in water environment can cause health effects such as diarrhoea, encephalopathy, anaemia, hepatitis, kidney damage, lung damage, skin dermatitis, and malfunction of central nervous system. Nickel is easily accumulated into living organism since, it is non-biodegradable in nature. Thus, nickel ion from industry wastewater is reduced before discharge into the land and water environment (Kinhikar, 2012). Dermentzis, *et al*., 2011 studied the electrocoagulation process for removing nickel from industry wastewater. Ismail, *et al*., 2014 had assessed the nickel removal in an electroplating industry wastewater by ion exchange method. Nickel removed from industry wastewater was also studied by various researchers using different adsorbents (GáborBorbély and EndreNagy, 2009; Gizem, *et al*., 2015; Zahabi, *et al*., 2016). Application of reverse osmosis for removing nickel from industry wastewater was observed by Jessica*, et al*., 2015. Among various methods, the adsorption technique is widely used for treating industry wastewater because the cost of the methods is minimum (Wang and Peng, 2010; Kwon *et al*., 2010; Yadanaparthi *et al*., 2010). Common adsorbent used to remove various metal ions from various industrial wastewater are activated carbon (Satapathy and Natarajan, 2006; Wilson *et al*., 2006), biomaterial (Wan and Hanafiah, 2008), clay minerals (Wang *et al*., 2008; Vieira, *et al.,* 2010), zeolites (Wang and Peng, 2010). Though several adsorbent materials are available (Sivakumar and Shankar, 2015; Sivakumar, *et al*., 2016a), activated carbon adsorption is effectively used for removing various parameters from industrial wastewater (Sivakumar, *et al*., 2016b; Dimple, *et al*., 2016). The activated carbon has more powerful adsorbent than others because it has high number of pores, large surface area for adsorption. This study focused to remove nickel in an electroplating industry wastewater by bamboo activated carbon. The removal of nickel using bamboo activated carbon was done at various adsorbent dosages, agitation speeds, particle sizes and concentrations dilution. The functional groups available in a bamboo activated carbon before and after treatment were determined by fourier-transform infrared spectroscopy (FTIR) analysis. The experimentation on removal of nickel was validated with the removal of other associated parameters present in the electroplating industry wastewater at the same selected process parameters. Further, isotherm models were fixed to identify the bamboo activated carbon adsorption for removing nickel from electroplating industry wastewater. This study has been carried out in Vel Tech High Tech Dr.Rangarajan Dr.Sakunthala Engineering College, Avadi, Chennai, India for removing nickel from electroplating industry wastewater of Ambattur industrial estate, Chennai using bamboo activated carbon and the experimentation was done in the month of January 2018.

MATERIALS AND METHODS

Collection of bamboo

For the present study, the bamboo was collected from wood shop, Avadi, Chennai, Tamil Nadu, India. Bamboo (Bambusa vulgaris) is a fastest growing flowering plant species of in the family of Poaceae and in the sub family of Bambusoideae. It is used as building materials in the Asian continent. Parts of bamboo are hollow stems, thick rhizomes, shoots. More than 1000 species of same family are found in hot tropical and cool mountainous regions.

Characterization of bamboo activated carbon

The collected bamboo wood samples are broken into several pieces with the help of mechanical instruments. The cut pieces are transfer into muffle furnace to convert the activated carbon at the temperature of 400 °C and at 2 h contact time. The details of determination of various properties of bamboo activated carbon are as follows. The characteristics of bamboo activated carbon are presented in Table 1.

Bulk Density: The activity of carbon was measured by the property called bulk density (IS 877, 1989).

Moisture content: As per IS 877, 1989, the moisture content was determined from the collected bamboo. Moisture content was found with 10 g of the bamboo material placed in an electric oven at a temperature of 110 ± 5 °C with the time period of 4 h.

Particle size: There are four sieve sizes were selected for this study are 2.36, 1.18, 0.6 and 0.3 mm IS sieve. The material retained in a given sieve size was considered as the particle size (IS 877, 1989).

pH: pH was determined using pH meter. The procedures followed as per IS 877, 1989.

Hardness: It is used to measure the strength against the wear. It is measure against the particular sieve size as per the procedure of IS 877, 1989.

Decolorizing power: It is expressed in terms of mg of methylene blue adsorbed by 1 g of activated carbon as per IS 877, 1989.

Collection of wastewater sample

The aquatic system is disturbed when nickel electroplating industry wastewater is released directly into the surface water bodies. The nickel electroplating wastewater contains high nickel pollution along with other process parameters. The low pH is used for plating on metal surface using nickel ion leads to nickel ion retained in the wastewater along with acidic pH. The wastewater from the nickel electroplating industry was discharged on land leads the percolation of wastewater through porous medium and finally groundwater gets contaminated. The presence of nickel ion in land, water environment is more toxic when its concentration exceeds the permissible limits as prescribed by BIS effluent discharge standard. Thus, determination of physico-chemical parameters in a nickel electroplating industry wastewater is sued to access the quality of water for drinking, irrigation, fishing and industry purposes. The nickel electroplating industry wastewater collected, Ambattur Industrial Estate, Chennai with the help of sterilized bottles. The collected wastewater was stored in the Environmental engineering laboratory at the temperature of 5°C. The nickel from the electroplating industry wastewater was determined using flame atomic absorption spectroscopy (FAAS) with the adsorption wavelength of 232 nm. The

