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Abstract—A mesoporous silica was synthesized by annealing (3-Aminopropyl) triethoxysilane grafted chitosan at 800°C. The mesoporous silica was characterized by the XRD (X-ray diffraction) analysis. The BET specific surface area and pore size of silica was found to be 178.42 m²/g and 4.13 nm. The mesoporous silica was then employed for the efficient remediation of aqueous solutions contaminated with Cu(II) under batch and column reactor operations. The mesoporous silica showed extremely high per cent removal of Cu(II) at wide pH range i.e., pH ~2.0 to 7.0. Relatively a fast uptake of Cu(II) was occurred and high percentage removal was obtained at initial concentrations studied from 1.0 to 15.0 mg/L. The equilibrium state sorption data were utilized for the Langmuir and Freundlich adsorption isotherm studies. Moreover, the effect of an increase in background electrolyte concentrations from 0.0001 to 0.1 mol/L NaNO₃ was assessed for the uptake of Cu(II) by mesoporous silica. The equilibrium sorption was achieved within 240 min of contact and the kinetic data is best fitted to the pseudo-second-order and fractal like pseudo-second-order kinetic models. In addition, the mesoporous silica was used for dynamic studies under column reactor operations. The breakthrough curve was then used for the non-linear fitting of the Thomas equation and the loading capacity of the column for Cu(II) was estimated.

Keywords: Chitosan, Mesoporous Silica, Cu(II), Column Reactor

INTRODUCTION

The contamination of aquatic environment with heavy metals is widespread around the globe and the diverse sources make serious environmental concerns. These heavy metals are non-biodegradable, persistent and relatively possess high bio-toxicity even at low level concentrations.

Removal of toxic heavy-metal contaminants from wastewater streams is one of the most important environmental issues to be addressed adequately. Copper (Cu(II)) is a common hazardous pollutant and one of the most widespread heavy metal contaminants in the environment [1]. It is released from several sources of industries such as electro plating, mining and smelting, brass manufacturing, petroleum refining and Cu-based agrochemical industries [2-4]. Major sources of Cu(II) in non-industrial areas include run off from road surfaces and parking lots, automobile corrosion, building materials, and lawn fertilizers [5]. The presence of high level concentration of Cu(II) in drinking water causes vomiting, abdominal pain, nausea, diarrhoea, liver and kidney damage, chronic disorders, cramps in the calves and hepatic and renal damage, capillary damage, gastrointestinal irritation and central nervous system irritation [6-8]. Due to these threats towards human health, environmental agencies enforced stringent levels for the maximum acceptable limits of heavy metals discharge into the rivers, lakes and landscapes. Maximum permissible limit of Cu(II) in drinking water is suggested to be 0.05 mg/L (US Environmental Protection Agency (EPA)) [9,10]. Therefore, it is vital to
remove the Cu(II) at low levels from wastewaters effectively before an usual discharge of effluent into the water bodies.

Several methods are demonstrated to remove the Cu(II) from waste water such as precipitation, ion exchange, adsorption, membrane process, etc [11,12]. Among them, adsorption technique is found to be most economical and widely used method for the removal of metal cations and metalloid anions [13]. Recent works have shown that many materials such as functionalized nanomaterials, magnetic particles, functionalized silica, Nanotubes etc [14–17], are employed as effective sorbent materials for the removal of Cu(II) from wastewaters. Numerous mesoporous materials (2–5 nm) based on silica are synthesized and employed in the remediation of aquatic environment contaminated with several heavy metal toxic ions due to several advantages such as high specific surface area, thermal and mechanical stability, uniform pore distribution, high adsorption capacity, and high functionalization ability [18].

A renewable, amphoteric functionalized mesoporous silica (AG-SBA-15) was synthesized and exhibited an excellent performance for simultaneous removal of Cu(II) cations and Cr\(_{2}\)O\(_7\)\(^{2-}\) metalloid anions from aqueous solution, with a maximum adsorption capacity of 2.216 mmol/g Cu(II) and 3.305 mmol/g Cr\(_{2}\)O\(_7\)\(^{2-}\), respectively [19]. The other study shows the direct immobilization of a synthesized (3-(3-(methoxycarbonyl)benzylidene) hydrazinyl)benzoic acid onto mesoporous silica monoliths and employed for its potential use in Cu(II) ions sensing and removal from wastewater [20]. The present communication deals the synthesis of mesoporous silica using the silane grafted chitosan as a template. The synthesized mesoporous material is found to possess a high specific surface area and shows remarkably high adsorption capacity towards the removal of Cu(II) from aqueous solutions conducted under the batch and column reactor studies.

