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Fixed bed column study for Cd(II) removal from wastewater using treated rice husk

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Abstract

A fixed bed of sodium carbonate treated rice husk was used for the removal of Cd(II) from water environment. The material as adopted was found to be an efficient media for the removal of Cd(II) in continuous mode using fixed bed column. The column having a diameter of 2 cm, with different bed depths such as 10, 20 and 30 cm could treat 2.96, 5.70 and 8.55 l of Cd(II) bearing wastewater with Cd(II) concentration 10 mg/l and flow rate 9.5 ml/min. Different column design parameters like depth of exchange zone, adsorption rate, adsorption capacity, etc. was calculated. Effect of flow rate and initial concentration was studied. Theoretical breakthrough curve was drawn from the batch isotherm data and it was compared with experimental breakthrough curve. An amount of 0.01 mol/l HCl solution was used for desorption of adsorption column. Column regeneration and reuse studies were conducted for two cycles of adsorption–desorption.

Keywords: Cadmium; Sodium carbonate treated rice husk (NCRH); Adsorption; Column study; Breakthrough curve

1. Introduction

Cadmium is a metal widely used in industries such as cadmium plating, alkaline batteries, copper alloys, paints and plastics. It is a non-essential and non-beneficial element to plants and animals. Its toxic effects are well documented. Diseases such as renal damage, anemia, hypertension and itai–itai are associated with excess cadmium [1]. Hence it is important to eliminate trace of cadmium from drinking water, or to remove cadmium from wastewaters before they are discharged into receiving bodies. Various treatment techniques have been employed to eliminate or reduce cadmium in wastewater including precipitation, adsorption, ion exchange and reverse osmosis. As of now, adsorption by activated carbon is accepted to be the best available technology for the reduction of heavy metals, except that its manufacturing cost is quite high. Hence, a search is on world wide for a low-cost alternative. Research in the recent years has indicated that some natural biomaterials including agricultural products and by-products can accumulate high concentration of heavy metals. Adsorbent generated from these biomass are cost effective and efficient. Low-cost agricultural products and by-products have been reported to be effective in removing cadmium. Corncob [2], Sugar beet pulp [3] and Petiolar felt-sheath of palm [4] to name a few.

Rice husk, an abundant biomaterial, is capable of removing heavy metals and can be considered as an efficient and low-cost adsorbent for heavy metals. The earlier studies on rice husk has also been reported to be effective in removing cadmium, such as rice husk ash [5], phosphate-treated rice husk [6], rice husk [7] and sodium carbonate treated rice husk (NCRH) [8]. Most of the studies mentioned above have been conducted in batch mode, which are usually limited to the treatment of small quantities of wastewater. The sorption capacity parameter obtained from a batch experiment is useful in providing information about effectiveness of metal–biosorbent system. However, the data obtained under batch conditions are generally not applicable to most treatment system (such as column operations) where contact time is not sufficiently long for the attainment of equilibrium [9]. Hence, there is a need to perform equilibrium studies using columns. Volesky and Prasetyo [10] studied the cadmium removal by *Ascophyllum nodosum* in a biosorption column. Column studies for the adsorption of chromium(VI) using sphagnum moss peat have been reported by Sharma and Foster [11].

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Nomenclature

a, a_1, a_2	slope (h/cm)
b, b_1 b_2	intercept (h)
c_b	effluent concentration at influent concentration C_1 (mg/l)
c_f	effluent concentration at influent concentration C_2 (mg/l)
C	effluent concentration at any time t (mg/l)
C_B	desired concentration of solute at breakthrough (mg/l)
C_e	equilibrium concentration (mg/l)
C_E	concentration of solute at exhaust point (mg/l)
C_0	initial concentration (mg/l)
C^*	equilibrium concentration of solute in solution corresponding to an adsorbed concentration, q_e (mg/l)
F_w	wastewater flow rate (l/h)
h	total bed depth (cm)
h_z	height of exchange zone (cm)
K	adsorption rate constant (l/mg h)
K_F	constant in the Freundlich isotherm model
K_m	overall mass transfer coefficient (cm^2/min)
m	weight of adsorbent (g)
NCRH	sodium carbonate treated rice husk
N_0	adsorption capacity (mg/l)
q_e	adsorption capacity (mg/g)
t	service time of column (h)
V	linear flow velocity of feed to bed (cm/h)
V_B	total volume of wastewater treated to the point of breakthrough (l)
V_E	total volume of wastewater treated to the point of exhaustion (l)
x	amount of adsorbate adsorbed (mg)
X	bed depth of column (cm)
X_0	minimum column height necessary to produce an effluent concentration C_B (cm)
$1/n$	constant in the Freundlich isotherm model representing intensity of sorption