Table 1: Characteristics of bamboo activated carbon

S. No	Properties	Value
1	Bulk density	0.68
2	Moisture content	7.6
3	Particle size	2.36, 1.18, 0.6 and 0.3 mm
4	pH	8.21
5	Hardness	0.366
6	Decolorizing powder	570

Table 2: Physico-chemical characteristics of nickel electroplating industry wastewater

S. No.	Parameters*	Values	Permissible discharge limits for industrial effluents
1	pH	5.5	5.5-9.0
2	Biochemical Oxygen Demand (BOD)	174.5	30
3	Chemical Oxygen Demand (COD)	542.3	250
4	Chloride	643	250
5	Sulphates	412	200
6	Total Dissolved Solids (TDS)	4865	500
7	Nickel	132	3.0

*All parameters are expressed as mg/L except pH other physico-chemical characteristics of nickel electroplating industry wastewater were determined by the procedure stipulated in APHA, 2005. Table 2 indicates the main physico-chemical characteristics of nickel electroplating industry wastewater.

Sorption experiments

The role of bamboo to remove nickel in an electroplating industry wastewater was identified with the help of jar test apparatus. This study followed the batch mode adsorption experiments involving variations in adsorbent dosage of 0.5, 1.0, 1.5 and 2.0 g, agitation speeds of 25, 50, 75 and 100 rpm, particle size of 500, 230, 125 and 63 micron, concentrations dilution of 25, 50, 75 and 100 %. The 1000 mL capacity of glass beaker used to collect the electroplating industry wastewater and was placed on the jar test apparatus for running the experiment at various contact times against different process parameters. The treated samples were filtered with Whatman filter paper after 24 h. Nickel removal percentage in an electroplating industry wastewater by bamboo activated carbon against the different process parameters at various contact time was calculated by Eq. 1.

$$\text{Removal percentage} = \frac{(C_i - C_f)}{C_i} \text{x } 100 \qquad (1)$$

The nickel ion uptake by bamboo activated carbon against different process parameters at any contact time is calculated by Eq. 2.

$$q_t = \frac{(C_i - C_f)V}{C_i M} \qquad (2)$$

in which, q_t is quantity of nickel adsorbed onto bamboo activated carbon at any time 't' (mg/g); C_i and C_f are the initial and final nickel ion concentration at any time 't' in the wastewater (mg/L), respectively; V is volume of the wastewater treated (L); and M is the mass of bamboo activated carbon used for adsorption (g).

Langmuir isotherm model

In this model, the maximum adsorption capacity of absorbent for removing any metal ions against the various process parameters are calculated when surface of the adsorbent was fully saturated with the various ions and correspondingly energy is constant (Sivakumar, *et al*., 2015). The Langmuir model is formulated as Eqs. 3 and 4.

$$q_e = \frac{q_m k_L C_e}{1 + k_L C_e} \qquad (3)$$

The linear form of Eq. 3 may be written as

$$\frac{C_e}{q_e} = \frac{1}{K_L q_m} + \frac{C_e}{q_m} \qquad (4)$$

In which, C_e is equilibrium concentration of nickel from electroplating industry wastewater (mg/L), q_e is equilibrium adsorption capacity of nickel onto bamboo activated carbon (mg/g), q_m is maximum adsorption capacity of nickel onto bamboo activated carbon (mg/g) and K_L is the Langmuir isotherm equilibrium constant (L/mg). The q_m and K_L were calculated by plotting the graph between C_e/q_e and C_e such that the intercept gives K_L value and the slope gives the q_m value.

Freundlich isotherm model

The adsorption capacity of bamboo activated carbon for removing nickel from electroplating industry wastewater is calculated by Freundlich isotherm model and it indicates the multilayer sorption process. Freundlich adsorption isotherm is representing the amount adsorbed per unit mass of adsorbent at equilibrium (q_e), and concentration of the nickel at equilibrium (C_e). The mathematical model is described as Eq. 5 (Sivakumar, *et al*., 2016a; 2016b).

$$q_e = K_f C_e^{\frac{1}{n}} \qquad (5)$$

The Eq. 5 may be written in terms of logarithmic form and it is written as Eq. 6.

$$\text{Log } q_e = \log K_f + \frac{1}{n} \log C_e \qquad (6)$$

In which, K_f and n are the Freundlich constants and non-linearity exponent of the system respectively. Value of K_f and n are obtained by plotting the values of log C_e vs log q_e such that intercept gives value of K_f and slope gives value of n.

RESULTS AND DISCUSSION

Functional groups of bamboo activated carbon was identified with the help of FTIR analysis and the prepared bamboo activated carbon used for conducting experimental investigations on removal of nickel form electroplating industry wastewater. The experimental investigations were conducted with Phipps & Bird Jar apparatus for various adsorbent dosages, agitation speeds, particle sizes, and concentration dilutions with various contact time against the pH of 5.5. The results are presented below.

