



Study on Removal of Cadmium(II) Ions from Wastewater Using Activated Carbon of *Salvadora persica* Stem

Vimla Chaudhary, Kanchan Deep Chaudhary, Nirmal Godara and Bhanupriya Mordhiya

Department of Chemistry, J. N. V. University, Jodhpur, Rajasthan, India

Corresponding Author: Kanchan Deep Chaudhary

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 23-11-2013

Accepted: 16-1-2014

Key Words:

Heavy metals

Water treatment

Adsorption

Salvadora persica

ABSTRACT

The effective removal of heavy metals from industrial wastewater is among the most important issues for many industrialized countries. Removal of cadmium(II) from aqueous solutions was studied using activated carbon made from stems of *Salvadora persica*. Batch adsorption experiments were performed as a function of pH, contact time, solute concentration and adsorbent dose. The optimum pH required for maximum adsorption was found to be 5 for cadmium. The maximum contact time for the equilibrium condition is 180 min at the sorbent dose rate of 2.5 g. The maximum efficiency of cadmium removal by activated carbon was found to be 81.7%. The results were well fitted with both Langmuir and Freundlich isotherm models.

INTRODUCTION

Heavy metals accumulate in living tissues throughout the food chains, which have humans at their top. These toxic metals can cause accumulative poisoning, cancer and brain damage when found above the tolerance level. The presence of cadmium in drinking water above the permissible limit (5 mg/mL) may cause adverse health effects such as anaemia, encephalopathy, hepatitis and nephritic syndrome. Hence, it is very important that it should be removed from wastewater (Potgieter et al. 2006). The major advantages of adsorption technology are its effectiveness in reducing the concentration of heavy metal ions to very low levels and the use of inexpensive adsorbent materials (Saeed et al. 2005, Singanan et al. 2007, Tien 2002). Adsorption processes are particularly suitable for the treatment of wastewater containing low concentrations of heavy metals (Feng & Aldrich 2004).

In this study an attempt was made to determine the effectiveness of the activated carbon prepared from stem of the plant *Salvadora persica*. It was used to remove cadmium from synthetic wastewater and to investigate the mechanisms of adsorption onto activated carbon by performing a batch experimental process (Hall et al. 1996, Axtell et al. 2003).

MATERIALS AND METHODS

Preparation of synthetic wastewater: Synthetic wastewater sample was prepared by using analytical grade cadmium nitrate. For pH adjustment throughout the experiment, hydrochloric acid and/or sodium hydroxide solutions were

used as necessary. The stock solution contained 2 g/L of Cd(II).

Carbon preparation: Stem of plant *Salvadora persica* was collected and air dried for 48 h. Activated carbon of the *S. persica* was prepared by treating the pieces of stem with the concentrated sulphuric acid (5 times its volume) and kept in oven at 150°C for 24 hours. It was filtered and washed with distilled water repeatedly to remove sulphuric acid (washing tested with two drops of barium chloride solution) and finally dried in oven at 300°C, and powered using mortar and pestle. The resulting black product was kept in an air-free oven maintained at 300°C for 5 h. The particle size of the activated carbon between 40 and 60 mesh size was used. Batch experiments were performed at 27°C (Hall et al. 1996). Then samples were mechanically agitated at 100 rpm. The concentration of cadmium was estimated.

RESULTS AND DISCUSSION

Effect of pH: The pH is one of the most important parameters of adsorption of heavy metals. The adsorption of cadmium by activated carbon of *S. persica* at different pH levels is presented in Fig. 1. In the present investigation, the rate of removal of Cd(II) ions in synthetic wastewater is mainly controlled by pH of the solution. The optimal pH for Cd(II) removal was 5. At pH higher than 5 metal was precipitated due to the formation of hydroxides and removal due to sorption was very low. At low pH the concentration of protons was high and metal binding sites became positively charged repelling the Cd(II) cations. With an increase in pH (Ho

2005), the negative charge density on the activated carbon increases due to deprotonation of the metal binding sites, thus increasing metal sorption.

Effect of amount of activated carbon: It is important to fix the amount of the activated carbon of the adsorbent to design the optimum treatment systems and for a quick response of the analysis. To achieve this aim, a series of batch experiments were conducted with the adsorbent dose of 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 g per 100 mL of test solution. When the addition of the adsorbent dose increased, the percentage removal of metal ions also increased. Maximum removal of 81.7% of cadmium was obtained at 2.5 g of the activated carbon. It can be seen from Fig. 2 that an adsorbent dose of 2.5 g is sufficient for optimal removal of metal in aqueous solutions. A further increase in the quantity of activated carbon dose will not have any significant effect on the removal of cadmium ions from the solution.