Reports regarding the removal of pollutants in continuous mode using fixed bed column are only a few [7,9–15]. Thus, the present study aims towards the removal of Cd(II) from Cd(II) bearing wastewater in fixed bed column filled with sodium carbonate treated rice husk (NCRH). The present research work basically deals with the design parameters of fixed bed adsorption column, so that it may find practical application to the real world.

2. Materials and methods

2.1. Reagents

All chemicals used were of analytical grade (E. Merck, India). Stock solutions of 1000 mg/l was prepared for Cd(II) using cadmium nitrate. In order to avoid hydrolysis as well as high adsorption of species in the flask wall the stock solution was prepared with HNO_3 2% (v/v), which were diluted with distilled water to prepare working solutions. pH of the working solutions were adjusted to 6.0 ± 0.2 for all studies using dilute NaOH solution.

2.2. Instrumentation

A atomic absorption spectrophotometer (AA-6650, Shimadzu, Japan) was used for Cd(II) measurement. A high precision electrical balance (Sartorious GMBH) was used for weighing and a digital pH meter (DHP-500, SICO, India) was used for pH measurement. A peristaltic pump (Miclins India Limited, PP 30) was also used for providing constant flow of metal and desorbing solution in fixed bed column.

2.3. Preparation of NCRH

Fresh rice husk was obtained from a local rice mill and was passed through different sieve size. The fraction of particle between 425 and 600 μm (geometric mean size: 505 μm) was selected [8]. Rice husk was washed thoroughly with distilled water and was dried at 60 °C. This was treated with 0.1 mol/l sodium carbonate solution at room temperature for 4 h. Excess of sodium carbonate was removed with water and the material was dried at 40 °C. Sodium carbonate treated rice husk was designated as NCRH [8].

2.4. Experimental methods

Fixed bed column studies were conducted using columns of 2 cm diameter and 55 cm length. The column was packed with NCRH between two supporting layers of preequilibrated glass wool. The bed depths were taken as 10, 20 and 30 cm. The schematic diagram of the column study is shown in Fig. 1. The column was charged with Cd(II) bearing wastewater in the up flow mode with a volumetric flow rate of 9.5 ml/min (∼1.81 m^3/m^2/h). The initial concentration of Cd(II) was 10 mg/l. The samples were collected at certain time intervals and were analysed for Cd(II) using atomic absorption spectrophotometer (AA-6650, Shimadzu). Experiment was also conducted with initial Cd(II) concentration of 20 mg/l keeping a bed depth of 10 cm and flow rate of 9.5 ml/min. Effect of flow rate was also studied, with flow rates of 5 and 15 ml/min, with the bed depth of 10 cm and initial Cd(II) concentration of 10 mg/l. The temperature was 28 ± 2 °C and the pH was 6.0 ± 0.2 for all studies. This was in accordance with the earlier study [8]. The optimum pH should be within the adsorption edge and should have the lowest solution pH for maximum metal ion adsorption and also should be near to pH of the solution prepared with metal salts. It is also well known that the pH of wastewater is generally in a slightly acidic range. It should also be such that the precipitation of metal ions should not occur.

After exhaustion of the NCRH by Cd(II) it is necessary to regenerate it for further use. The column desorption was studied by using 0.01 mol/l HCl (1200 ml) and the column were regen-