**MATERIALS AND METHOD**

**Materials**

Medium-molecular weight chitosan, having 75–85% degree of de-acetylation with a given viscosity 20–200 cP was procured from Sigma Aldrich, USA and used without further purification. (3-aminopropyl) triethoxysilane (97%) was obtained from Sigma Aldrich, USA. Copper sulphate, glacial acetic acid, methanol and N, N-dimethylformamide was procured from Merck, India. Ethanol (AR) was obtained from Jebsen & Jessen Gmbh & Co., Germany. The other chemicals such as sodium nitrate, hydrochloric acid and sodium hydroxide were used of AR (Analytical Reagent) Grade. The water was used as de-ionized distilled water (18 M\(_2\) - cm) obtained from the Millipore water purification system (Milli-Q+).

**Preparation of Mesoporous Silica**

For the synthesis of mesoporous silica, silane grafted chitosan was first prepared by using the sol-gel preparation process. For this first step process, 30 g of chitosan was dispersed under stirring in 300 mL of N, N-dimethylformamide in a three neck round bottom flask and then 30.52 mL of (3-Aminopropyl) triethoxysilane was added to the dispersion. The flask was sealed and stirred for 48 hrs at 105°C under the N\(_2\) atmosphere. Further, the mixture of acetic acid and ethanol was introduced in this flask with the final molar ratio of (3-Aminopropyl) triethoxysilane: acetic acid: ethanol to 1:3:6. The suspension was then again stirred in the sealed flask for another 24 hrs at room temperature in N\(_2\) atmosphere. The gel was clearly dispersed in the solution mixture. Subsequently, the solvents were removed from the product by centrifugation and the solid sample was carefully collected. The solid was washed with methanol at least for 10 times and dried at 50°C in a drying oven. Furthermore, the solid sample prepared was annealed at 800°C using muffle furnace for three hours to obtain mesoporous silica.

**Characterization of Mesoporous Materials**

The mesoporous silica was characterized by the XRD analytical method. The X-ray diffraction (XRD) data was recorded by the X-ray diffraction machine (PANalytical, Netherland; Model X’Pert PRO MPD using Cu K\(_\alpha\) radiation having wavelength 1.5418 Å. The specific surface area, pore volume and pore size of the solids were obtained by nitrogen adsorption and desorption using the BET Analyzer (Macsorb HM machine, Model-1201, Japan).

**Batch Reactor Experiments**

A stock solution 100.0 mg/L Cu(II) was prepared by dissolving an appropriate amount of copper sulphate in purified water. The required Cu(II) concentrations were then obtained by the successive dilution of stock solutions. A 50 mL aliquot of 5.0 mg/L of Cu(II) solution was taken into several polyethylene bottles and the pH of each bottle was adjusted adding drop-wise the concentrated HCl/ NaOH solution. 0.1 g of mesoporous silica was then introduced
into these bottles containing Cu(II) solutions. The bottles were kept in an automatic incubator shaker (TM Weiber, ACMAS Technologies Pvt. Ltd., India) for 24 hrs at 25°C. The samples were then removed from the shaker and filtered using 0.45 μm syringe filter; the pH was then checked again and recorded as equilibrium pH. The filtrates were subjected to measure the absorbance of solutions using Microwave Plasma Atomic Emission Spectroscopy (MP-AES; Agilent 4100 MP-AES).

The concentration dependence study was performed with the initial Cu(II) concentration ranged from 1.91 mg/L to 13.51 mg/L at constant pH ~5.0 with a solid dose of 2.0 g/L. The sorption process was carried out as reported previously. The results were reported in terms of the initial Cu(II) concentration (mg/L) against the percentage of Cu(II) removal.

