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Removal of acid dyes from aqueous media by adsorption onto amino-functionalized nanoporous silica SBA-3

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ABSTRACT

Adsorption of acid dyes on SBA-3 ordered mesoporous silica, ethylenediamine functionalized SBA-3 (SBA-3/EDA), aminopropyl functionalized SBA-3 (SBA-3/APTES) and pentaethylene hexamine functionalized SBA-3 (SBA-3/PEHA) materials has been studied. The structural order and textural properties of the synthesized materials have been studied by XRD, FT-IR and nitrogen adsorption–desorption analysis. The adsorption capacity of the adsorbents varies in the following order: SBA-3/PEHA > SBA-3/APTES > SBA-3/EDA > SBA-3. The SBA-3/PEHA is found to have the highest adsorption capacity for all acid dyes. The adsorption mechanism which is based on electrostatic attraction and hydrogen bonding is described. Batch studies were performed to study the effect of various experimental parameters such as chemical modification, contact time, initial concentration, adsorbent dose, agitation speed, solution pH and reaction temperature on the adsorption process. The Langmuir and Freundlich isotherm models have been applied and the Freundlich model was found to be fit with the equilibrium isotherm data. Kinetics of adsorption follows the second-order rate equation.

1. Introduction

Acid dyes are used in many industries such as textile, paper, food processing, cosmetics, plastics, printing, leather, pharmaceutical and dye manufacturing. Water pollution caused by industrial wastewater has become a common problem for many countries [1–3]. It is reported that over 100,000 different commercial dyes and pigments exist, and each year over 7×10^5 ton of dyestuffs is produced. About 1–20% of the total world production of dyes is lost during dyeing process and therefore a large quantity of the dyes appear in wastewater [4,5]. Removal of dyes from water is very important because the water quality is greatly affected by colour and even the presence of very small concentrations of dyes (less than 1 mg L^{-1}) in water is highly visible and is considered unpleasant. Besides that, many of these dyes also cause health problems such as allergic dermatitis, skin irritation, cancer and mutation in human [6–8].

A wide range of methods including biological and physicochemical technologies have been used for removing coloured contaminants from wastewater to decrease their impact on the environment. The main treatment processes include: oxidation or ozonation [9,10], coagulation and flocculation [11], membrane separation [12] and adsorption [13,14]. Among the numerous techniques of dye removal, adsorption has been found to be the most convenient and effective, and it is also less expensive than the others. This process transfers the species from the water effluent to a solid phase thereby keeping the effluent volume to a minimum [15]. During the past few years new promising adsorbents have been reported to be used in adsorption process [16–25].

Mesoporous materials, such as SBA-3 [26,27], ammonium functionalized MCM-41 [28], and silane-modified HMS [29], have been found to be as suitable adsorbents for the removal of dyes from wastewater.

These materials are typically prepared in the presence of surfactant, which act as template during sol–gel hydrothermal synthesis and they are characterized by uniform and controlled adjusted pore sizes, by high specific surface areas and by long-range order [30–32]. A large variety of mesoporous silica has been synthesized by using several templates under various conditions and the formation mechanism of the mesostructures has also been studied by some research groups [31,33–36].

In 1998, Zhao et al. [37] synthesized a new type of mesoporous material called SBA, with uniform hexagonal structure. SBA-3-typemesoporous molecular sieves were synthesized using a low molecular weight alkyl quaternary ammonium template room temperature and under acidic condition. SBA-3 has been shown to possess some micropores inside their mesopore walls, which may be served as active sites for modification [38–40].

A well established fact is that SBA-3 has a negative charge density due to the presence of Si–O and Si–OH groups, which

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