FTIR analysis

Carboxyl, amide, alkaline, hydroxyl, aldehydes alkanes, alkyls are the various chemical functional groups, that are responsible for adsorption process. These functional groups are identified by fourier-transform infrared spectroscopy (FTIR). The uptake of metals onto the adsorbent depends on the availability of sites, chemical state, and affinity between metal ions with adsorption sites. The adsorbent spectra (functional groups) in the form of large numbers of peaks were measured by using Perkin Elmer spectrum in the range between 400 and 4000 cm[1]. Several previous studies identified the functional groups from activated carbon prepared from various sources. Ince, 2014 was identified the functional groups of clay mineral using FTIR analysis for removing nickel. Nanomagnetite was characterized by FTIR, SEM and XRD analyses for removing heavy metals in an aqueous solution (Karami, 2013). Vieira *et al*., 2010 characterized the bofe bentonite clay using FTIR, XRD, BET and energy dispersion X-ray (EDX) analyses for removing nickel from aqueous solution. *Trichoderma viride* biosorbent was described by FTIR analysis and SEM analysis (Sujatha, *et al*., 2013) for removing nickel from aqueous solution.

Functional groups before Adsorption

From Fig. 1, it may be witnessed that the wave length varied between 582.39 and 3418.21/cm and the functional groups were identified as alkyl, alkyl halides, alkanes, aldehydes, carboxylic acids and amides. The wavenumbers 582.39 and 557.32/cm show that it has alkyl halides functional group. The wavenumber 1054.87/cm shows that it has assigned to be alkyl halides or primary alcohol functional group. The wavenumber 1107.90/cm shows that it has assigned to be alkyl halides or secondary alcohol functional group. The wavenumbers 1158.04, 1238.08 and 1329.68/cm show that it has assigned to be alkyl halides or tertiary alcohol functional group.

The wavenumber 1381.75/cm shows that it has alkanes and alkyls functional group. The wavenumber 1452.14/cm shows that it has assigned to be alkanes and alkyls or aromatic compounds functional group. The wavenumbers 1488.78, 1511.92, and 1537.95/cm show that it has aromatic compounds functional group. The wavenumber 1636.18/cm shows that it has assigned to be aldehydes or carboxylic acids functional group. The wavenumber 2925.48/cm shows that it has alkanes and alkyls functional group. The wavenumber 3418.21/cm shows that it has assigned to be amides or carboxylic acids functional group.

Functional groups after adsorption

The wavelength was shifted because of the adsorption of nickel onto the bamboo activated carbon. The new functional groups identified on the bamboo activated carbon are esters functional groups. The wavenumber 447.40, 557.32, 653.75, and 678.82/cm shows that it has alkyl halides functional group (Fig. 2). The wavenumber1031.73 and 1256.4/cm shows that it has assigned to be alkyl halides or esters functional groups. The wavenumber 1117.56/cm shows that it has assigned to be alkyl halides or tertiary alcohol functional group. The wavenumber 1238.08/cm shows that it has

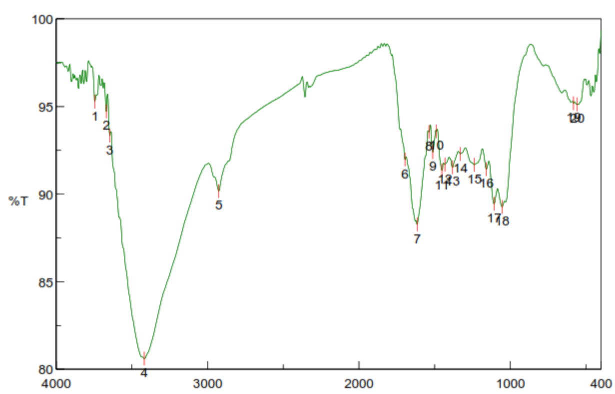

Fig. 1: FTIR spectrum of bamboo activated carbon before adsorption

assigned to be alkyl halides or tertiary alcohol functional group. The wavenumber 1379.18/cm shows that it has only alkyl halides functional group.

The wavenumber 1450.21/cm shows that it has assigned to be alkanes and alkyls or aromatic compounds functional group. The wavenumbers 1507.1 and 1536.99, 1560.13/cm show that it has aromatic compounds functional group. The wave number 1594.84/cm shows that it has assigned to be aromatic compounds, amides or amines functional group. The wavenumber 1650.77/cm shows that it has only amides functional group. The wave number 1696.09/cm shows that it has assigned to be aldehydes or carboxylic acid functional group. The wavenumber1727.91 shows that it has esters functional group. The wavenumber 2963.56/cm shows that it has Alkanes and alkyls functional group. The wavenumber 3532.39/cm shows that it has assigned to be amides or amines of or carboxylic acids functional group. The wavenumber from 582.39 to 1329.68/cm (before adsorption by bamboo activated carbon), was shifted to the range between 447.40 and 1379.18 (after adsorption) for alkyl halides functional group. The wavelength 1381.75/cm of alkanes and alkyls functional group before treatment was shifted for after treatment to 1450.21/cm. The wavelength from 1452.14/cm in before treatment shifted to the wavelength after treatment 1594.84/cm for aromatic compounds, amides or amines functional group. The wavelength from 1636.18/cm was moved to 1696.09/cm for aldehydes or carboxylic acid functional group. Further, the wavelength from 3418.21/cm was lifted to 3532.39/cm for amides or amines of or carboxylic acids functional group.

