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Original Research Paper

Removal of Heavy Metal Cadmium from Industrial Wastewater Using Chitosan Coated Coconut Charcoal

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ABSTRACT

Of the various toxic heavy metals discharged into the environment, cadmium is highly toxic and has a serious health concern. Removal of metals from industrial wastewaters has conventionally been accomplished by precipitation, ion exchange and electrolytic technology. More recently, adsorption using commercial activated carbon and carbon from different plant materials is in force. Use of activated carbon is quite expensive. Hence, the use of carbon from natural biopolymers has attracted attention of industrialists. Recently, surface modified carbon has generated diversity with far superior adsorption capacity. Among the various low cost adsorbents identified, chitosan has the highest adsorption capacity for several metals. But chitosan is slightly soluble at low pH, soft and has a tendency to agglomerate or form a gel in aqueous solutions, which makes the active binding sites of chitosan not readily available for sorption. Hence, providing a physical support will increase the accessibility of the metal binding sites. In the present investigation an attempt has been made to overcome these mass transfer limitations by synthesizing a biosorbent by coating chitosan on the surface of coconut shell charcoal. The chitosan coated charcoal showed higher efficiency of adsorption of cadmium than the pure charcoal.

INTRODUCTION

Heavy metal pollution has a serious threat for the survival of living biota and the physico-chemical nature of the environment. Water is the natural and preferred sink for the contamination and its pollution becomes an important concern for human health. Heavy metal compounds are widely used in electroplating, cement, metal processing, wood preservatives, paint and pigments, and steel fabricating industries. These industries produce large quantities of toxic wastewaters (Raji & Anirudhan 1997). A wide range of physical and chemical processes are available for the removal of these metals from wastewater such as precipitation, ultrafiltration, ion exchange and reverse osmosis (Rengaraj et al. 2001, Yurlova et al. 2002, Benito & Ruiz 2002).

A major drawback with precipitation is sludge production. Ion exchange is found to be a better alternative, but it is not economically appealing. Adsorption using activated carbon can remove heavy metals from wastewater such as Cd (Ramos et al. 1997), Ni (Shim et al. 2001), Cr (Ouki et al. 1997) and Cu (Monser & Adhoum 2002). But, activated carbon remains an expensive material for heavy metal removal.

The use of carbon from natural biopolymers has attracted attention of the industrialists (Saifuddin & Palanisamy 2002). Recently, surface modified carbon has generated diversity with far superior adsorption capacity. In industry, 17000 tons of Cd is used annually of which only 5% is recovered. Cadmium is referred to as the 'dissipated element' with regards to the environment. Cadmium is one of the toxic heavy metals whose presence in water and soil should be controlled. Hence, in the present investigation, activated carbon is encapsulated with chitosan for surface modification, and is used for the treatment of wastewater containing cadmium.

MATERIALS AND METHODS

Preparation of coconut shell carbon (CSC): The coconut shell was cut, ground and sieved. This was burnt at very high temperature for 2-3 hrs. The surface of carbon was activated by shaking with 7% sulphuric acid for 24 hrs. The carbon was then washed several times with deionised water till no acid remains. The pure carbon was dried in hot air oven for 5 hours at 110°C.

Preparation of chitosan gel: Chitosan (from crab shells) was obtained from Central Fisheries Institute Kochi, Kerala. About 50 g of chitosan was slowly added to 1000 mL of 10% acetic acid with constant stirring. The mixture was heated to get a whitish viscous gel of chitosan-acetic acid mixture.

Surface coating of coconut shell carbon with chitosan (CCCSC): About 400 mL of chitosan gel was diluted with water (400 mL) and heated to 40-50°C. About 400 g of activated coconut shell carbon was slowly added and mechanically agitated using a rotary shaker at 150 rpm for 24 hours. This gel-coated activated carbon was washed with deionised water and dried. This process was repeated to get a thick coating of chitosan on activated coconut shell carbon. The amount of chitosan coated was found to be 25% by weight.