The sorption data obtained for varied sorptive concentration at constant pH and temperature was further utilized to deduce the adsorption isotherms particularly Langmuir and Freundlich adsorption isotherms. The linearized Langmuir adsorption model [21] was utilized to estimate the maximum Cu(II) adsorption capacity \( q_o \) of mesoporous silica within the studied concentration range (Eq. (1)):

\[
\frac{C_e}{q} = \frac{1}{q_o} + \frac{C_e}{q_o} \tag{1}
\]

where, \( q \) is the amount of solute adsorbed per unit weight of adsorbent (mg/g) at equilibrium; \( C_e \) is the equilibrium bulk concentration (mg/L); \( q_o \) is the Langmuir monolayer adsorption capacity, i.e., the amount of solute required to occupy all the available active sites in unit mass of solid sample (mg/g) and \( 'b' \) is the Langmuir constant (L/g). Similarly, a simple linear form of Freundlich equation [22] was also employed to fit the sorption data at different sorptive concentrations of Cu(II) (Eq. (2)):

\[
\log q_e = \frac{1}{n} \log C_e + \log K_f \tag{2}
\]

Where \( q_e \) and \( C_e \) are the amount adsorbed (mg/g) and bulk sorptive concentration (mg/L) at equilibrium, respectively, and \( K_f \) and \( \frac{1}{n} \) are the Freundlich constants referring to adsorption capacity and adsorption intensity or surface heterogeneity, respectively.

The dependence of the Cu(II) adsorption on the background electrolyte concentration was determined varying the background electrolyte concentrations from 0.0001 to 0.1 mol/L NaNO₃ in the sorptive solution. The solution pH is maintained at ~5.0 of and temperature 25°C was kept constant throughout the experiment. The results were presented as the percentage of Cu(II) removed against the background electrolyte concentration.

The time dependence adsorption of Cu(II) by mesoporous silica was also carried out. The initial Cu(II) concentration was taken as 5.0 mg/L and kept a constant pH of ~5.0. A constant dose of solid 2.0 g/L was used and the temperature was maintained at 25°C. The results were reported as the amount of Cu(II) removed (mg/g) as a function of time (min) (Fig. 6. It is reported in percentage). The time dependence data were further utilized to deduce the kinetic studies to obtain the rate constant and the sorption capacity of these solids to remove Cu(II). Various empirical kinetic models viz., the pseudo-first order (PFO) [23], pseudosecond order (PSO) [24] and fractal-like pseudosecond-order (FL-PSO) [25] models in its non-linear form i.e., Eq. (3), (4) and (5), respectively, were utilized for kinetic modelling studies.

\[
q_t = q_e \left(1 - e^{-k_i t}\right) \tag{3}
\]

\[
q_t = \frac{q_o k_i t}{1 + q_o k_i t} \tag{4}
\]

\[
q_t = \frac{k_{2f}^{2f} t^{n}}{1 + k_{2f}^{2f} t^{n}} \tag{5}
\]

Where \( q \) and \( q_e \) are the amounts of Cu(II) adsorbed at time ‘\( t \)’ and the adsorption capacity at equilibrium, respectively. \( k_{1} \) and \( k_{2} \) are the PFO and PSO rate constants, respectively. The constants \( k \) and \( \mathbf{\alpha} \) are the rate constant and the fractal constant, respectively.

**Fixed Bed Column Experiments**

The fixed bed column experiment was conducted to assess the performance of mesoporous silica in the removal of Cu(II) under the dynamic conditions. The breakthrough time and the shape of the breakthrough curves were, of course, important characteristics to deduce the unit operation and dynamic response of a column [22]. The fixed bed column study was performed using a glass column of 30 cm long and having an inner diameter of 1 cm. 0.5 g of porous silica was kept in the middle of the column, and rest of the column was packed with glass beads. A Cu(II) solution having ~5.0 mg/L concentration with a constant pH ~5.0 was pumped upward from the bottom of the column using a peristaltic pump (KrosFlo Research I Peristaltic Pump, Spectrum Laboratories Inc., CA, USA) at a constant flow-rate of 1.0 mL/min. The effluent samples were collected using a
fraction collector (Spectra/Chrom CF-2 Fraction Collector, Spectrum Laboratories). The liquid samples collected were filtered using a 0.45 μm syringe filter and the total bulk sorptive concentration was measured using MP-AES. The breakthrough data obtained was simulated to deduce the removal capacity of mesoporous silica using the Thomas equation (Eq. (6)) [26]:

\[
\frac{C_e}{C_i} = \frac{1}{1 + \theta K_T (q_m - C_i) V/Q}
\]

where \( C_i \) and \( C_e \) are the concentrations (mg/L) of the influent and effluent Cu(II) solutions, respectively; \( K_T \) the Thomas rate constant (L/min/mg); \( q_m \) is the maximum amount of the Cu(II) which can be loaded (mg/g) under the specified column conditions; \( m \) is the mass (g) of mesoporous silica used; \( V \) is the throughput volume (L); and \( Q \) is the flow rate of the pump sorptive solution (L/min). A non-linear regression of the breakthrough data were performed by the least square fitting method of the two unknown parameters \( K_T \) and \( q_m \).