Effect of adsorbent dosage

Fig. 3 shows influence of bamboo activated carbon for removing nickel from electroplating industry wastewater against the adsorbent dosage. Chosen adsorbent dosages for this study are 0.5, 1.0, 1.5 and 2.0 g/L. Further, the effect of adsorbent dosage was done against the agitation speed of 25 rpm, the particle size of 0.3 mm and the concentration dilution of 0 % (original wastewater concentration) with pH 5.5 and contact time 60 min. From Fig. 3, it may be found that for low adsorbent dosages, removal was low and it was steadily increased with increased adsorbent dosage. This low adsorbed percentage was due to the complete utilization of supplied adsorbent dosage for removing nickel from electroplating industry wastewater. The removal was increased as supplied adsorbent dosage was increased. It may be noted that upto 1.5 g, the removal was increased beyond which, there was no such variation on removal of nickel from electroplating industry wastewater by bamboo activated carbon. Thus, the maximum removal of nickel from electroplating industry wastewater using bamboo activated carbon is found to be 1.5 g and it is considered as optimum adsorbent dosage. The removal of nickel from electroplating industry wastewater for adsorbent dosages of 0.5, 1.0, 1.5 and 2.0 g was found to be 43.3, 51.8, 57.9, and 58.1 % respectively (Fig. 3). Thus, the maximum uptake of nickel from electroplating industry wastewater using bamboo activated carbon at an optimum adsorbent dosage of 1.5 g is 76.43 mg/L and corresponding residue in the electroplating industry wastewater is 55.57 mg/L.

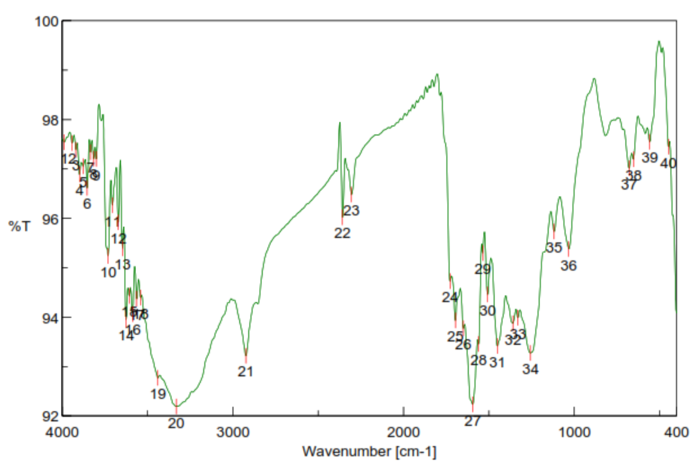

Fig. 2: FTIR spectrum of bamboo activated carbon after adsorption

Effect of agitation speed

Fig. 4 shows influence of bamboo activated carbon for removing nickel from electroplating industry wastewater against the agitation speed. Chosen agitation speed for this study are 25, 50, 75 and 100 rpm. Further, the effect of agitation speed was done against the optimum adsorbent dosage of 1.5 g, the particle size of 0.3 mm and the concentration dilution of 0 % (original wastewater concentration) with pH 5.5 and contact time 60 min. From Fig. 4, it may be found that for low agitation speed, removal was low and it was steadily increased with increased agitation speed. This low adsorbed percentage at low agitation speed was due to lack of affinity of adsorbent with the nickel ion present in the electroplating industry wastewater. The removal was increased as agitation speed was increased. It may be noted that upto 75 rpm, the removal was increased beyond which, there was no such variation on removal of nickel from electroplating industry wastewater by bamboo activated carbon. Thus, maximum removal of nickel from electroplating industry wastewater using bamboo activated carbon is found to be 75 rpm and it is considered as optimum agitation speed. The removal of nickel from electroplating industry wastewater for agitation speeds of 25, 50, 75 and 100 rpm was found to be 48.3, 59.4, 66.8, and 66.9 % respectively (Fig. 4). Thus, the maximum uptake of nickel from electroplating industry wastewater using bamboo activated carbon at an optimum agitation speed of 75 rpm is 88.18 mg/L and corresponding residue in the electroplating industry wastewater is 43.82 mg/L.

Effect of particle size

Fig. 5 shows influence of bamboo activated carbon for removing nickel from electroplating industry wastewater against the particle size. Chosen particle size for this study are 2.36, 1.18, 0.6 and 0.3 mm.

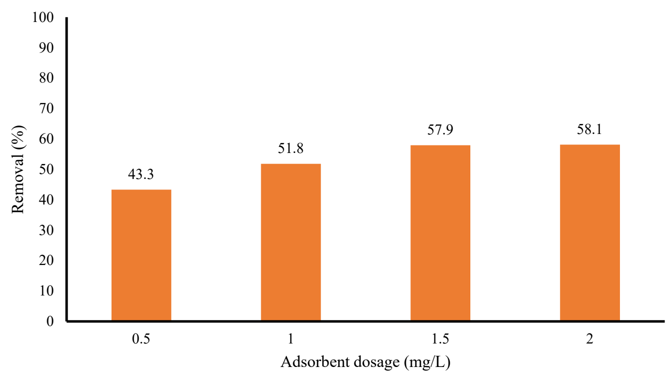

Fig. 3: Influence of bamboo activated carbon for removing nickel from electroplating industry wastewater against the adsorbent dosage

