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APPLICATION OF SUGARCANE BAGASSE AS AN ADSORBENT FOR TREATMENT OF A TEXTILE DYE RHODAMINE B

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Abstract

Dyes are widely employed for colouring in textile industries and a significant loss of it is occurred during the manufacture and processing of dyes. These lost and untreated chemicals are discharged in the water resources, which damage the aquatic ecosystem. The study was carried out for the establishment of a standard wastewater treatment process using sugarcane bagasse (SB) as a bio-adsorbent to remove the reactive dyes. Various parameters such as contact time, amount of adsorbent, initial concentration of dye and temperature were considered to optimize the removal process. The adsorption behavior has been explained on the basis of pseudo-first-order, pseudo-second-order and intra-particle diffusion model. For sugarcane bagasse, the maximum removal efficiency of Rhodamine B (RB) was found at an adsorbent mass of 5.5 g/100 mL, at 19 ^{o}C temperature, at 1×10^{-4} M concentration and 45 minutes of contact time. The results of the experiment suggest that the SB could be a better adsorbent for the removal of reactive dyes from the wastewater.

Keywords: Adsorption, sugarcane bagasse, kinetic study, effect of temperature.

Introduction

The increase in industrialization and urban contamination causes the discharge of wastewater directly into water resources without proper treatment. Dyes are being an essential part of our civilized life. The widely uses of dye and their improper treatment in various industries such as textile, leather, paper, printing, food, solvent, rubber, plastic, cosmetics, petroleum, pesticides, wood preserving chemicals, paint, pigment and pharmaceuticals industry cause severe destruction of the aquatic environment (Berradi et al., 2019). Water pollution is a great threat toward both human health and the ecological environment. Organic dyes, one of the major water pollutants might be toxic, chemically

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stable and hard to degrade (Zhang et al., 2010, Adevemo et al., 2012). The water resource is polluted day by day due to the dumping of industrial wastes into rivers, eutrophication, spraying insecticides and by human activities, which causes harms not only the aquatic being but also contaminates the entire food chain (O'Mahony et al., 2002, Aksu and Çağatay, 2006, Miah et al., 2016). The untreated textile dye is not excluded from it. Several conventional methods, for instance, physical (adsorption, coagulation, and filtration), chemical (oxidation, reduction) and biological (aerobic and anaerobic microbial degradation) have been applied to dispose the hazardous dyes from industrial effluent (Czelej et al., 2016, Czelej et al., 2016). Among all these methods, the physical adsorption process at the solid-liquid interface is regarded as one of the economic, efficient and effective methods for the removal of dyes from the industrial effluent (Basnet and Zhao, 2014, Zhu et al., 2014). Dye degradation is a process in which large dye molecules are broken chemically into smaller molecules. The resulting products are water, carbon dioxide and mineral byproducts. All the dye molecules are not degraded and a large extent of it is found to the natural water resources. Many of these dye molecules are not reactive towards light, acids, bases and oxygen. The color of the material becomes permanent.

Since synthetic dyes have been widely used in many technological processes, the discharge of wastewater of these industries to the environment affect both human health and living organism of the aquatic ecosystem due to toxicity and carcinogenicity (Forgacs et al., 2004), So before their discharge, the treatment of dye contaminated water is essential with sanitization process. Adsorption is a method that involves the accumulation of a substance in molecular species in higher concentrations on the surface. Adsorption is affected by the temperature, pressure, nature of adsorbent, nature of adsorbate, concentration of adsorbate and adsorbent dose respectively. Activated carbon composites are the simplest and economical method for the removal of dye from aqueous solution by adsorption process (Hu et al. 2014, Yang et al. 2011, Madrakian et al. 2013).

