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RESEARCH ARTICLE

REMOVAL OF STRONTIUM FROM AQUEOUS SOLUTIONS USING COIR PITH AS BIOSORBENT: KINETIC AND EQUILIBRIUM STUDIES

***Harshala Parab, Niyoti Shenoy, Sanjukta A. Kumar, Sangita D. Kumar and A. V. R. Reddy**

Analytical Chemistry Division, Bhabha Atomic Research Centre, Trombay, Mumbai- 400085, India

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ABSTRACT

Coir pith a natural, lignocellulosic, low-cost, agricultural by-product has been evaluated as a sorbent to remove strontium from aqueous solutions. Sorption studies were performed in a batch mode by varying the experimental parameters such as solution pH, initial metal ion concentration and contact time. The extent of strontium sorption was found to increase with increase in initial metal ion concentration and contact time. The optimum sorption of Sr(II) on coir pith was achieved in the pH range of 5-8. Kinetic studies showed that the strontium sorption process was rapid and followed pseudo second-order kinetics. Equilibrium data were evaluated using Langmuir and Freundlich adsorption isotherms. Maximum sorption capacity of coir pith for Sr(II) was found to be 87.16 mgg^{-1} in the studied concentration range. Repeated sorption-desorption cycles were performed to examine the reusability and metal recovery efficiency of the biosorbent. Sr(II) could be desorbed almost completely from the spent coir pith using HCl or EDTA solutions within 1h. Quantitative removal of strontium was obtained from spiked ground water samples. The studies revealed that, coir pith is a promising biosorbent for Sr(II) removal from aqueous solutions owing to its low cost and high uptake capacity.

INTRODUCTION

Strontium-90 is one of the major fission products present in the waste solutions from nuclear power plants and spent nuclear fuel reprocessing (Baisden and Choppin, 2007; USEPA, 2002). It has a relatively long half-life of about 29 years. Separation of ^{90}Sr from waste solutions is essential to reduce the personnel radiation exposure and the volume of disposable waste during the conditioning of the waste. Due to its chemical resemblance to calcium, strontium follows the path of calcium in the food chain and enters the human body. It is easily incorporated into bones. If radioisotope ^{90}Sr enters bone, it irradiates localized tissues leading to bone sarcoma, leukemia and other chronic illnesses depending on its concentration (EVS, 2006; Atsdr, 2004; Mangano and Sherman, 2011; PHGSDW, 2006). This poses a risk to human health. Hence, low levels of Sr, if present, need to be removed. The mean concentration of strontium in surface water is <1 mg/L. Dissolved strontium has been detected in groundwater and surface water used for drinking water supplies with average concentrations of 0.81 and 1.1 mg/L, respectively (Atsdr, 2004). Seawater contains 8 ppm strontium on average. River water generally contains about 50 ppb of strontium. The EPA limit for stable Sr in drinking water is 4 mgL^{-1} and that of Sr-90 is 8 pci per liter (Atsdr, 2004). Thus from the perspective of environmental protection; development of efficient methods to concentrate and separate the Sr(II) ions from the aqueous solutions is an area of active research. Biosorption using biomass or waste bioproducts is considered as a promising biotechnology for metal ion removal from aqueous solutions, due to its simplicity, efficiency, low cost and availability. A number of reviews have illustrated the sorption potential of low cost biomaterials for different metal ions (Ahmaruzzaman and Gupta, 2011; Aksu, 2005; Ali and Gupta, 2006; Bailey *et al.*, 1999; Das, 2012; Demirbas, 2008; Gadd, 2009; Gupta *et al.*, 2009; Kapoor and Viraraghavan, 1995; Romera, 2006; Sud, 2008; Veglio and Beolchini, 1997; Vijayaraghavan and Yun, 2008). The performance of different biomasses is mainly based on the affinity of available functional groups to metal ions; for their removal/recovery from different solutions. In the present studies, coir pith- a lignocellulosic waste biomaterial from coir processing industries has been used as a candidate sorbent for the removal of strontium from aqueous solutions. Coir pith is available in the husk of coconut fruit along with the fiber. The separation of coir fiber from coconut husk produces a large amount of coir pith as a waste in the agricultural sector of India. Utilization of this freely available solid waste for bioremediation will provide an inexpensive alternative to the existing sorbents. The presence of functional groups, such as carboxylic, hydroxyl, and lactone, which have an affinity for metal ions, are mainly responsible for the exchange/sorption properties of coir pith (Tan *et al.*, 1993). Sorption properties of coir pith for few metal ions of nuclear importance have been previously studied in our laboratory (Parab *et al.*, 2006; Parab *et al.*, 2005; Parab and Sudersanan, 2010).

****Corresponding author: Harshala Parab***
Analytical Chemistry Division, Bhabha Atomic Research Centre, Trombay, Mumbai- 400085, India.