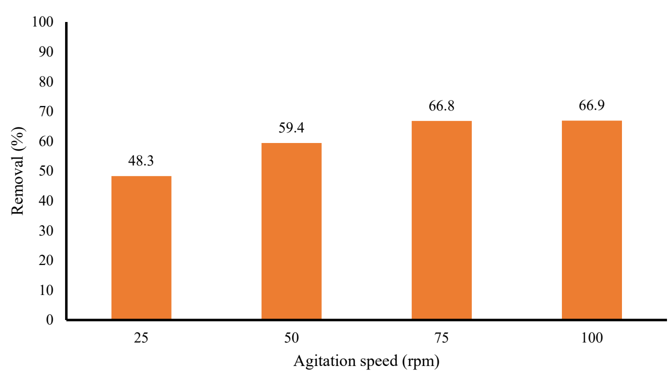

Fig. 4: Influence of bamboo activated carbon for removing nickel from electroplating industry wastewater against the agitation speed

Further, the effect of particle size was done against the optimum adsorbent dosage of 1.5 g, optimum agitation speed of 75 rpm and the concentration dilution of 0 % (original wastewater concentration) with pH 5.5 and contact time 60 min. From Fig. 5, it may be found that for large particle size, removal was low and it was steadily increased with decreased particle size. This low adsorbed percentage at large particle size was due to less surface area, less pore volume of bamboo activated carbon. The removal was increased as particle size reduced. It may be noted that upto 0.6 mm particle size, the removal was increased beyond which, there was no such variation on removal of nickel from electroplating industry wastewater by bamboo activated carbon. Thus, maximum removal of nickel from electroplating industry wastewater using bamboo activated carbon is found to be 0.6 mm and it is considered as optimum particle size. The removal of nickel from electroplating industry wastewater for particle sizes of 2.36, 1.18, 0.6 and 0.3 mm was found to be 56.8, 68.9, 75.3, and 75.5 % respectively (Fig. 5). Thus, the maximum uptake of nickel from electroplating industry wastewater using bamboo activated carbon at an optimum particle size of 0.6 mm is 99.4 mg/L and corresponding residue in the electroplating industry wastewater is 32.6 mg/L.

Effect of concentration

Fig. 6 shows influence of bamboo activated carbon for removing nickel from electroplating industry wastewater against the concentration dilution. Chosen concentration dilution for this study are 0, 25, 50, 75 and 100 %. Further, the effect of concentration dilution was done against the optimum adsorbent dosage of 1.5 g, optimum agitation speed of 75 rpm and optimum particle size of 0.6 mm with pH 5.5 and contact time 60 min. From Fig. 6, it may be found that for the higher concentration, removal of nickel by bamboo activated carbon was low and it was steadily increased with increased dilution ratio. Since, at higher dilution, the metal ions are dispersion easily and the same was adsorbed by the bamboo activated carbon, results higher the adsorption removal percentage. The removal was increased as concentration dilution ratio increased. It may be noted that upto 75 % concentration dilution, the removal was increased beyond which, there was no such variation on removal of nickel from electroplating industry wastewater by bamboo activated carbon. Thus, maximum removal of nickel from electroplating industry wastewater using bamboo activated carbon is found to be 75 % and it is considered as optimum concentration dilution. The removal of nickel from electroplating industry wastewater for concentration dilution ratios of 0, 25, 50, 75 and 100 % was found to be 64.8, 72.1, 79.3, 86.2, and 86.4 % respectively (Fig. 6). Thus, the maximum uptake of nickel from electroplating industry wastewater using bamboo activated carbon at an optimum concentration dilution of 75 % is 113.78 mg/L and corresponding residue in the electroplating industry wastewater is 18.22 mg/L.

Equilibrium study

Mono layer adsorption and multilayer adsorption by various adsorbents was identified by the Langmuir and Freundlich isotherm models respectively. The equilibrium study was conducted to remove nickel ion from electroplating industry wastewater at the optimum adsorbent dosage of 1.5 g, agitation speed 75 rpm, and particle size of 0.6 mm and the concentration dilution of

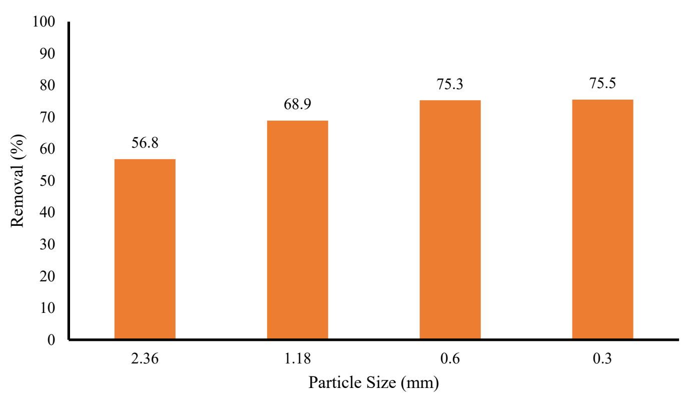

Fig. 5: Influence of bamboo activated carbon for removing nickel from electroplating industry wastewater against the particle size