Batch equilibrium studies were carried out using CSC, CCCSC as adsorbents. $CdCl_2$ was used as a source of Cd(II). The Cd solutions with 5 to 25 mg/L were prepared in deionised water. To maximize Cd removal by the adsorbents, batch experiments were carried out at different conditions and optimized. The removal efficiency (E) of the adsorbent on Cd(II) was calculated with as below.

$$E\ (\%) = [(C_o - C_1) / C_o] \times 100$$

Where C_o and C_1 are the initial and equilibrium concentration of Cd solution (mg/L) respectively. Once the conditions were optimized, the percentage removal of Cd was measured during the time interval of 20, 40, 60, 80, 100, 120 minutes. The Cd concentration was determined by standard methods of APHA (1990) using Varian AAA-10 atomic absorption spectrophotometer.

RESULTS AND DISCUSSION

The effect of several parameters such as initial pH (Table 1 and Fig. 1), dose of adsorbent (Table 2 and Fig. 2), agitation speed (Table 3 and Fig. 3) and contact time (Table 4 and Fig. 4) on the removal of cadmium from the wastewater were investigated.

Effect of pH: pH is an important factor for metal adsorption processes in aqueous solutions. The effect of pH on Cd adsorption efficiency was studied with pH from 1 to 9 (Table 1 and Fig. 1). The optimal pH was found to be 5 (CCCSC) and 4 (CSC) with the adsorption decreasing at higher pH.

Influence of dose: The dependence of Cd sorption on dose of adsorbent was studied by varying the amount of adsorbents from 5 to 30 g/L (Table 2 and Fig. 2) keeping other parameters (pH, agitation-speed and contact time) constant. From the results, it can be observed that the removal efficiency increased with increase in adsorbent dose. This may be due to the greater availability of exchangeable sites for the ions. The adsorption efficiency was maximum at 15 g/L for CCCSC and 20 g/L in the case of CSC. This shows that, maximum adsorption efficiency was observed at lower dose in CCCSC due to the presence of the more exchangeable sites.

Table 1: Effect of pH on the removal of cadmium from wastewater.

pH	Percent Cd removal (CSC)	Percent Cd removal (CCCSC)
2	40	30
3	80	50
4	90	70
5	90	70
6	50	80
7	30	70
8	10	55
9	5	20

Table 2: Effect of dosage of adsorbent (g/100mL) on cadmium removal.

Dose of adsorbent g/100 mL	Percent Cd removal (CSC)	Percent Cd removal (CCCSC)
5	30	40
10	35	50
15	40	60
20	45	60
25	45	60
30	45	60

Table 3: Effect of agitation speed on removal of cadmium from wastewater.

Speed (rpm)	Percent Cd removal (CSC)	Percent Cd removal (CCCSC)
60	70	70
80	75	80
100	80	90
120	90	90
140	90	90
160	90	90
180	90	90
200	90	90

Table 4: Effect of contact time on cadmium removal.

Time in minutes	Percent Cd removal (CSC)	Percent Cd removal (CCCSC)
30	10	15
60	20	25
90	35	50
120	40	55
150	40	55
180	40	55
210	40	55

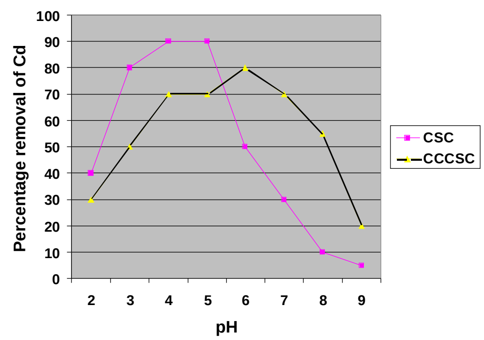

Fig. 1: Effect of pH on the removal of cadmium from wastewater.