In the present studies, sorption behavior of Sr(II) ions on coir pith has been investigated for the first time. Effect of experimental parameters such as solution pH, initial strontium concentration and contact time on the uptake of Sr(II) was evaluated. Biosorption isotherms and kinetics of the process were studied using different mathematical models. The calculated model parameters are useful in case of further scale-up of the process. Desorption studies were performed to recover Sr(II) ions and to regenerate the sorbent. The applicability of this material is tested for spiked ground water samples.

MATERIALS AND METHODS

Materials

Coir pith, sorbent used for the sorption studies has been provided by Central Coir Research Institute, Kerala, India. The obtained material was repeatedly washed with deionized water to remove adhering dirt if any and soluble impurities. It was then air dried; ground and sieved. Particles of size 300–600 μm were used for sorption studies without any further pretreatment. The powdered biomass was stored in an airtight plastic container. All chemicals used were of analytical reagent grade. Strontium nitrate ($(Sr(NO_3)_2$) was obtained from Sigma Aldrich with 99.99% purity. A stock solution of 10 gL^{-1} strontium was prepared by dissolving the appropriate amount of $Sr(NO_3)_2$ in deionized water The working standard solutions in the range of 20-800 mgL^{-1} were prepared by diluting the stock solution with deionized water to get the appropriate concentration. All sample bottles and glassware were cleaned; rinsed with deionized water and oven dried at 60°C.

Adsorption and Desorption studies

Batch sorption experiments, were performed with Sr(II) solutions (50 mL) of desired concentrations in contact with 0.1 g of coir pith biomass. The solutions were agitated using shaking machine (Sarit rotary shaker model SOS-101-AT, India) at a speed of 200 rpm and temperature 300 ± 2 K for 5 h. The sorbent phase was then separated from the solution by centrifugation at 15,000 rpm for 10 minutes. Residual strontium in the solution was measured by atomic absorption spectrometry (AAS) or inductively coupled plasma mass spectrometry (ICP-MS). Influence of solution pH on the sorption of strontium (20 mgL^{-1}) was studied in the pH range of 1.0 to 8.0 under similar experimental conditions. Before each experiment, the solution pH was initially adjusted using 0.1 M HCl and/or 0.1 M NaOH depending on the required pH value. The pH of the reaction mixture was not controlled during the experiments but solution pH was measured after the experiment. Kinetic studies were carried out in the concentration range of 100-800 mgL^{-1} for Sr (II), at a few time intervals during the experiment upto a time period of 500 min. For each predetermined time interval, a fixed amount of sample was withdrawn, centrifuged and the supernatant solution was analyzed for residual strontium concentration in the solution. For isotherm studies the concentration of Sr(II) was varied from 20-800 mgL^{-1}. For desorption studies of strontium, coir pith loaded with Sr(II) (by exposing to 20 mgL^{-1} of Sr(II) at pH= 6) was separated from the solution by filtration. It was washed with distilled water to remove unadsorbed strontium and then agitated with 50 mL HCl (0.1, 0.2 and 0.5 M) and 0.1M EDTA separately for 1 h at 200 rpm. The remaining procedure was the same as that employed in the sorption experiments. All the experiments were carried out in triplicates.

Spectrometric determination of Sr(II) ions in solution phase

The concentration of Sr(II) ions before and after sorption were determined by either a flame-AAS (contrAA-300, analytikjena-Germany) equipped with nitrous oxide-acetylene burner at the wavelength, 460.73 nm or ICP-MS (VG PQ Ex Cell- Thermo Elemental, U.K).

The strontium uptake q_t (mg/g) at any time t was calculated from the mass balance as follows:

$$q_t = \frac{(C_0 - C_t)V}{M} \tag{1}$$

Where, C_0 (mgL^{-1}) is the initial metal ion concentration, C_t (mgL^{-1}) is metal ion concentration at any time t, V (L) is the volume of solution and M (g) is the weight of sorbent used.
And metal ion removal efficiency (% of sorption) was calculated as

$$\%\,\text{sorption} = \frac{(C_0 - C_t)}{C_0} \times 100 \tag{2}$$

Kinetic models

The sorption mechanism, particularly potential rate-controlling step, the transient behavior of the metal sorption process was analyzed by treating the measured data using pseudo-first order, pseudo-second order and intra-particle diffusion models as explained below (Aksu, 2005, Aksu, 2002; Aksu and Tezer, 2000).