Due to high cost of activated carbon, many researchers prefer to use natural adsorbents such as rice husk, banana peel, vine, soybean hull, coconut husk, sunflower seed hull, agricultural waste byproduct and teak wood bark for the purification of wastewater (Safa and Bhatti, 2011, Dabwan et al., 2015, Weng et al., 2013). In the present study, the adsorption of RB has been investigated by the sugarcane bagasse (SB). After crushing and extraction of juice from the sugarcane stalk there remain a fibrous residue which is called sugarcane bagasse. Sugarcane bagasse is also called the most abundant lignocelluloses agro-industrial residue (Siqueira et al., 2020). Since SB has numerous and variety of functional groups, so it shows a strong attractive force for the binding of pollutant ions (Okoro and Okoro, 2011). Therefore, it is expected that sugarcane bagasse can efficiently remove its target adsorbent from an aqueous solution like toxic heavy metals, dyes, petroleum, phenolic compounds and organic nutrients.

Materials and Methods

SB was collected from the local area, washed with de-ionized water and dried in an oven till a constant weight was obtained. The sugarcane bagasse was ground in a blender (Miyako) and kept in desiccators for further use.

An aqueous solution of 1×10^{-3} M Rhodamine B (Alfa UK) was prepared in a 250 mL volumetric flask and kept as the stock solution. Diluted solutions of different concentrations were prepared by appropriate dilution.

A definite amount of SB was added to a solution of RB and allowed for agitation in an orbital shaker (Model No-JSOS-300). A small portion of the solution was collected after a definite time interval. The absorbance of each solution was measured with a double beam UV-Visible spectrophotometer (Lamda-365) and the removal efficiency was monitored. Deionized water was used as a reference for all the measurements. The procedure was repeated with the change of different parameters such as adsorbent dosage, concentration of the adsorbate, time and temperature. The percentage of adsorption was determined by -

$$\% \text{ of dye removal} = \frac{(A_0 - A_t)}{A_0} \times 100\%$$

where, A_0 and A_t are the initial absorbance of dye solution and absorbance of dye solution after adsorption at any time t respectively.

Results and Discussion

The wavelength at which aqueous solution of RB shows maximum absorption was determined spectroscopically and this value was 554 nm. The molar extinction coefficient was determined to be 7.85×10^4 $Lmol^{-1}cm^{-1}$. The concentrations of all solutions were monitored at this wavelength.

Effect of adsorbent dosage

The percentage of adsorption is found to be increased with increase of adsorbent dosage upto a maximum at 5.5 g and then decreases (Fig. 1). The removal efficacy of an adsorbent usually increases with the increase in its dose due to a large number of existing adsorption sites. On the contrary, the adsorption capacity decreases after a certain amount may be due to the unsaturation of adsorption sites. A decrease in adsorption density is also attributed to interactions of adsorbent particles for instance by aggregation. This is caused by high adsorbent concentration which decreases the entire surface area of the

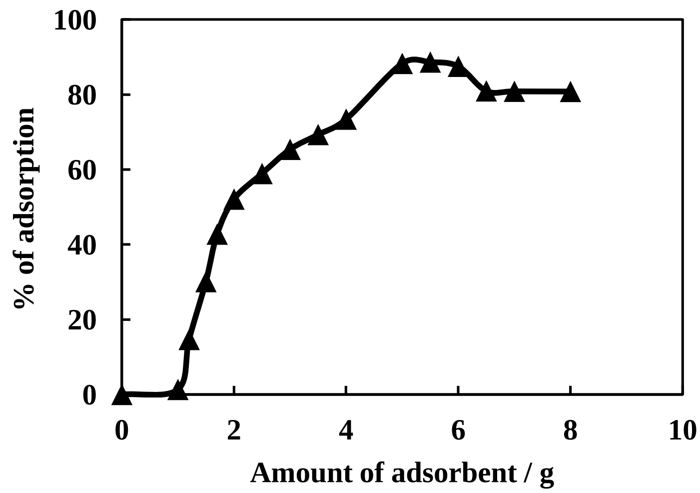

Fig. 1. % of adsorption vs. amount of adsorbent.

adsorbents and increases diffusion path length (Kayes et al., 2016). Adsorption sites may also overlap due to overcrowding of adsorbent particles and this also explains why the increase in adsorbent dosage could lead to a decline in adsorption.