**RESULTS AND DISCUSSION**

**CHARACTERIZATION OF MESOPOROUS SILICA**

In order to obtain the textural properties of the synthesized porous silica, the BET surface area analyser was used to measure the specific surface area, pore size and pore volume of the solid. Relatively high surface area, i.e., 178.42 m²/g was obtained and the pore size and pore volume were obtained to be 4.13 nm and 0.0023 cm³/g, respectively. These results indicated that the synthesized silica material possessed relatively high surface area with mesopores on its surface. Moreover, X-ray diffraction analysis was conducted for the synthesized porous silica and the diffraction pattern is graphically shown in Fig. 1. It is evident from the Fig. 1 that a predominant reflection is occurred at the 2θ value of 23 to 24 which clearly indicated the presence of silica as a major component in this sample. This again confirms the presence of silica on the porous Chi-APTES.

**BATCH REACTOR OPERATIONS**

**Effect of pH**

The pH dependence removal of Cu(II) by the mesoporous silica is studied with the pH range from ~2.0 to 7.0. The batch experiments are conducted as detailed before and the results are presented graphically in Fig. 2. Figure clearly indicated that increasing the initial pH of the sorptive solution is significantly caused for an apparent increase in the adsorption of Cu(II). Moreover, the percent uptake of Cu(II) by the mesoporous silica is significantly high comparing to the bare chitosan sample throughout the studied pH region i.e., pH ~2.0 to 7.0. This further points the applicability of this mesoporous silica towards the removal of Cu(II) from aqueous solutions. It is observed that increasing the pH from 2.11 to 6.82 has caused to increase in Cu(II) removal respectively from 12.41 to ~100%. The low removal of Cu(II) at lower pH is attributed due to the competition of Cu(II) ions with H⁺ ions towards the solid surface. Also the surface of porous silica possesses net positive charge at lower pH values which apparently repels Cu(II) ions [27]. However, a gradual increase in solution pH results a gradual increase in negative charge density onto the solid surface. This ultimately favours the sorption of Cu(II) ions onto the solid surface [28]. The Fig. 2 further indicates that the removal of Cu(II) is reached 100% at pH 7.0. Moreover, the speciation studies of Cu(II) shows that the formation of insoluble tenorite predominates from pH 5.2. Hence, the higher uptake of Cu(II) at higher pH is, perhaps, due to the adsorption along with co-precipitation of the Cu(II) onto the solid surfaces [29].

Additionally, it is interesting to note that within the studied pH, the uptake of Cu(II) is significantly high comparing to the unmodified chitosan precursor. Therefore, the porous silica shows a potential materials for the removal of Cu(II) from aqueous solutions.

![XRD Pattern of Mesoporous silica](image1.png)

*Fig. 1: XRD Pattern of Mesoporous silica*

![Effect of pH on the Removal of Cu(II) Using Porous Silica](image2.png)

*Fig. 2: Effect of pH on the Removal of Cu(II) Using Porous Silica.*
**Effect of Equilibrium Cu(II) Concentration**

The concentration dependence sorption of Cu(II) by the synthesized mesoporous silica was studied at a wide range of initial Cu(II) concentration i.e., from 1.91 to 13.51 mg/L at a constant equilibrium pH~5.0 with a solid dose of 2.0 g/L at temperature 25°C. The equilibrium stage percent removal of Cu(II) against the initial concentration of Cu(II) using the mesoporous silica is presented graphically in Fig. 3. From the Fig., it is evident that increasing the concentration of Cu(II) results in an apparent decrease in percent uptake of Cu(II). In brief, increasing the concentration of Cu(II) from 1.91 to 13.51 mg/L, the corresponding decrease in percent removal of Cu(II) is found to be 85.34 to 49.74%. This decrease in percent uptake of Cu(II) is explicable with the fact that on increasing the sorptive concentrations at a constant solid dose, solid provides relatively lesser number of active sites for large number of Cu(II) ions. This consequently results in less percent removal of the Cu(II) ions from aqueous solutions [30,31]. However, the amount of Cu(II) adsorbed by mesoporous silica is increased from 0.8 to 3.36 mg/g while increasing the initial Cu(II) concentration from 1.91 to 13.51 mg/L. This suggests an higher affinity of mesoporous silica towards Cu(II). This again suggests the potential applicability of the material in the remediation of copper contaminated water even at higher concentration levels.

