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Adsorption of reactive blue 21 and reactive red 141 from aqueous solutions onto hydrotalcite

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ABSTRACT

The adsorption potential of hydrotalcite (HT) for reactive blue 21 (RB-21) and reactive red 141 (RR-141) in aqueous solutions has been investigated by batch technique.HT was characterized by X-ray photoelectron spectroscopy (XPS), X-ray diffractometry (XRD), FT-IR spectroscopy (FT-IR), zeta potential and scanning electron microscopic (SEM) techniques. Adsorption studies were carried out as a function of various parameters like pH, adsorbent dose, co-existing anions, time of contact and initial dye concentration. The isotherm parameters of both the dyes were found to be in good agreement with Langmuir and Freundlich models. The adsorption capacity of HT for RB-21 and RR-141 was found to be 266.7 mg/g and 320.5 mg/g respectively at an optimum pH of 2.0. The adsorption of RB-21 resulted in reconstruction of HT as indicated by XRD analysis. Both RB-21 and RR-141 could be effectively desorbed using 0.1 N Na_2CO_3 and HT could be reused upto three adsorption-desorption cycles

1. Introduction

The rapid urbanization, industrialization as well as technological development have led to the problem of environmental pollution. The surface and ground water in many places around the world is contaminated and not fit for drinking purposes. The increasing release of large amounts of synthetic dyes into the environment is of public concern and a serious challenge to environmental scientists [1]. Various chemical manufacturing units synthesize organic molecules which are widely used in dye industries [2,3]. Dyes are extensively used in textile, rubber, paper, leather and cosmetic industries and are thus one of the key components in the effluents of these industries. Water pollution from dyeing industries has always been an escalating problem [4,5]. The discharged dyes affect the aquatic flora and fauna in a significant way. For instance, the photosynthetic process of aquatic plants is affected as the presence of color does not allow light to penetrate into the water. The discharged dyes also increase the biological oxygen demand of water and are also known to be toxic to aquatic organisms [6–9]. Reactive dyes are reported to be more toxic and induce allergies, irritation, dermatitis, cancer and mutation in humans [10–14]. Therefore it is necessary to treat the dye containing effluents before they are discharged to natural water bodies. Various methods have been developed for the treatment of dyes containing waste water which include physical, chemical [15] and biochemical processes [16–18] as well as photocatalytic degradation [19,20] techniques. Among these methods of treatment, adsorption techniques have proven to be most advantageous in removing dyes [21,22] especially using non-conventional low cost adsorbents such as bottom ash, industrial waste, peat, wood, wool carbonizing waste, eucalyptus bark, bagasse pith, chitosan fibers and hydrotalcite [23–29].

Layered double hydroxides (LDHs) have been identified as potential adsorbents due to their large surface areas, anion exchange capacities, low cost and non-toxicity [29]. LDHs comprise a class of layered materials with positively charged layers and charge balancing anions in the interlayer regions [30]. LDH is generally expressed by the formula $[M_{1-x}{}^{2+}M_x{}^{3+}(OH)_2]^{x+}(A^{n-})_{x/n}\cdot mH_2O$, where $M^{2+}$and M^{3+} are divalent and trivalent metal cations, A^{n-} represents interlayer anion of negative charge n, m is the number of interlayer water molecules and $x\,(=M^{3+}/M^{2+}+M^{3+})$ is the charge density of the layers. Hydrotalcite is the most widely used layered double hydroxide with the formula $Mg_6Al_2(OH)_{16}(CO_3)\cdot 4H_2O$]. The interlayer anions in LDHs and HT can be easily exchanged with other simple anions as well as complex bio molecules and dyes [31–33]. The presence of these highly exchangeable interlayer anions has resulted in the use of LDHs in wide range of applications such as catalysis, ion exchange, molecular stabilization, separation, membrane technology and controlled release of anions. In environmental clean-up, LDHs have

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Table 1
Characteristics of hydrotalcite.

1	Physical properties	A white colour powder
2	Al_2O_3	16–22%
3	Aluminium	9–12%
4	MgO	30–35%
5	Magnesium	18–22%
6	pH (5% Suspension in EtOH)	7.0–9.5
7	Moisture (105 °C, 2 h)	$\leq$0.5%
8	BET—Surface area	13.225 m^2/g
9	Particle size Distribution (Malvern)	D50% $\leq$ 3 μm, D90% $\leq$ 6 μm

been used for the removal of phenolic compounds, pesticides and dyes [34,35]. The adsorption of anionic dyes [36–39] and azoic dyes [40–42] onto LDHs has been investigated. It has been reported that photostability of the dyes improved after adsorption and intercalation.