The rate of uptake by pseudo-first order model is expressed as

$$\frac{dq}{dt} = k_{1,ads}(q_e - q) \tag{3}$$

where, q_e (mgg^{-1}) and q (mgg^{-1}) represent the amount of metal ions taken up by the adsorbent at equilibrium and at time t respectively. $k_{1,ads}$ (min^{-1}) is the rate constant of pseudo first order adsorption. By solving differential Eq. (3), Eq. (4) is obtained

$$\log(q_e - q) = \log q_e - \frac{k_{1,ads} \times t}{2.303} \tag{4}$$

The adsorption rate constant, $k_{1,ads}$ is calculated from the plot of log (q_e -q) versus t. The rate of uptake by pseudo-second order model is expressed as

$$\frac{dq}{dt} = k_{2,ads}(q_e - q)^2 \tag{5}$$

Where, $k_{2,\,ads}$ (g/mg.min) is the rate constant of pseudo second order sorption. By solving differential Eq. (5) the following equation is obtained

$$\frac{1}{(q_e - q)} = \frac{1}{q_e} + k_{2,ads}t \tag{6}$$

Eq. (6) is linearized in the following form, which allows to apply this model without experimental estimation of q_e

$$\frac{t}{q} = \frac{1}{k_{2,ads}q_e^{\ 2}} + \frac{1}{q_e}t \tag{7}$$

A plot t/q versus t is linear if pseudo second-order kinetic model is applicable. The values of q_e and $k_{2,ads}$ can be determined from the slope and intercept of the plot, respectively. Intra-particle diffusion model is generally employed to determine the adsorption mechanism, on the premise that the sorption of analyte on sorbent involves transport of solute molecules from aqueous phase to the surface of sorbent and diffusion of solute molecules into interior of the pores, which is usually a slow process. The possibility of intraparticle diffusion as a rate determining step during the sorption process was evaluated by a mathematical model. According to Webber and Morris (Weber and Morris, 1963), the intraparticle diffusion coefficient, K_{id}, is defined by Eq. (8) as given below

$$q_t = K_{id}t^{0.5} \tag{8}$$

Where, q_t (mgg^{-1}) represents the amount of metal ions taken up by the adsorbent at time t and K_{id} (mgg^{-1}(min$^{0.5}$)$^{-1}$) is intraparticle diffusion rate constant.

Equilibrium models

The possible utilization of the biosorbent material is quantitatively evaluated by the amount of sorbate it can take up and hold in an immobilized form in the chosen conditions. For this purpose, equilibrium data are analyzed using different isotherm models and the most appropriate correlation for equilibrium conditions is established, which can be useful for further designing and optimizing the operating procedure. The two isotherms selected in this study are Langmuir and Freundlich isotherm (Gadd and 2009; Kapoor and Viraraghavan, 1995). The Freundlich adsorption isotherm, which assumes that adsorption takes place on heterogeneous surfaces, can be expressed as

$$q_e = K_F(C_e)^{1/n} \tag{9}$$

Where, q_e (mgg^{-1}) is the amount adsorbed at equilibrium, C_e (mgL^{-1}) is the equilibrium concentration, K_F and n are equilibrium constants, which represent adsorption capacity and adsorption intensity, respectively. Langmuir equation is based on the assumption of a structurally homogeneous adsorbent, where all sorption sites are identical and energetically equivalent. This model predicts the monolayer coverage of adsorbate on the surface of adsorbent with a finite sorption capacity beyond which no further sorption can take place.
Langmuir equation is given in Eq. (10)

$$q_e = \frac{Q^0 bC_e}{1 + bC_e} \tag{10}$$

Where, Q^0 (mgg^{-1}) is the mass of adsorbed solute required to saturate a unit mass of adsorbent and b (Lmg^{-1}) is a constant related to the energy or net enthalpy of adsorption. Q^0 represents a practical limiting adsorption capacity when the surface is fully covered with metal ions. This value is useful in sorption performance comparison in cases where the adsorbent did not reach to its saturation value practically. (Aksu and Tezer, 2000).

RESULTS AND DISCUSSION

Influence of solution pH

Solution pH plays an important role in the interaction of the solutes with a sorbent. Specifically it affects the solution chemistry of the solute as well as the functional groups present in the sorbent. To examine the effect of solution pH on the sorption, studies were conducted over a pH range of 1-8 with initial Sr(II) concentration of 20 mgL^{-1} and 0.1 g of coir pith. The results obtained are shown in Figure 1.

