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SBA-16: Application for the removal of neutral, cationic, and anionic dyes from aqueous medium

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ABSTRACT

The adsorption of four dyes, namely Neutral Red (Basic Red 5, NR), Congo Red (Sodium salt of 3,3′-([1,1′-biphenyl]-4,4′-diyl)bis(4-aminonaphthalene-1-sulfonic acid, CR)), Safranin O (Basic Red 2, SF), and Reactive Red 2 (Red MX-5B, RR2) onto SBA-16 material was studied in detail to investigate the plausible effect of interactions between the adsorbate and adsorbent molecule vis-a-vis determining the pore structure stability of SBA-16 and its potential application for the removal of these dyes from aqueous media. Various characterization techniques including FTIR spectra, Nitrogen adsorption–desorption isotherms, HR-XRD patterns, FE-SEM and HR-TEM analyses of the adsorbent were carried out to get an insight of pre and post adsorption in surface morphology. It was observed that the dye adsorption did not introduce any serious disorder on the pore structure stability of SBA-16 and this material probably be a very promising adsorbent for the removal of both NR and SF (q_m = 276.24 mg g^{-1} for NR, q_m = 240.39 mg g^{-1} for SF) from aqueous medium. Various adsorption parameters such as pH, contact time, temperature, dye concentration and adsorbent dosage was studied to provide more information about the adsorption characteristics of SBA-16. Kinetics of adsorption followed pseudo-second-order model as well as intraparticle diffusion model. The adsorption isotherms data was well fitted with the Langmuir isotherm model. Thermodynamic parameters suggest that the dye adsorption process is spontaneous. Finally, desorption experiment indicates very good regeneration efficiency of the adsorbent.

1. Introduction

One of the major sources of water pollution is coloured wastewater, which is coming out from dye, pigment and textile industries. The increase in population is the key factor for the requirement of millions of tons of dyes; those are being consumed mainly by various textile industries [1]. These dyes are not easily biodegradable owing to their complex structures. Moreover, the degraded intermediates are also toxic. It was reported that even less than 1 ppm dye makes the effluents coloured [2]. The coloured waste water is a real threat to the growth of biota, enhanced microtoxicity to aquatic life, and reduced light penetration and retardation of photosynthetic activity [3]. Thus, it is essential to remove the dyes from effluent, without disturbing the quality of water and make it reusable for various industrial and agricultural purposes. Among the various chemical, physical, and biological treatment processes, adsorption is a simple, yet effective method for dye uptake [4,5]. Mesoporous materials such as M41s, SBA-*x*, HMS-*x*, FSM and so on have ordered pore-structure with high surface area [6–8] which provides ideal materials for chemical separations [9] and reactions [10–12]. The concept of "supramolecular templating" has enabled the design of mesoporous silica with adjustable pore size and structure [13,14]. Hence, these have been used for various applications [15–17]. Specifically, adsorption properties of mesoporous materials have been studied and shown to be perform well [18–21]. In addition, SBA-16 due to its wall thickness, relative and absolute amounts of micro and meso pore size as well as the existence of negative charge density of Si—O and Si—OH groups, could be effective for the adsorption of cationic dyes in comparison to anionic dyes. NR is a eurhodin dye which is generally used for staining in histology and it is observed as some growth medium for bacterial and cell culture. CR is commonly known to metabolize to benzidine, a known human carcinogen, and a potential danger of bioaccumulation. It can cause allergic

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problems [22,23]. SF is used for biological staining. RR2 is mainly used for dying cotton, and viscose rayon. In the present study, our objective is to examine the possible effect of interaction among various dyes with SBA-16 to changes in pore structure of the adsorbent and to determine the potential of SBA-16 for the removal of four dyes, namely NR, CR, SF and RR2 from aqueous solution. This is the first time, the adsorption of these dyes onto SBA-16 is reported here. The changes of surface characteristics and pore structure of SBA-16 introduced by those dyes adsorption were characterized based on the analyses of FTIR spectra, nitrogen adsorption–desorption isotherms, HR-XRD patterns, FE-SEM and HR-TEM. The H-bonding interactions among the active groups on the surface of SBA-16 and with the functional groups present in those corresponding dye molecules is the key factor for adsorption. In addition, significantly higher surface area, narrow pore-size distribution, better accessibility of the pores, and a moderate hydrophobic character of templating mesoporous SBA-16 also plays the crucial role towards sorption process. The effect of some important and independent variables like pH, contact time, temperature, dye concentration and adsorbent dosage on the adsorption process was also studied to evaluate the nature of sorption process. Further, the desorption studies demonstrate the very good recyclability of the SBA-16 material.