**Adsorption Isotherm Studies**

The linear fitting of Langmuir and Freundlich adsorption isotherm with the experimental data obtained for the removal of Cu(II) using mesoporous silica is shown in Fig. 4(a) and 4(b), respectively. High values of correlation coefficient (R²) obtained for the isotherm fitting for Cu(II) indicated that equilibrium data is reasonably fitted well to the Langmuir and Freundlich adsorption isotherms; however, Langmuir adsorption isotherm shows relatively better fit than the Freundlich adsorption isotherm. The unknown constants i.e., Langmuir monolayer sorption capacity (qo) and Langmuir constant (b), Freundlich constants (Kf and 1/n) are estimated and returned in Table 1. The high value of Langmuir constant (b) reflects the affinity of mesoporous silicatowards Cu(II) and the fractional value of Freundlich constant (1/n); (0 < 1/n < 1) infers the heterogeneous surface structure of hybrid materials with an exponential distribution of active sites on the surface [32].

![Langmuir](a)

![Freundlich](b)
Table 1: Langmuir and Freundlich Constants Along with R² Values Obtained for the Adsorption of Cu(II) Bymesoporous Silica.

<table>
<thead>
<tr>
<th>Constants</th>
<th>Langmuir</th>
<th>Freundlich</th>
</tr>
</thead>
<tbody>
<tr>
<td>q₀ (mg/g)</td>
<td>b (L/g)</td>
<td>R²</td>
</tr>
<tr>
<td>3.619</td>
<td>0.117</td>
<td>0.973</td>
</tr>
</tbody>
</table>

**Effect of Background Electrolyte Concentration**

The background electrolyte concentration dependence study is an important parameter which is generally used to distinguish the nonspecific and specific adsorption of sorbing species onto the solid surfaces. Specific sorption is characterized by more selective and less reversible reactions, including chemisorbed inner-sphere complexes while nonspecific adsorption (or ion exchange) involves weak and less selective outer-sphere complexes [33]. Outer sphere complexes involve only electrostatic interactions and are strongly affected by the ionic strength of aqueous phase, while inner sphere complexes involve much stronger covalent or ionic binding and weakly affected by the ionic strength [34]. Therefore, the study is extended varying the background electrolyte concentrations from 0.001 to 0.1 mol/L of NaNO₃ in the sorption of Cu(II) by the mesoporous silica. The percent of Cu(II) removal as a function of background electrolyte concentration is shown graphically in Fig. 5. It is observed that increasing the background electrolyte concentration from 0.0001 mol/L to 0.1 mol/L (1000 times) could not show significant effect in percent removal of Cu(II). Quantitatively, increasing the background electrolyte concentration from 0.0001 mol/L to 0.1 mol/L is caused to decrease the uptake of Cu(II) from 90.61% to 87.03% (i.e., only 3.38% decrease) by the porous silica. Further, these results suggest that Cu(II) aggregates onto the solid surface and forms an 'inner-sphere complexes' onto the solid surfaces. In other words, Cu(II) is bound onto the solid surface with strong chemical forces.

![Fig. 5: Effect of Background Electrolyte (NaNO₃) Concentrations in the Removal of Cu(II) by Porous Silica.](image)

**Kinetic Studies**

The time dependence sorption of Cu(II) by the porous silica is studied varying the time of contact from 1 to 360 min keeping the initial Cu(II) concentration at 5.0 mg/L and at pH 5.0. The time dependence sorption results are returned in Fig. 6. Fig. 6 clearly reveals that a fast initial uptake of Cu(II) is occurred onto the solid surface and achieved an apparent equilibrium within 240 min of contact between the solid/solution interface. The fast initial uptake of Cu(II) indicates seemingly the higher affinity of this porous silica towards Cu(II).

The adsorption kinetic modelling is performed using the pseudo-first order (PFO) (Eq. (3)), pseudo-second order (PSO) (Eq. (4)) and fractal-like pseudo-second-order (FL-PSO) (Eq. (5)) kinetic models. A non-linear fitting is conducted using the Excel add-ins solver with user-defined functions to minimize the residuals between the models calculated and measured values. The estimated values of the unknown parameters along with the least-square sum of fittings are given in Table 2. The kinetic data is fairly fitted well to the PSO and FL-PSO models compared to the PFO model. It is reported previously that the rate coefficient of PSO model (k₂) is a complex function of the initial concentration of the adsorbate species [23]. However, the FL-PSO model is developed with the fact that different paths of adsorption take place and the adsorption rate coefficient is defined as a function of time [35].