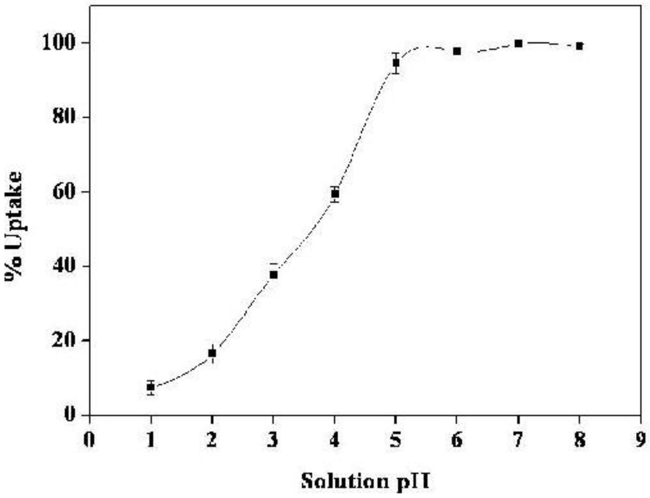


Figure 1. Effect of solution pH on uptake of Sr(II) by coir pith

In this pH range, the biosorption potential of coir pith increased with increasing pH upto pH= 5 and thereafter it remained constant. The variation in the removal of the Sr with respect to pH can be elucidated by considering the functional groups present on the surface of the sorbent and the nature of the physicochemical interaction of the species in solution. Coir pith comprises of various functional groups (Tan *et al.*, 1993; Parab and Sudersanan, 2010), which are affected by the pH of the solution. The point of zero charge pH$_{pzc}$ of coconut coir in aqueous solution as reported earlier is 4.8 (Shen *et al.*, 2012). In the acidic pH, the predominant charges on coir pith are positive, which results in the lower uptake of positively charged Sr ions on coir pith. When solution pH increases, the surface acidic functional groups get deprotonated and negative charge on the sorbent increases. Above pH 4.8, coir pith is negatively charged and there exist an electrostatic attraction between the negatively charged sorbent surface and the positively charged Sr(II) ions. Therefore, the optimum uptake of Sr^{2+} ions is observed in the pH range 5-8. Also the lower sorption in acidic pH is due to the competition of excess H$^+$ ions with strontium ions for binding onto the biomass surface. As the pH increases, active sorption sites available for strontium ions increase leading to the increase in uptake at higher pH. Further, a decrease in the solution pH was observed after equilibration as compared to the initial solution pH. The drop in equilibrium pH suggests that H^+ ions are liberated from the solid surface into the aqueous phase as a result of the exchange with metal cations. Carboxyl groups present in lignocellulosic materials are responsible for the biosorption of different metal ions. Similar trends were also observed for strontium removal by gels based on polysaccharide derivates and magnetically modified fodder yeast (Kluyveromyces fragilis) cells (Wang *et al.*, 2009; Ji, 2010).

Effect of contact time and initial metal ion concentration on the sorption kinetics

One of the important factors that define the efficiency of the sorption process is the solute uptake rate by the sorbent material. To understand the sorption behavior of coir pith towards Sr(II), kinetic experiments were conducted with varying initial metal ion concentration and the results are shown in Figure 2.

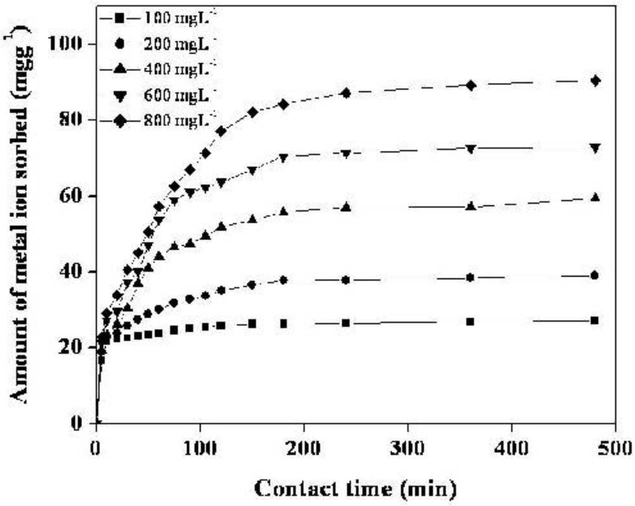


Figure 2. Variation of sorption of Sr(II) by coir pith as a function of contact time for different initial metal ion concentrations