75 % with the pH of 5.5 against various contact time. Fig. 7 shows the influence of bamboo activated carbon for removing nickel ion from electroplating industry wastewater at an optimum process parameters against various contact time. From Fig. 7, it may be noted that as concentration reduced, nickel ions removal from electroplating industry wastewater by bamboo activated carbon reduced. The removal percentage was increased up to the concentration dilution of 75 %, beyond which there was no such variation in reduction of nickel ion from the electroplating industry wastewater using bamboo activated carbon. Further, up to 110 min. of contact time, the reduction nickel ion increased and beyond 110 min. contact time, there was no such variation. Hence, contact time of 110 min. is considered as optimum contact time. Thus, the maximum uptake of nickel from electroplating industry wastewater using bamboo activated carbon is found to be 130.15 mg/L (98.7 %) and corresponding residue in the electroplating industry wastewater is 1.85 mg/L (Fig. 7) for the optimum adsorbent dosage of 1.5 g/L, agitation speed 75 rpm, particle size of 0.6 mm, concentration dilution of 75 % and the contact time of 110 min.

Adsorption isotherm models

Isotherm adsorbent models were used to design the adsorption system between adsorbate and adsorbent (Malarvizhi, *et al*., 2013). The equilibrium concentration of nickel in an electroplating industry wastewater for various concentration dilutions (Fig. 7) was used in the Langmuir and Freundlich adsorption isotherm models. For developing sorption isotherm models, varying the initial concentration of nickel electroplating industry wastewater and keeping

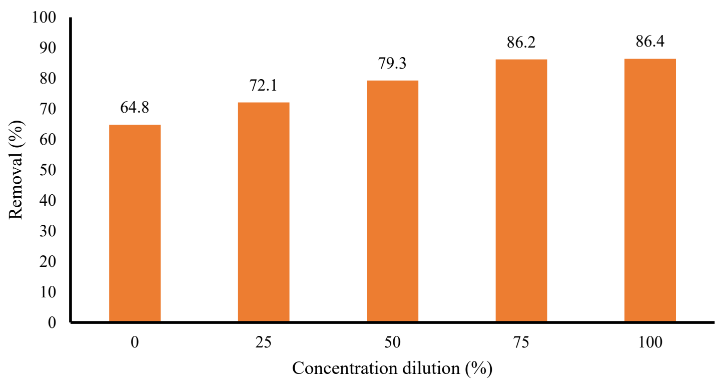

Fig. 6: Influence of bamboo activated carbon for removing nickel from electroplating industry wastewater against the concentration dilution

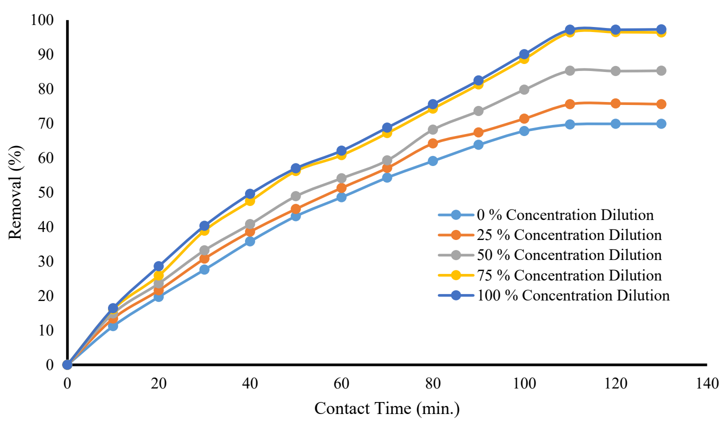

Fig. 7: Influence of bamboo activated carbon for removing nickel ion from electroplating industry wastewater at an optimum process parameters values against various contact time with the pH of 5.5

constant for all other associated parameters present in the nickel electroplating industry wastewater. The Langmuir and Freundlich isotherm models are depicted in Figs. 8 and 9 respectively.

Langmuir adsorption isotherm model (Fig. 8) indicated that equilibrium experimental data fits well to Langmuir model equation with R^2 value of 0.9976. The values of Langmuir constant q_m and K_L are obtained as 61.35 mg/g and 1.34 L/mg respectively for nickel removal from electroplating industry wastewater against the different concentration dilution with the pH of 5.5 and an equilibrium contact time of 110 min. Freundlich adsorption isotherm model (Fig. 9) indicated that equilibrium experimental data fits well to Freundlich model equation with the R^2 value of 0.7538. The values of Freundlich constant K_f and n are obtained as 1.02 and 35.46 respectively for the nickel removal from electroplating industry wastewater against the different concentration dilution with the pH of 5.5 and equilibrium contact time of 110 min. From Figs. 8 and 9, it was established that Langmuir isotherm fitted well with equilibrium experimental data than Freundlich isotherm model. From Langmuir isotherm (Fig. 8), it was found that the adsorption of nickel from electroplating industry wastewater using bamboo activated layer is monolayer adsorption. Further, dimensionless constant R_L can also be used to determine, if adsorption is favarouble or unfavourable for Langmuir isotherm model. It is formulated as Eq. 7.

$$R_L = \frac{1}{1 + k_L C_i} \quad (7)$$

It is established that when $R_L > 1$ shows unfavourable adsorption, $R_L = 1$ shows linear adsorption, $0 < R_L < 1$, shows favourable adsorption and $R_L = 0$ shows irreversible adsorption. In this study, R_L value shows 0.0058 (R_L values are between 0 and 1) indicated the favourable adsorption process. As similar to Langmuir