Effect of dye concentration

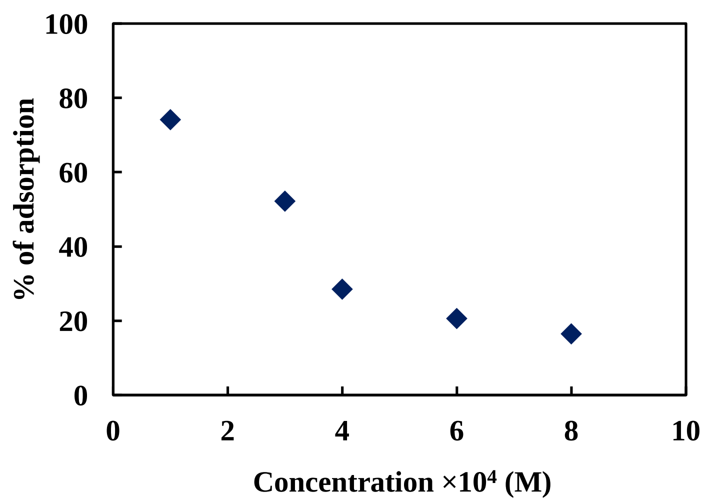

Fig. 2. % of adsorption vs. initial concentration of RB.

The initial dye concentration parameter provides a vital driving force to encounter all mass transfer resistance of the dye between the dye molecules and solid-phase adsorbent

(Ofomaja and Ho, 2007). Fig. 2 illustrated that the percentage of dye removal decreased from 74.17% to 16.50% for RB with the increase of dye concentration. The increase of dye concentration leads to a decrease in the adsorption process, suggesting the adsorption of this dye was highly dependent on dye concentration. This phenomenon was caused by unoccupied active sites on the bio-sorbent surface that were filled with dye molecules and saturation of bio-sorbent surface might be occurred when the dye concentration increased (Banerjee and Chattopadhyay, 2017).

Effect of temperature

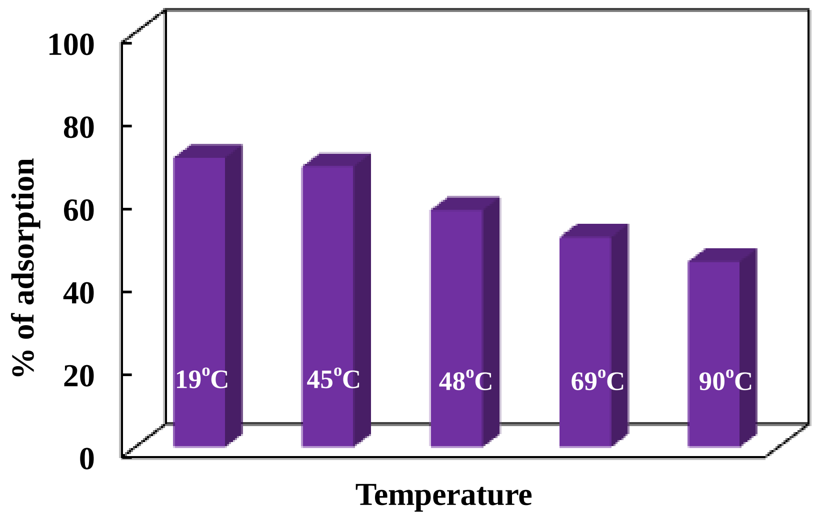

Fig. 3. % of adsorption at different temperature.