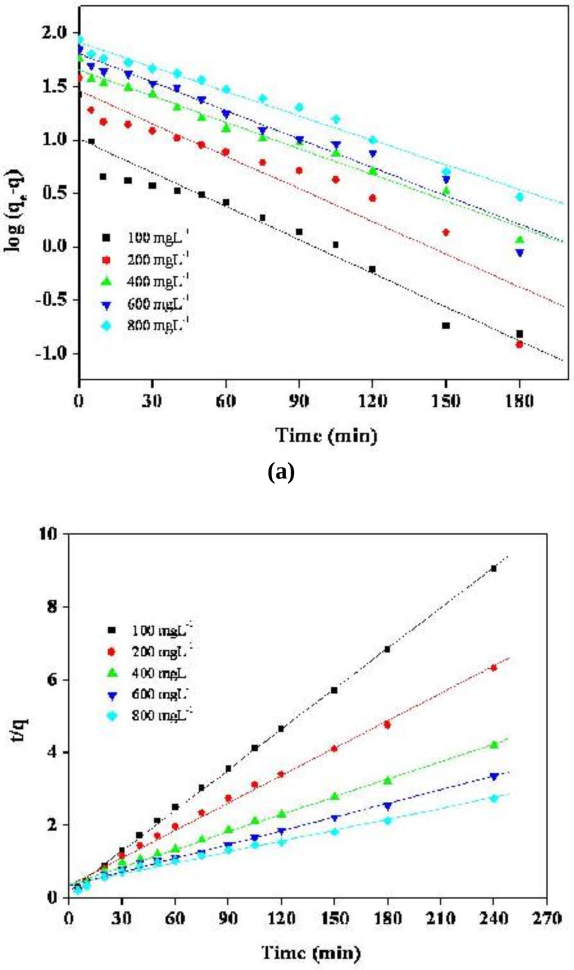
Removal of strontium was found to be dependent upon the initial concentration of strontium. The rate of metal sorption by coir pith was high during the initial stages of the reaction, which then decreased gradually with time and finally reached equilibrium. It was observed for initial metal ion concentrations < 200 mgL^{-1}, more than 70% of the target analyte was sorbed within 30 min and the equilibrium was reached within an hour for the same. However, for higher initial concentrations (i.e. ≥ 200 mgL^{-1}) the time taken to attain equilibrium (4h) was increased. The short time needed for sorption to reach equilibrium state (for 100 or 200 mgL^{-1}) could be attributed to the high sorption efficiency and readily available vacant binding sites (functional groups) of the sorbent surface and lower aqueous concentrations of sorbate. At higher initial concentrations, the ratio of available sorption sites to strontium ions is less and the binding sites saturate more rapidly. In addition the presence of less favorable sites could also influence the sorption kinetics. The adsorption density (mgg^{-1}) increased with increase in initial strontium concentration (Table 1). The dependence of the specific uptake capacity of sorbent with initial metal ion concentration reflects the equilibrium between metal ion concentration in solution and that adsorbed on coir pith. Though equilibrium is attained in a short time, for the near complete removal of Sr, a contact time of 5 h was selected for further experiments.

Table 1. Equilibrium uptake (q_e) and fraction of strontium adsorbed (%) by coir pith at initial concentrations 'C_0'

C_0 (mgL^{-1})	q_e (mgg^{-1})	Uptake (%)
20	9.77 ± 0.03	97.67
50	18.06 ± 0.56	72.24
100	26.44 ± 2.05	52.87
200	37.86 ± 0.93	37.86
400	56.91 ± 2.96	28.46
600	71.34 ± 4.6	23.78
800	87.16 ± 4.2	21.79

Kinetic studies of strontium sorption on coir pith

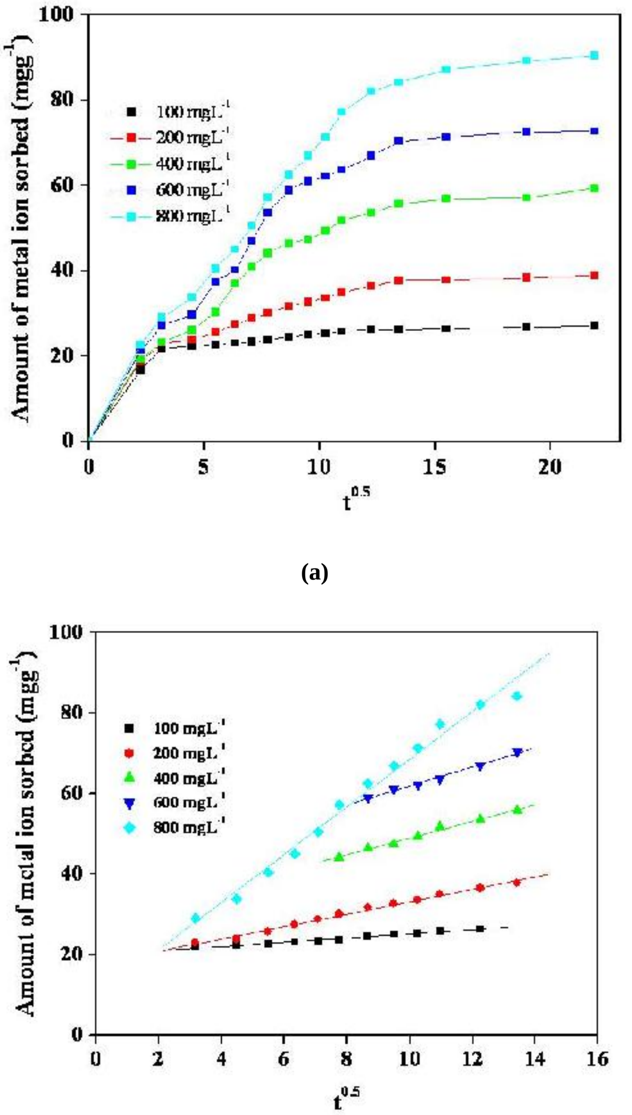
The insight of batch adsorption kinetics is necessary for the industrial sorption process designing. The nature of the sorption process will depend on physicochemical characteristics of the sorbent system and the experimental conditions. The sorption kinetics data observed in the present system have been analyzed using pseudo-first-order; pseudo-second-order and intraparticle diffusion kinetic models (Figure 3 and 4). The parameters determined from the kinetic models in the studied concentration range along with the corresponding determination coefficients are presented in Table 2.