Effect of contact times: After optimization of the adsorbent dose at 2.5 g per 100 mL test solution and the pH at 5 for cadmium ion solution, the effect of contact time for the efficient removal of metal ions was studied. The metal showed a steady rate increase of sorption during the sorbate-sorbent contact process and the rate of removal became almost insignificant due to a quick exhaustion of the adsorption sites. The rate of metal removal is higher in the beginning due to a larger surface area of the adsorbent being available for the adsorption of the metal. In this study 81.7% removal of cadmium was achieved at 150 min. Further, no significant changes were observed in the removal of metal ions from the solution after 24 h of equilibration (Fig. 3).

Effect of metal ions concentration: The metal uptake mechanism is particularly dependent on the heavy metal concentration. Initial concentration of 60 mg/L of metal ions was selected for Cd(II). Fig. 4 shows the effect of metal ion concentration on the removal of cadmium ions. At the metal ion concentration of 60 mg/L and the optimum dose of 2.5 g of the activated carbon, the maximum removal of Cd(II) was achieved within 150 min. This observation clearly indicates that the removal of metal ions purely depends on the amounts of adsorbent and contact time. The heavy metals are adsorbed by specific sites provided by the acidic functional groups on the activated carbon, while with increasing metal concentrations the specific sites are saturated and the exchange sites due to excessive surface area of the activated carbon are filled. It is clear that with increasing initial concentrations, the metal removal decreases.

Adsorption isotherms: The adsorption isotherms are very important in describing the adsorption behaviour of solutes on the specific adsorbents. In this work, two important iso-

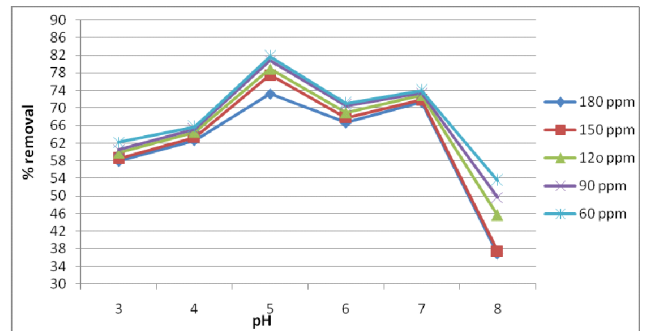


Fig 1: Effect of pH on removal of Cd(II) ions at time 150 min and adsorbent dose 2.5g.

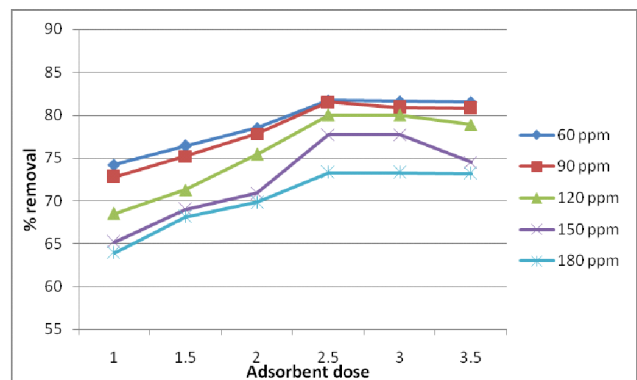


Fig 2: Effect of adsorbent dose on removal of Cd(II) ions at pH5, contact time 150 min.

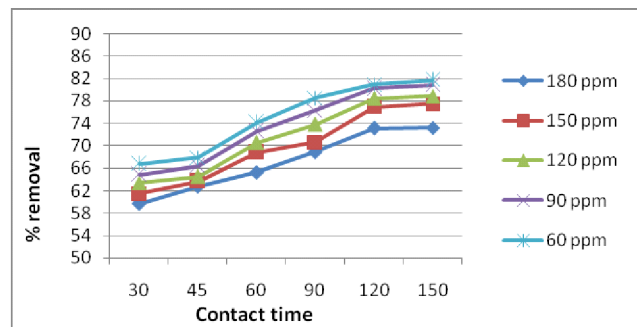


Fig 3: Effect of contact time on removal of Cd(II) ions at pH 5 and adsorbent dose of 2.5g.

therm models such as Langmuir and Freundlich were selected and studied

Langmuir isotherm: The Langmuir isotherm (Langmuir 1916) takes an assumption that the sorption occurs at specific homogeneous sites within the adsorbent.