![Fig. 6: Effect of Contact Time in the Removal of Cu(II) by Porous Silica.](image)

Table 2: Estimated Kinetic Parameters for the PFO, PSO and FL-PSO Kinetic Models in the Removal of Cu(II) by Mesoporous Silica

<table>
<thead>
<tr>
<th>Models</th>
<th>Constants Estimated</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFO</td>
<td>qₑ (mg/g)</td>
<td>Porous Silica</td>
</tr>
<tr>
<td></td>
<td>k₁ (min⁻¹)</td>
<td>2.086</td>
</tr>
<tr>
<td></td>
<td>s²</td>
<td>0.034</td>
</tr>
<tr>
<td>PSO</td>
<td>qₑ (mg/g)</td>
<td>2.29</td>
</tr>
<tr>
<td></td>
<td>k₂ (g/mg min)</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td>s²</td>
<td>0.618</td>
</tr>
<tr>
<td>FL-PSO</td>
<td>qₑ (mg/g)</td>
<td>2.989</td>
</tr>
<tr>
<td></td>
<td>k₂ (g/mg min)</td>
<td>0.0015</td>
</tr>
<tr>
<td></td>
<td>s²</td>
<td>0.218</td>
</tr>
<tr>
<td></td>
<td>á</td>
<td>0.089</td>
</tr>
</tbody>
</table>

s²: Least Square Sum
Fixed Bed Column Studies

Fixed-bed column reactor study is carried out as described previously. The results are presented graphically in Fig. 7. Fig. shows that a complete breakthrough is obtained at the throughput volume of 0.24 L. The high value of breakthrough volume indicates strong affinity of the mesoporous material towards the Cu(II) even under the dynamic conditions. A non-linear fitting is conducted with an known Thomas equation (Eq. (6)) using the basic breakthrough data. As shown in Fig. 7, the column data is reasonably fitted to the non-linear Thomas equation and the least square sum is obtained to be $2.4 \times 10^{-1}$. The low value of the least square sum reflects better applicability of the Thomas fitting [36]. The Thomas rate constant ($K_T$) and the loading capacity ($q_o$) are found to be $3.72 \times 10^{-3}$ L min$^{-1}$ mg$^{-1}$ and 3.43 mg/g, respectively. The results clearly indicate that very high loading capacity is achieved even under the dynamic conditions; indicating the applicability of synthesized mesoporous silica for the removal of Cu(II) in real wastewater treatment technology.

Fig. 7: Breakthrough Curves Obtained for Cu(II) Using Porous Silica

Conclusion

Mesoporous silica is successfully synthesized using chitosan as template precursor material and characterized by the XRD and BET analysis. The BET and XRD results confirm the presence of silica as a major component in the solid sample where as the specific surface area of mesoporous silica is found to be 178.42 m$^2$/g. Further, the mesoporous silica is utilized for the treatment of Cu(II) contaminated waters under batch and column reactors operations. Batch studies show that the mesoporous silicas possessed an extremely high percent removal of Cu(II) within the pH range from 5.0 to 7.0. The high percent removal of Cu(II) by the mesoporous silica is attributed due to the high specific surface area of solid which provides more active sorbing sites for the Cu(II) ions. The mesoporous material shows a fast uptake of Cu(II) which attains an apparent saturation within 240 min of contact. The high percent removal of Cu(II) is obtained for varied initial concentrations of Cu(II) i.e., from 1.91 to 13.51 mg/L and the equilibrium state sorption data is fitted reasonably well to the linear Langmuir adsorption isotherm than Freundlich adsorption isotherm. An increase in background electrolyte concentrations (i.e., from 0.001 to 0.1 mol/L NaNO$_3$) could not affect the percent uptake of Cu(II) by mesoporous silica. This implied that the Cu(II) ions are sorbed onto the surface of the adsorbent by strong chemical forces and forms an inner sphere complexes. Furthermore, a fixed-bed column reactor studies show that the mesoporous material possesses a significantly high loading capacity for Cu(II) i.e., 3.43 mg/g under the dynamic conditions. All these results indicate that the synthesized mesoporous silica is the highly promising adsorbent for the removal of heavy Cu(II) from aqueous solutions.

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