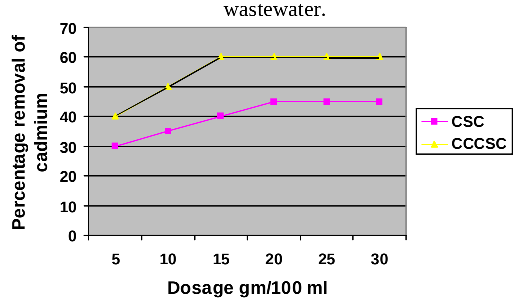

Fig. 2: Effect of dosage of adsorbent (g/100mL) on cadmium removal.

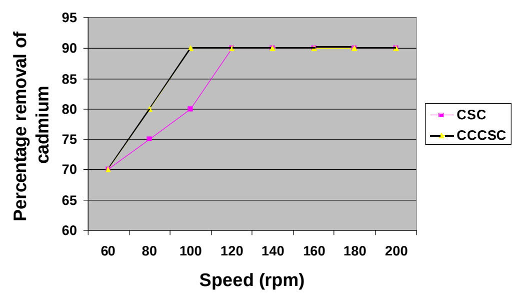

Fig. 3: Effect of agitation speed on removal of cadmium from wastewater.

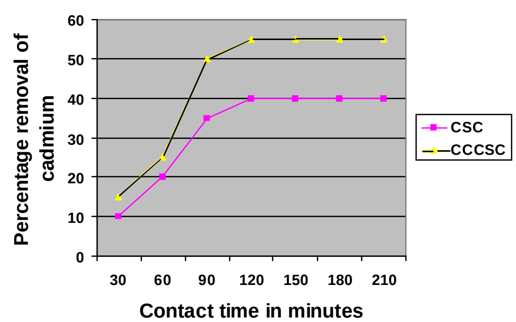

Fig. 4: Effect of contact time on cadmium removal.

Table 5: Percent removal of cadmium from wastewater using coconut shell carbon and chitosan coated coconut shell carbon at optimum conditions.

Time in minutes	Percent Cd removal (CSC)	Percent Cd removal (CCCSC)
20	35	40
40	40	55
60	45	65
80	50	75
100	55	85
120	60	90

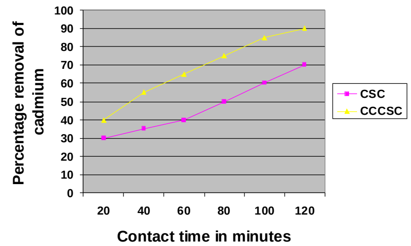

Fig. 5: Percent removal of cadmium from wastewater using coconut shell carbon and chitosan coated coconut shell carbon at optimum conditions.

Effect of agitation speed: The effect of agitation speed on the cadmium removal efficiency was studied by varying the speed of agitation from 0 (no shaking) to 200 rpm (Table 3 and Fig. 3), keeping the other factors constant. It was found that the Cd removal efficiency increased from 70% to 90% when the agitation speed was increased from 60-80 rpm in CCCSC and 60-120 rpm in CSC.

Effect of contact time: The results (Table 4 and Fig. 4) indicate that the Cd removal efficiency increased with an increase in contact time before equilibrium is reached. It was found that the optimum contact time for both CCCSC and CSC was 120 minutes.

Removal of cadmium using CSC and CCCSC: From Table 5 and Fig. 5, it is found that coconut shell carbon (CSC) and chitosan coated coconut shell carbon (CCCSC) are efficient in removing heavy metal cadmium from wastewater up to 90%.

In conclusion, it can be inferred that the use of chitosan coated acid treated coconut shell carbon for cadmium removal appears to be technically feasible and eco-friendly with high efficacy. Besides, being composed entirely of agricultural and fishing industry waste, it helps in waste minimization. The adsorbent can be regenerated by using sodium hydroxide and, therefore, can be reused.

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