Very few studies have focused on the uptake of reactive dyes onto hydrotalcite [24,43,44]. Our aim in this study was to evaluate the adsorption performance of HT for reactive anionic dyes using RB-21 and RR-141 as model dyes. The effects of various parameters, such as dye concentration, system pH, adsorbent quantity, temperature and coexisting ions on the adsorption process were investigated by batch technique. The fitting of the obtained adsorption isotherms to the Langmuir and Freundlich models, was also studied to understand the adsorption mechanism of the reactive dyes onto HT. Several kinetic models were also used to fit the experimental data for the purpose of understanding the adsorption mechanism. XPS, XRD and IR studies were also done to investigate the nature of interaction between the dyes and HT.

2. Materials

Commercial grade RB-21(λ_{max}—610 nm) and RR-141 (λ_{max}—540 nm) dyes were used without further purification. Hydrotalcite (HT) was a gift sample from Heubach Color Private Limited, Ankleshwar, Gujarat, India. The characteristics of hydrotalcite are shown in Table 1.

2.1. Preparation of dye solutions

Dye solutions were prepared by weighing the required amount of dye and diluting to the desired concentrations. The structures of the dyes are shown in Fig. 1a and b.

2.2. Characterization

FTIR was used to determine the changes in vibrational frequencies of the functional groups in the adsorbent and dye loaded adsorbents. The infrared spectral data were collected using PerkinElmer RX1 model in the wave number range 400–4000 cm^{-1}. About 5–10 mg of samples were mixed with

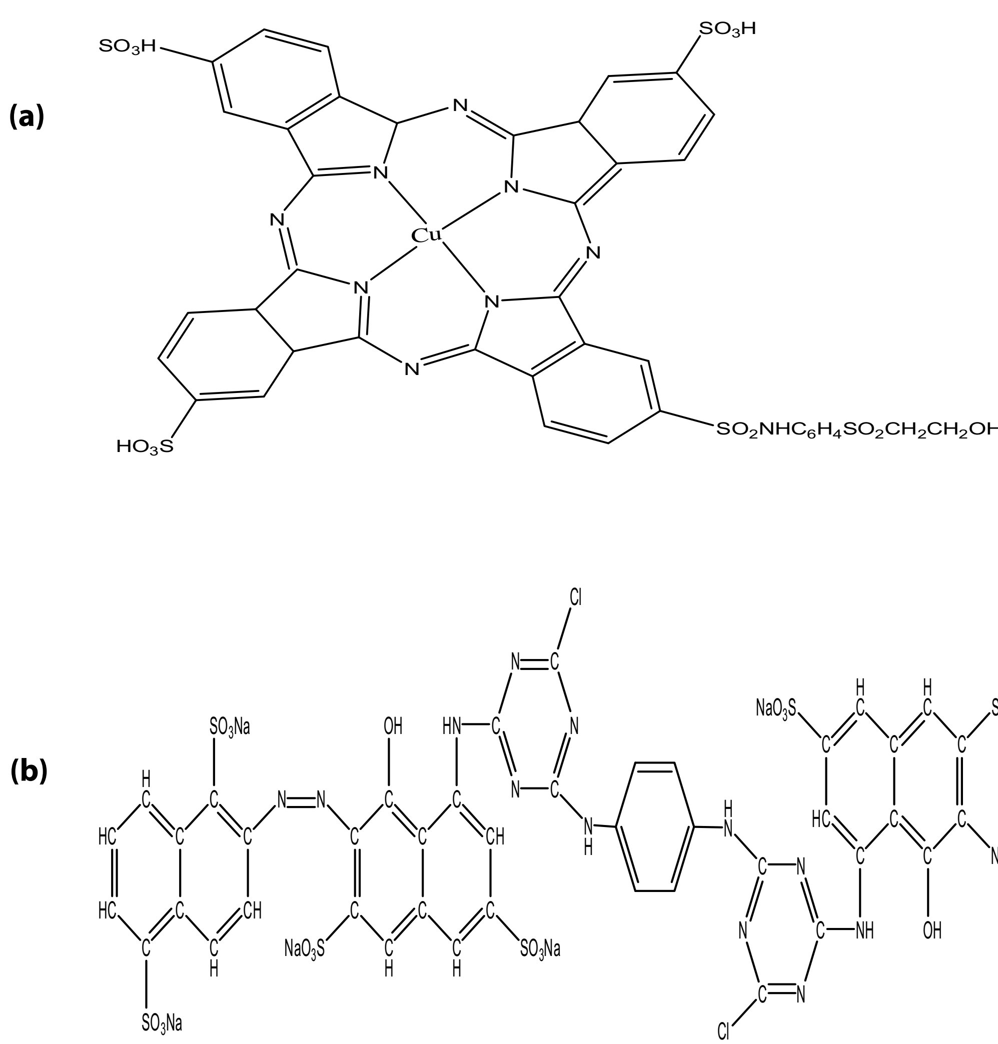

Fig. 1. (a) Structure of reactive blue-21 (RB-21). (b) Structure of reactive red-141 (RR-141).