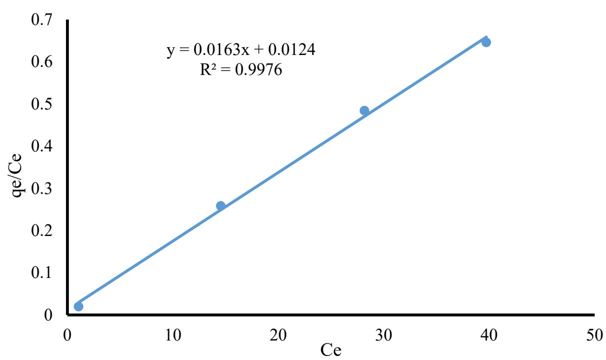

Fig. 8: Langmuir isotherm model for removing nickel from electroplating industry wastewater using bamboo activated carbon

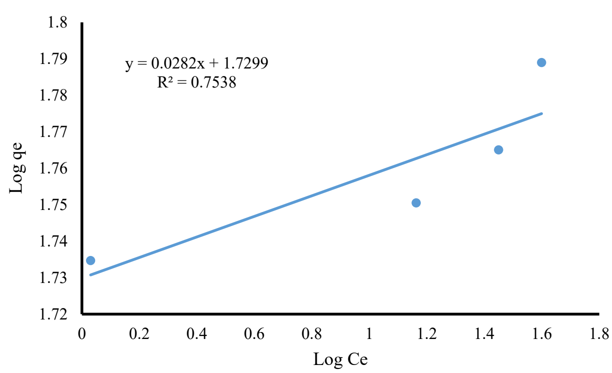

Fig. 9: Freundlich isotherm model for removing nickel from electroplating industry wastewater using bamboo activated carbon

isotherm, 1/n can be used for finding if the adsorption is favourable or unfavourable for Freundlich isotherm model. From Fig. 9, it was noted that the 1/n value is less than 1, indicated that adsorption is favourable, but the correlation between the model and equilibrium data, the study suggested that Langmuir adsorption isotherm model is most suited model for determining maximum uptake of nickel from electroplating industry wastewater using bamboo activated carbon. The Langmuir and Freundlich isotherm parameters based on the equilibrium experimental data are presented in Table 3.

Validation of experimentation

The associated parameters in any water and wastewater influenced the removal percentage of particular ions. Vijayaraghavan, *et al*., 2004 observed that the other ions like copper, cobalt, zinc and magnesium was influenced the nickel removal efficiency using crab shell. This study also validates the experimentation on removal percentage of nickel from electroplating industry wastewater with associated parameters. The removal of associated parameters from the electroplating industry wastewater was determined at the optimum adsorbent dosage of 1.5 g/L, agitation speed 75 rpm, particle size of 0.6 mm and concentration dilution of 75 % with pH 5.5 and contact time 110 min. The percentage removal of associated parameters from electroplating industry wastewater using bamboo activated carbon is presented in Table 4.

From Table 4, it may be concluded that the an optimum adsorbent dosage of 1.5 g, agitation speed 75 rpm, particle size of 0.6 mm and concentration dilution of 75 % with the pH of 5.5 and contact time of 110 min. effectively used for removing nickel and associated parameters from electroplating industry wastewater using bamboo activated carbon. The maximum uptake of nickel by different adsorbents is presented in Table 5.

In addition to previous studies concentrated for nickel removal from wastewater and aqueous solution (Table 5), Ince, 2014 studied the maximum removal was observed as 19.4 mg/g of nickel on to clay mineral in an aqueous solution. Further, Ince, 2014 used tea waste, astragalus plant and chestnut shell for removing nickel from aqueous solution with adsorption capacity of 5.4, 1.3 and 5.6 mg/g respectively. Karami, 2013, studied nickel removal from an aqueous solution using nanomagnetite and the adsorption capacity was observed to be 95.42 mg/g. Qi and Aldrich, 2008 reported that tobacco dust was successfully used to remove nickel in an aqueous solution 24.5 mg/g of maximum removal efficiency. The maximum uptake of 192.3 mg/g of nickel was removed by nettle ash from wastewater (Zavvar and Seyedi, 2011). The adsorption capacity of granular activated carbon for removing nickel from aqueous solution was found to be 7.65 mg/g (Dimple, *et al*., 2016). The maximum adsorption capacity of oil cake activated carbon for nickel removal in a wastewater was observed as 54.95 mg/g (Hema and Srinivasan, 2010). The adsorption maximum capacity of *T. viride* was observed as 47.6 mg/g for nickel ion at the pH of 4.5 (Sujatha, *et al*., 2013). In this study, maximum removal of nickel from electroplating

Table 3: Langmuir and Freundlich isotherm parameters for removing nickel from electroplating industry waster using bamboo activated carbon

Type of adsorption isotherm model	Parameters
Langmuir Isotherm Parameters	q_m = 61.35 mg/g K_L = 1.34 L/mg R_L = 0.0058 R^2 = 0.9976
Freundlich Isotherm Parameters	K_f= 1.02 1/n = 35.46 R^2 = 0.9976

Table 4: Percentage removal of associated parameters from electroplating industry wastewater using bamboo activated carbon