(a)

(b)

Figure 3. Sorption of Sr(II) by coir pith using (a) pseudo-first order kinetic model and (b) pseudo-second order kinetic model.



(a)

(b)

Figure 4. Intraparticle diffusion plots for sorption of Sr(II) by coir pith

values of rate constant, $K_{2,ads}$ decrease with increase in the initial metal ion concentration for coir pith (Table 2). The reason for this behavior may be due to the lower competition for the sorption sites at lower concentration. At higher concentrations, the competition for the surface active sites will be high and consequently lower sorption rates are obtained. Similar trend was observed by in case of an anionic dye sorption using pine cone sorbent (Dawood and Sen, 2012). For the process design and control of sorption systems, it is important to understand the underlying mechanism that results in the apparent dynamic behavior of the system. In case of solid-liquid system, the sorption rate can be controlled by film diffusion and/or intraparticle diffusion. For the present kinetic studies, the boundary layer resistance was minimized by adjusting the agitation speed at 200 rpm so that film diffusion would not be a major rate-controlling factor. The plots for intraparticle diffusion (Figure 4a), depict identical trend as that observed in Figure 2. For lower initial metal ion concentrations (i.e. for 100 and 200 mgL^{-1}) the sorption plots can be separated into three linear regions, which confirm the multistage sorption. The first one demonstrates rapid uptake signifying external surface sorption. The second stage exhibits slower uptake representing gradual sorption stage, where rate is controlled by intraparticle diffusion. This signifies that the metal ions were transported to the external surface of the coir pith biomass through film diffusion and its rate was fast. After that, the metal ions may enter into coir pith particles by intra-particle diffusion through pores. The third part is a plateau, which indicates the exchange is saturated and equilibrium is attained. However, for higher concentrations the difference between the first two stages is less. From the observations in case of lower concentrations, the same behavior was hypothesized for higher concentrations. The Figure 4b represents the linear portion illustrating the gradual sorption stage of the multilinear plot for each concentration. In all the plots, it is obvious that the lines do not pass through origin signifying that although Sr(II) sorption involves particle diffusion, it is not the only rate-limiting uptake mechanism. The kinetics of Sr sorption is unlikely to be just controlled by any one mechanism. A pseudo second order mechanism is more likely, suggesting chemisorption as the rate-controlling step with intra particle diffusion.

Table 2. Comparison between sorption rate constants associated with different kinetic models

		pseudo first order model			pseudo second order model			intraparticle diffusion model	
C_0 (mgL^{-1})	$q_{e\ exp}$ (mgg^{-1})	K_1 (×10^{-2}) (min^{-1})	$q_{e\ cal}$ (mgg^{-1})	R^2	K_2 (×10^{-3}) (g/mg.min)	$q_{e\ cal}$ (mgg^{-1})	R^2	K$_{id}$ (mgg^{-1}/min$^{0.5}$)	R^2
100	26.44	2.42	10.26	0.92	6.81	26.95	0.99	0.52	0.99
200	37.89	2.35	28.92	0.88	1.69	39.84	0.99	1.54	0.99
400	56.91	1.89	45.33	0.98	0.68	62.11	0.99	2.07	0.99
600	71.34	2.05	64.27	0.95	0.45	79.36	0.99	2.36	0.99
800	87.16	1.75	81.87	0.98	0.26	100.0	0.98	5.91	0.99

The experimental values did not fit well to the pseudo first order model (Figure 3a) which reflects the unsuitability of this model. Moreover, pseudo first order model predicted significantly lower values of the equilibrium sorption capacity (q_e) than the experimental ones. From the above observations, it is clear that the sorption is not a first order reaction. On the other hand, for pseudo second order model, a good match was obtained between the experimental and theoretical q_e values (Figure 3b). The determination coefficients for this model are nearly equal to 1 (Table 2). This indicates that the strontium sorption on coir pith follows pseudo second order kinetics. The

Equilibrium studies of strontium sorption on coir pith

The representation of experimental data in the form of sorption isotherm is important for understanding of interaction of sorbate with sorbent and also to get a possible insight of the sorption capacity of the sorbent. The sorbent surface phase may be considered as a monolayer or multilayer. Sorption isotherms were studied by varying the Sr(II) concentration in the range of 20-800 mgL^{-1} at a fixed pH value of 6.0. Modeling of the Sr(II) sorption equilibrium data using the Langmuir and Freundlich isotherms are shown in Figure 5 and the sorption constants evaluated from these isotherms along with the determination coefficients are given in Table 3. Higher determination coefficient (i.e. with values nearly ≈ 1) showed that Freundlich model is more suitable for describing the sorption equilibrium of strontium in the studied concentration range. The value of the Freundlich constant, '*n*' ($0 < n > 1$) obtained for the present system indicates favorable adsorption (Treybal, 1980). The maximum sorption capacity Q^0 determined from the Langmuir isotherm was 106.25 mgg^{-1} whereas the practically observed value was 87.16 mgg^{-1} for 800 mgL^{-1} initial concentration of Sr.