A general form of the Langmuir equation is:

$$q_e = q_m \frac{b C_e}{1 + b C_e} \quad \dots(1)$$

The linear form of isotherm equation can be written as

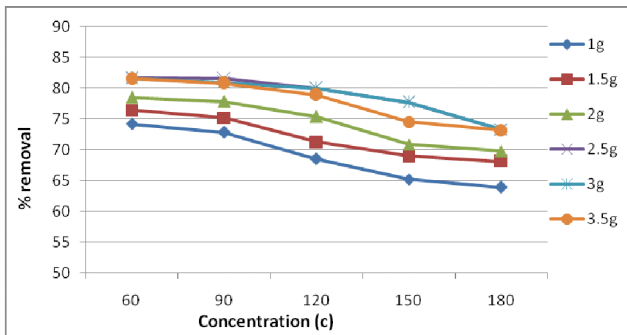


Fig 4: Effect of metal ion concentration on removal of Cd(II) ions at pH 5, for 150 min.

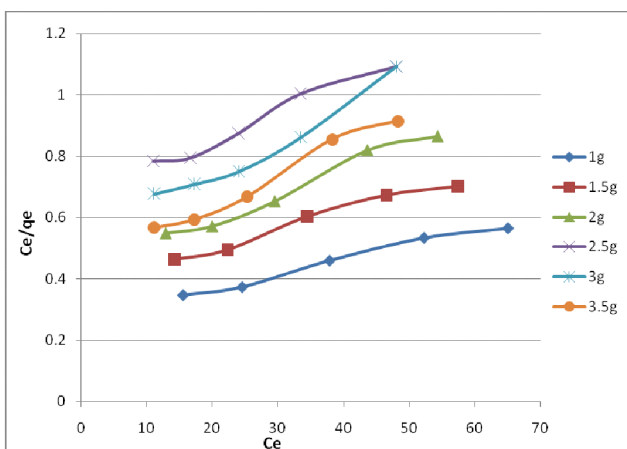


Fig. 5: Langmuir adsorption isotherm for Cd(II) ions (Ce/q_e vs Ce).

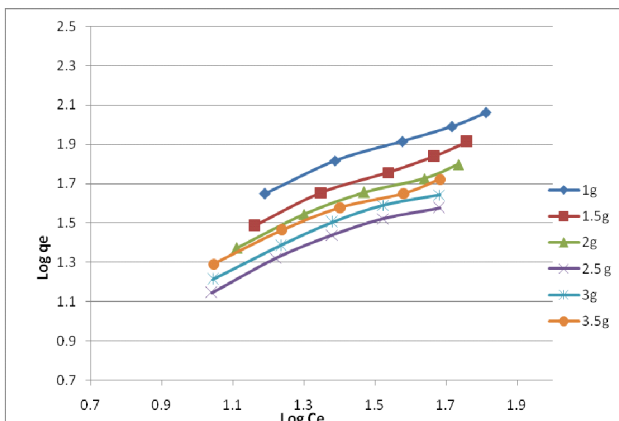


Fig. 6: Freundlich isotherm for Cd(II) adsorption (Log (q_e) vs Log (C_e)).

$$C_e/q_e = 1/q_0 b + C_e/q_0 \quad \dots(2)$$

Where, q₀ = maximum metal uptake corresponding to the saturation capacity of the adsorbent; b = energy of adsorption; q_e = the amount of metal adsorbed on the activated carbon at equilibrium; C_e = equilibrium metal

concentration in the solution.

The constants q₀ and b are the characteristics of the Langmuir isotherm and can be determined from eq. (2). Therefore, a plot of C_e/q_e versus C_e gives a straight line of slope (1/q₀) and intercept (1/bq₀). The data fit the Langmuir isotherms model well for Cd(II) ions. The values of Langmuir parameters for the removal of Cd(II) metal ions are presented in Table 1. The linearity of the plot (Fig. 5) indicates application of the Langmuir equation, supporting monolayer formation on the surface of the adsorbent. The values of b and q₀ indicate that the adsorption of the metal ions is concentration and pH dependent. The expression of separation factor (RL) in the dimensionless form of the Langmuir isotherm is:

$$RL = 1/(1 + b C_0)$$

Where, C₀ is the initial concentration of metal ion and b is the Langmuir constant. The separation factor (RL) can be used to predict affinity between the sorbate and sorbent in the adsorption system. The characteristics of the RL value indicates the nature of adsorption as:

- Unfavourable when (RL > 1)
- Linear when (RL = 1)
- Favourable when (0 < RL < 1)
- Irreversible when (RL = 0)

It is well observed that, in all the selected concentrations of metal ion, the separation factor (RL) is less than 1.0 indicating the favourable adsorption conditions.