2. Experimental

2.1. Materials

Tetraethoxysilane (TEOS, ≥99%) and Pluronic F127 ($EO_{106}PO_{70}EO_{106}$, MW = 12,600) were purchased from Sigma Aldrich. Hydrochloric acid (HCl, ~37%) was purchased from Merck India. NR, CR, SF and RR2 (~99%) were selected as adsorbate and were supplied by Loba Chemie and used without further purification. All the chemicals were used as received without further purification. Deionised water was used for all the experiment. The structures of these dyes are shown in Fig. 1.

2.2. Synthesis

SBA-16 was synthesized using a method comparable to that reported earlier [24]. Pluronic F127 (4.0 g) was dissolved in 81 mL of 2 M HCl solution and 30 mL of deionised water with stirring for 2 h at room temperature. Then, 9.04 m of TEOS was added to that solution and stirred for 20 h at room temperature. The mixture was then aged at 80 °C for 24 h under static conditions. The solid product (Yield ~98%) was filtered, washed with deionised water, distilled ethanol and air-dried overnight. Calcination was carried

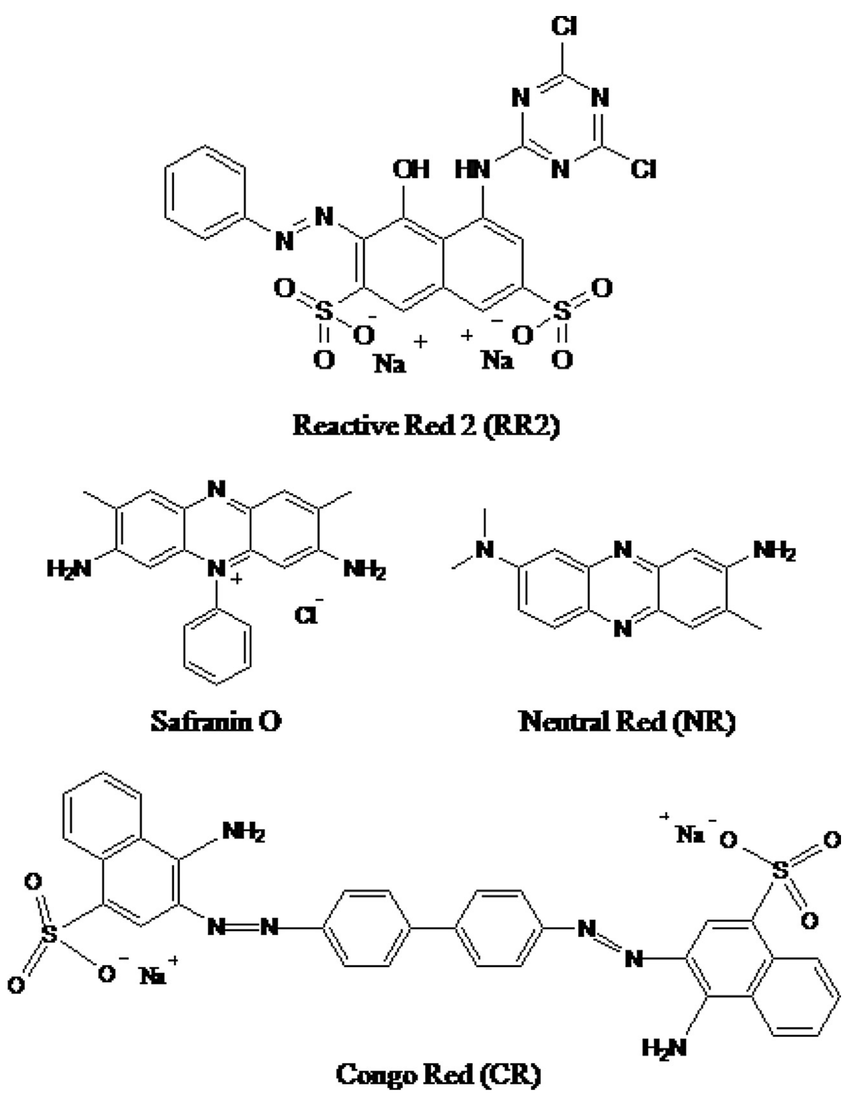

Fig. 1. Chemical structures of dyes used for adsorption.