Silica monolith with mesopore structure: synthesize, characterization and application for cadmium removal from wastewater

H. Sharififard[1*], R. Hayati[2], S. Hayati[1]

[1] Chemical Engineering Department, Yasouj University, Yasouj, I.R. Iran
[2] Materials Engineering Department, Yasouj University, Yasouj, I.R. Iran

ABSTRACT: One of the most important issues in today's world is the pollution of water with toxic and dangerous metals. Cadmium is one of the toxic metals that enter the surface and groundwater through various industrial wastewaters. In this paper, polyethylene oxide-based silica monolith was synthesized with a uniform porous structure and was used to remove cadmium ions from the aqueous medium. The chemical and physical properties of silica monolith were characterized by SEM, BET, and FTIR techniques. The results of BET and SEM analysis showed that the monolith has a mesopore structure with a specific surface area of 543 m2g-1. The synthesized silica monolith was used as an adsorbent for cadmium removal in a batch adsorption process and the effects of operating parameters including pH, adsorbent concentration, cadmium initial concentration, and contact time were investigated. The Central Composite Design method was used to optimize the effects of operating parameters. The results of the experimental design showed the importance of pH and adsorbent concentration parameters. The analysis of equilibrium data indicated that the maximum adsorption capacity of the monolith for cadmium is 153 mg g-1. The kinetic data were analyzed with various models and results indicated the importance of chemical adsorption. The results of regeneration and reuse of monolith as an adsorbent showed that the synthesized monolith has a high ability to adsorb heavy metal ions from an aqueous solution and can be an option for water treatment at industrial scale.

1. Introduction

One of the most important issues in today's world is environmental pollution with toxic and hazardous metals [1-3]. One of the most common heavy metals is cadmium, which is widely used through the combustion of fossil fuels, the production of cement, color, and batteries, and electroplating. It enters the environment through the effluents of these industries. The presence of cadmium in water, even at very low concentrations, is extremely harmful to the environment, humans, and even aquatic live [4]. The maximum permitted cadmium concentration in drinking water is 0.003 mg/L [5]. Studies in recent years have shown that adsorption is a cost-effective and high-efficiency method for the separation of heavy metals from wastewater [6]. The adsorbent is one of the important factors in the performance of the adsorption process. The adsorbent should have a high specific surface area, high porosity, suitable functional groups, and high mechanical and chemical strength. Silica or SBA-15 is one of the materials that has received much attention today due to its high strength properties and good porosity. SBA-15 is a porous material with a mesoporous structure [7-11]. However, most of the silica mesopore materials are synthesized in the form of powder, which their structural and porosity properties are usually reduced during the process due to their adhesion and agglomeration, and this problem is particularly severe when used in industrial applications. A review of the current research indicates that little research has been done on the synthesis of monolithic silica mesopores so far, its application as a cadmium adsorbent from the aquatic environment has not been reported. Therefore, in this research work, silica monoliths were synthesized and the effect of process parameters on the efficiency of the cadmium adsorption process was investigated and then the kinetics and equilibrium of adsorption were investigated.

2. Methodology

Silica monoliths were synthesized from polyethylene oxide according to the method presented in Sachse et al. paper [12]. To characterize the morphology, porosity structure, and surface chemistry of synthesized monolith, FTIR, SEM, and BET were used. Also, the pHZPC value was determined [6]. To optimize the adsorption of cadmium with silica monolith, central composite design (CCD) was used and the effects of solution pH, adsorbent concentration (g L^{-1}), and cadmium initial concentration (mg L^{-1}) was investigated. According to the CCD method, 20 experiments were performed and the removal percentage was selected as a response for analyzing data. Also kinetic and equilibrium experiments

*Corresponding author's email: h.sharififard@yu.ac.ir

were performed and analyzed with different kinetic methods and isotherms. The regeneration experiments were performed with 0.1 M EDTA solution at five cycles.