Table 3. Freundlich and Langmuir constants associated with Sr(II) uptake using coir pith

Freundlich Constants	K_F ($mg\ g^{-1}L^{1/n}\ mg^{-1/n}$)	4.73
	$1/n$	0.45
	R^2	0.9849
Langmuir Constants	Q^0 (mgg^{-1})	106.25
	b (Lmg^{-1})	5.07×10^{-3}
	R^2	0.9309

Reports on a variety of materials as the potential candidates for removal of strontium from aqueous solutions are available in literature (Wang *et al.*, 2009; Ji *et al.*, 2010; Small *et al.*, 1999; Barot and Bagla, 2012; Smiciklas *et al.*, 2007; Chen, 1997; Chegrouche *et al.*, 2009; Yan-li *et al.*, 2011; Yali *et al.*, 2011; Yuan-hong *et al.*, 2011; Mashkani and Ghazvini, 2009; Shaukat *et al.*, 2005). The comparison of coir pith with other sorbents reported in literature based on their maximum uptake capacity for Sr (II) ions is presented in Table 4. It is important to emphasize that a direct comparison of maximum capacity of coir pith with that of other sorbent is difficult, since applied experimental conditions might vary in each case. Nevertheless, it can be concluded from Table 4, that coir pith exhibits moderate sorption capacity towards Sr(II) ions as compared to other previously reported sorbents. But an additional advantage of coir pith stems from its use in the native form as it has been used without any pretreatment. Hence coir pith could find significantly important place in the list of cost-effective and economical materials used for Sr(II) sequestering.

Recovery of the sorbed metal ions and the regeneration of spent biosorbent are the two main attributes for cost considerations while assessing the potential applicability of the biosorbent. In addition, desorption studies help to elucidate the mechanism of the sorption process. To recover the loaded strontium on coir pith, desorption experiments were performed using HCl (0.1 M, 0.2 M and 0.5 M) and EDTA (0.1 M) as desorbents. The choice of acidic desorbent is made based on the observation of Figure 1, which revealed that, Sr(II) can easily be desorbed under acidic conditions. On the other hand, selection of EDTA as a desorbent was due to its well known chelating properties with various metal ions. In the present studies, metal ions were desorbed with both the reagents quantitatively within 1h; exhibiting the high desorption efficiencies. The performance of acidic desorbents further confirms the involvement of negatively charged functional groups in the sorption process, as H^+ ions could easily exchange with bound Sr(II) ions under strongly acidic conditions. This reveals that ion exchange is probably the major mode of sorption process. Regeneration without reducing the capacity of the biosorbent is an important factor for repeated use of the biomass. In the present studies, when coir pith was reused after desorption with acidic desorbents, its sorption capacity was found to decrease from 100 % to ~ 85% in the second cycle. In contrast, when EDTA was used as the desorbent, coir pith retained its original biosorption capacity for three consecutive sorption-desorption cycles, without any significant deviation (Figure 6). Repeated use of coir pith in several sorption-desorption cycles indicated an efficient regeneration of the sorbent.

Decontamination of Sr(II) from ground water

The utility of coir pith for decontamination of solutions containing Sr(II) was tested by spiking the ground water samples with 5, 10 and 15 mgL^{-1} Sr (in duplicates) obtained from Anantpur, India. The separation of Sr(II) was carried out in the similar manner as mentioned earlier. Strontium content could be brought down from 5, 10 and 15 mgL^{-1} to below

Table 4. Comparison of strontium sorption capacity of coir pith with other sorbents

Sorbent	Maximum sorption capacity (mgg^{-1})	Reference
Shewanella alga	6.9	Small *et al.*, 1999
dry cow dung powder (DCP)	9.0	Barot and Bagla, 2012
Natural clinoptilolite	9.8	Smiciklas *et al.*, 2007
Amaranthus spinosus root tissue powder	12.89	Chen, 1997
Activated carbon	44.4	Chegrouche *et al.*, 2009
Pseudomonas alcaligenes biomass	67.35	Yan-li *et al.*, 2011
Bacillus cereus biomass	78.34	Yali *et al.*, 2011
Pseudomonas fluorescens biomass	80.06	Yuan-hong *et al.*, 2011
HPMCP (hydroxypropyl methylcellulose phthalate) gel	83.3	Wang *et al.*, 2009
Coir pith (present study)	87.16	(present study)
CMCts (carboxymethylated chitosan gel adsorbent) gel	99.0	Wang *et al.*, 2009
CMC (carboxymethylated cellulose gel adsorbent) gel	108.7	Wang *et al.*, 2009
Dry Azolla. filiculoides biomass	117.2	Mashkani and Ghazvini, 2009
Pakistani coal powder	140.0	Shaukat *et al.*, 2005
Magnetically modified fodder yeast (Kluyveromyces fragilis) cells	140.8	Ji *et al.*, 2010
Fresh Azolla filiculoides (as living biomass)	149.5	Mashkani and Ghazvini, 2009