Freundlich isotherm: The Freundlich expression is an empirical equation based on a heterogeneous surface. The general form of Freundlich equation is:

$$q_e = K_f C_e^{1/n}$$

and the linearized form of this model is:

$$\log q_e = \log K_f + 1/n \log C_e$$

Where,

log K_f = the intercept, measure of adsorption capacity

1/n = the slope the intensity of adsorption

q_e = amount of metal ion adsorbed at the equilibrium

C_e = metal ion concentration in solution at equilibrium

The n should have values lying in the range of 1 to 10 for classification as favourable adsorption.

The Freundlich adsorption model is presented in Fig. 6. It is also observed that the Freundlich isotherm model is well fitted for the metal ions.

REFERENCES

Aksu, Z. 2001. Equilibrium and kinetic modelling of cadmium (II)

Table 1: For Langmuir isotherm.

m	$Q_0=1/m$	C=intercept	$Q_0 * C$	b	bC_0	$1+bC_0$	$RI=1/1+bC_0$
0.004	250	0.272	68	0.0147	0.882	1.882	0.53134
0.006	166.66	0.379	63.164	0.01583	0.9498	1.9498	0.51287
0.008	125	0.421	52.625	0.019	1.14	2.14	0.46728
0.009	111.11	0.668	74.22	0.013473	0.80838	1.80838	0.553
0.011	90.9	0.513	46.631	0.02144	1.2864	2.2864	0.4373
0.01	100	0.434	43.4	0.02304	1.3824	2.3824	0.4197

Table 2: For Freundlich isotherm.

m = 1/n	n	C = log Kf	Kf	r	r ²
0.635	1.574	0.908	8.09	0.994	0.990
0.686	1.457	0.704	5.05	0.995	0.991
0.654	1.529	0.669	4.67	0.990	0.981
0.673	1.485	0.478	3.01	0.982	0.966
0.684	1.461	0.527	3.36	0.984	0.969
0.649	1.540	0.637	4.33	0.9899	0.980

- biosorption by *C. vulgaris* in a batch system: Effect of temperature. *Separ. Purif. Tech.*, 21: 285-94.
- Axtell, N.R., Sternberg, S.P.K. and Claussen, K. 2003. Lead and cadmium removal using *Microspora* and *Lemna minor*. *Bioresource Tech.*, 89: 41-8.
- Feng, D. and Aldrich, C. 2004. Adsorption of heavy metals by biomaterials derived from the marine alga *Ecklonia maxima*. *Hydrometallurgy*, 73: 1-10.
- Hall, K.R., Eagleton, L.C., Acrivos, A. and Vermeulen, T. 1996. Pore and solid diffusion kinetics in fixed-bed adsorption under constant pattern conditions. *Industrial & Engineering Chemistry Fundamentals*, 5(2): 212-223.
- Ho, Y.S. 2005. Effect of pH on heavy metal removal from water using tree fern as the sorbent. *Bioresource Tech.*, 96: 1292-1296.
- Langmuir, I. 1916. The constitution and fundamental properties of solids and liquids. Part I: Solids. *J. Am. Chem. Soc.*, 38: 2221-2295.
- Padmavathy, V., Vasudevan, P. and Dhingra, S.C. 2003. Biosorption of cadmium (II) ions on Baker's yeast. *Process Biochem.*, 38: 1389-1395.
- Potgieter, J.H., Potgieter-Vermaak, S.S. and Kalibantonga, P.D. 2006. Heavy metal removal from solution by palygorskite clay. *Minerals Engineering*, 19(5): 463-470.
- Saeed, A., Akhter, M.W. and Iqbal, M. 2005. Removal and recovery of heavy metals from aqueous solution using papaya wood as a new biosorbent. *Separ. Purif. Tech.*, 45: 25-31.
- Singanani, M., Abebaw, A. and Vinodhini, S. 2007. Studies on the removal of hexavalent chromium from industrial wastewater by using biomaterials. *Electron. J. Environ. Agr. Food Chem.*, 6: 2557-2564.
- Tien, C.J. 2002. Biosorption of metal ions by freshwater algae with different surface characteristics. *Process Biochem.*, 38(4): 605-613.