3. Discussion and Results

The results of SEM and BET analysis showed that the synthesized monolith has a mesoporous structure with a surface area of 540 m^2g^{-1}. The value of pH_{ZPC} was 4.19. The results of the FTIR analysis confirmed the existence of Si-OH and Si-O-Si bonds. Results of ANOVA showed that pH and adsorbent concentration parameters had the most influence on cadmium removal with silica monolith. Also, the interaction between pH-adsorbent concentration and cadmium concentration-adsorbent had a significant effect on the cadmium separation process. Results showed that the cadmium adsorption increased with increasing pH. At pH <4.19, the silica monolith surface has a positive charge and its surface charge is negative at pH> 4.19. Also, the cadmium ions present in the solution as Cd2+. Therefore, at pH<4.19 due to electrostatic repulsion, the cadmium adsorption is low. Then with increasing pH and increasing the negative charge of the monolith surface, the amount of cadmium adsorbed increased. The optimum condition for cadmium adsorption is pH=5.99, adsorbent concentration: 1.39 g L^{-1},and initial concentration=84.34 mg L^{-1}.

Fig. 1(a) presents the kinetics data with different kinetics models. Results show that the pseudo-second-order model has very good agreement with the experimental data. Fig. 1(b) presents the equilibrium isotherms for the cadmium adsorption with silica monolith. Data shows the endothermic nature of cadmium adsorption process. The analysis of data with various isotherms indicates that the Langmuir model fits better with the data. These results indicate the predominance of chemical adsorption. The maximum adsorption capacity of silica for cadmium was 153 mg g-1 which is comparable with other adsorbents reported in papers [13-16]. The results of regeneration tests showed that the cadmium removal percentage has decreased from 100 to 73.5% after 5 cycles.

4. Conclusions

Silica monolith was synthesized and used to separate cadmium from an aqueous solution. The results of the characterization analyzes showed that the synthesized monolith has a uniform mesoporous structure. The results of the experimental design showed that pH and adsorbent concentration are important parameters. Kinetics and equilibrium analysis of the adsorption process showed that the predominant mechanism is chemical adsorption. By analyzing the equilibrium data at different temperatures, the maximum adsorption capacity of monosil for cadmium was 153 mg cadmium per g of monosil. It was also found
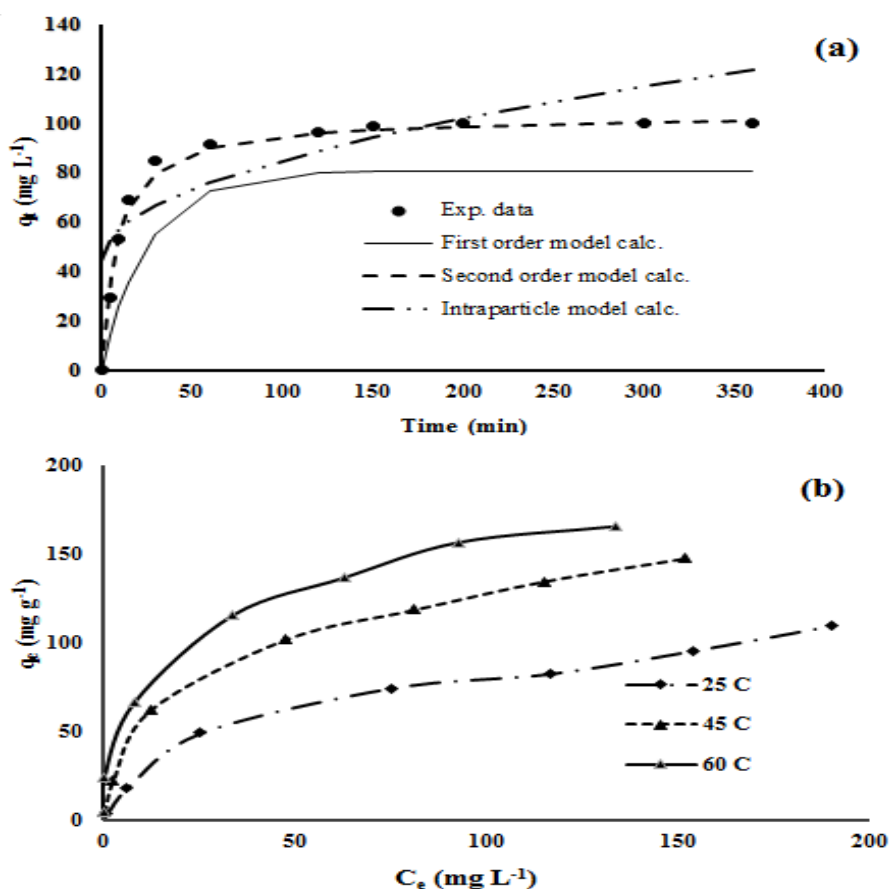

Fig. 1. (a): Kinetics data, (b): Equilibrium data

that the the adsorption process of cadmium with monosil is endothermic.

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