Sl. No.	Parameters	Percentage removal (%)
1	Biochemical oxygen demand	94.6
2	Chemical oxygen demand	88.4
3	Chloride	90.2
4	Sulphates	92.6
5	Total dissolved solids	96.7

Table 5: Maximum adsorption capacity by different adsorbents

S. No	Adsorbents	q_m (mg/g)	References
1	Peat	61.27	Wilson, *et al*., 2006
2	Tobacco dust	24.50	Qi and Aldrich, 2008
3	Oil cake activated carbon	54.95	Hema and Srinivasan, 2010
4	Holly sawdust	22.47	Samarghandi, 2011
5	Papaya seeds	30.58	Hema and Swamy, 2011
6	Araucaria cookie	37.03	Deepa, and Suresha, 2014
7	Pentaclethra macrophylla shell	2.45	Adeyemi and Dauda, 2014
8	Tea waste	5.40	Ince, 2014
9	Astragalus plant	1.30	Ince, 2014
10	Chestnut shell	5.60	Ince, 2014
11	Coconut coir pith	24.39	Ratan, *et al*., 2016
12	Mango leaf powder	16.62	Rajiv and Sarah, 2017
13	Coal fly ash	3.25	Ahmad, *et al*., 2017
14	Bamboo activated carbon	61.35	**Present study**

industry wastewater was at pH 5.5. But, maximum sorption capacity of nickel in an aqueous solution was observed at pH 4.5 (Vijayaraghavan, *et al*., 2004) and maximum removal of nickel in an aqueous solution using *Trichoderma viride* was obtained at the pH of 4.5 (Sujatha, *et al*., 2013). The variation of pH between this study and previous studies are due to presence of associated parameters in the electroplating industry wastewater than the aqueous solution. Maximum removal of nickel from electroplating industry wastewater using bamboo activated carbon was observed in this study as 98.7 %. Dimple, *et al*., 2016 studied the nickel removal using activated carbon from an aqueous solution with the efficiency of 87.52 %. The Maximum removal percentage of nickel in an aqueous solution using Leaves of *Araucaria cookie* was found to be 96.95 % at pH of 6 with 40 min. contact time. In this study, amine, hydroxyl and alcoholic functional groups in bamboo activated carbon was involved for removing nickel from the electroplating industry wastewater. Further, an electrostatic attraction of nickel ions onto various oxygen containing functional groups is the main property for removing nickel from electroplating industry wastewater (Muharrem and Ince, 2017). The same observation was made by Sujatha, *et al*., 2013. The Langmuir model was used for predicting maximum nickel uptake when situation was not suitable for determining the nickel concentration using experimental investigation. Further, the Langmuir constant depends on the pH values, as pH values are increased, the both Langmuir constant and maximum nickel uptake also increased (Vijayaraghavan, *et al*., 2004).

CONCLUSION

This study concentrated for nickel removal from electroplating industry wastewater using bamboo activated carbon. The selected process parameters for this study are adsorbent dosages, agitation speeds, particle sizes and concentration dilutions. The characterization of bamboo activated carbon indicated that the prepared carbon is having good properties for removing nickel from electroplating industry wastewater. The results revealed that the maximum removal of nickel (98.7 %) from electroplating industry wastewater using bamboo activated carbon was observed at an optimum adsorbent dosage of 1.5 g/L, optimum agitation speed of 75 rpm, optimum particle size of 0.6 mm, and optimum concentration dilution of 75% with the contact time of 110 min. and pH of 5.5. From FTIR analysis, alkanes, carboxylic acids, esters, amides, amines, aromatic compounds, alkyl halides, ethers, alcohols, carboxylic acids, aldehydes functional groups in bamboo activated carbon was contributed for removing nickel from the electroplating industry wastewater. The equilibrium experimental data was fitted to isotherm models and model results indicated that Langmuir adsorption isotherm model is fitted well (R^2=0.9976) with equilibrium experimental data than the Freundlich adsorption isotherm model. Because of high adsorption capacity of bamboo activated carbon and low cost of preparation, it may be used to purify water. The weak acid ion exchange character of bamboo activated carbon is effectively used for removing various ions present in any type industry wastewater. The capacity of bamboo activated carbon for removing nickel is increased by activating the carbon with both acidic and alkaline solutions. Thus, this study concluded that the bamboo activated carbon is best suited for removing not only nickel, any type of metal ions and other associated ions from any type of industry wastewater.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript.

ABBREVIATIONS

%	Percentage
°C	Degree centigrade
APHA	American Public Health Association
BET	Brunauer, Emmett and Teller
BOD	Biochemical oxygen demand
cm	Centimetre
COD	Chemical oxygen demand
Eq.	Equation
FAAS	Flame atomic absorption spectroscopy
Fig.	Figure
FTIR	Fourier-transform infrared spectroscopy
g	Gram
g/L	Gram per litre
h	Hour
IS	Indian standard
L/mg	Litres per milligram
mg/g	Milligram per gram
mg/L	Milligram per litre
min.	Minute
mL	Millilitre
mm	Millimetre
nm	Nanometre
pH	Potential of hydrogen
rpm	Revolution per minute
SEM	Scanning electron microscopy
TDS	Total dissolved solids
WHO	World Health Organisation
XRD	X-ray diffractometry

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