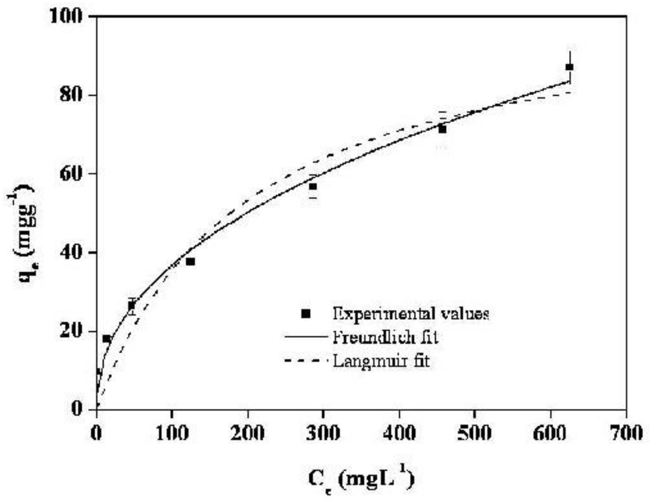


Figure 5. Sorption isotherms for Sr(II) on coir pith

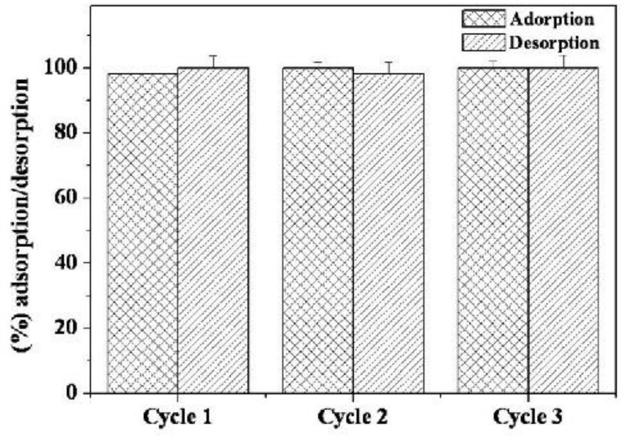


Figure 6. Efficiency for sorption-desorption cycles for Sr(II) using EDTA as a desorbent

detection limit (5 ngL^{-1}) in the presence of a maximum of 3500 mgL^{-1} Na^{+}, 30 mgL^{-1} K^{+}, 500 mgL^{-1} Mg^{2+} and 800 mgL^{-1} Ca^{2+} (Table 5).

Table 5. Removal of strontium from groundwater samples

Ground water samples	Conc. of Sr spiked before adsorption (mgL^{-1})	Conc. of Sr detected After adsorption (mgL^{-1})
1	5	N.D.
2	5	N.D.
3	10	N.D.
4	10	N.D.
5	15	N.D.
6	15	N.D.

* N.D. indicates not detected

This suggests almost complete removal of Sr was achieved and the recovery was found to be quantitative in the presence of other ions. The cations such as Na^{+}, K^{+}, Mg^{2+} and Ca^{2+}, which co-exist generally in groundwater, did not interfere with the sorption of Sr^{2+}. The result implies that interference of other metal ions on the sorption capacity may not be significant unless the sorbent is saturated. The present studies demonstrated the use of coir pith as an efficient sorbent material for the removal of strontium from aqueous solutions. In view of environmental protection, the eventual disposal of the biosorbent material should also be considered after its use as sorbent in several cycles. A number of alternatives are available, including incineration, disposal in existing landfills or further use in other applications. The first two options may be relatively expensive and not suitable in many situations. Nevertheless, coir pith can also be reused as the soil conditioner, soil compost, and organic growing medium for agricultural purposes.

Conclusion

The ability of coir pith biomass as a suitable candidate to remove strontium from aqueous solutions has been investigated. Optimum sorption of Sr(II) on coir pith occurred in the pH range of 5-8. The contact time of 4h was required to reach the equilibrium. The biosorption of Sr(II) is well-represented by the pseudo second order kinetic model with a contribution of intraparticle diffusion. The maximum sorption capacity of the biomass for Sr(II) was 87.16 mgg^{-1} in the studied concentration range. Ion exchange is probably the major mode of sorption process. Repeated use of coir pith in several sorption-desorption cycles indicated an efficient recovery of the sorbed metal ions and regeneration of the sorbent. Sr(II) was quantitatively removed from spiked groundwater samples, which proves the applicability of the sorbent in real situations. To conclude, this lignocellulosic biomass- coir pith is economical, environment-friendly and efficient sorbent for removal of Sr(II) ions from aqueous solutions.

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