Temperature is an important parameter that influences the adsorption of dye. The adsorption of RB on sugarcane bagasse as a function of temperature is shown in Fig. 3. The percentage of adsorption has been found to be decreased with the increase of temperature which recommends that the adsorption is exothermic in nature. The maximum amount of dye adsorbed is 69.81% at 19°C, while it is 44.84% at 90°C. The percentage removal of RB explored that the increase in temperature leads to a reduction in the percentage of dye removal. This is due to the weakening of supportive forces between active sites on the adsorbent and dye to that between adjacent dye molecules during the adsorption process (Badii et al. 2010). A reduction after 19°C was due to the decrease in surface activity at a higher temperature, which indicates that the adsorption process was exothermic and RB dye adsorption onto bagasse occurred mainly by physical adsorption (Ho et al., 2005, Aksu and Tezer, 2005). Therefore, the desorption of RB molecules at higher temperatures may be due to the deterioration of adsorptive forces between the dye molecule and functional groups on the adsorbent surface.

Effect of contact time

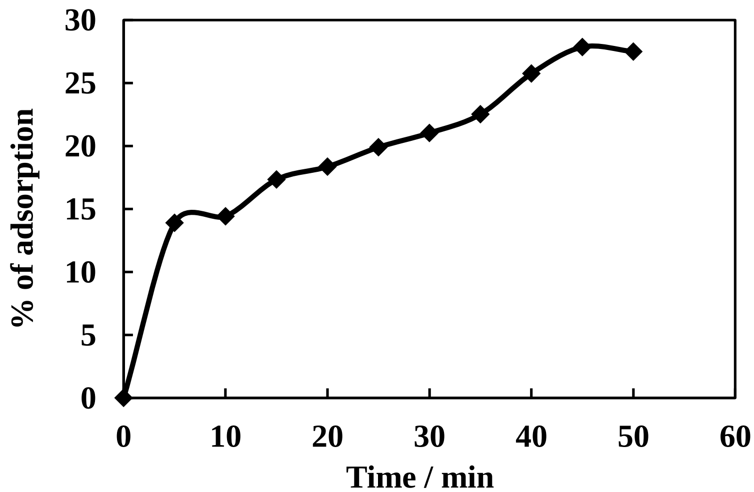

Fig. 4. % of adsorption vs. contact time.

The effect of contact time on the removal of RB on SB is investigated at different contact times (0, 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 minutes) using 100 mL solution with 1.0 g of the adsorbent (Fig. 4). Generally, the percent removal increases with increase of contact time, because a large number of free surface sites of bio-sorbent are available (Krishni et al., 2014). After 45 minutes of dye adsorption, the percentage of dye removal showed no significant difference in the amount of removing dye in this state. This could be considered as an equilibrium state since the active sites of bio-sorbent are considered to be fully occupied. There is a possibility of the adsorbate to desorb from the surface of the SB to the bulk solution and thus it is concluded that 45 minutes is the optimum time for RB removal using SB.

Kinetic studies

Several kinetic models (pseudo-first-order, pseudo-second-order, and intra-particle diffusion) have been applied to perceive the mechanism of dye adsorption from aqueous solution. The kinetic equations of pseudo-first and pseudo-second-order models are as follows (Tseng et al., 2010, Fytianos et al., 2000)

$$\log (q_e - q_t) = \log q_e - k_1 t \quad \ldots\ldots\ldots\ldots (1)$$

$$t/q_t = 1/(k_2 q_e^2) + t/q_e \quad \ldots\ldots\ldots\ldots (2)$$

Where q_e and q_t are the amount of adsorbate adsorbed on adsorbent (mg/g) at any time t. k_1 and k_2 are the rate constants for the pseudo-first and second-order respectively. The value of q_e and q_t are calculated by using the following equations (Vijayakumar et al., 2012),

$$q_t = \frac{(C_0 - C_t)\,V}{W} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$q_e = \frac{(C_0 - C_e)\,V}{W} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where, C_0 and C_t represents the initial and equilibrium concentration of dye in mg/L respectively. V is the volume of the solution (L) used for adsorption and W is the mass of dry adsorbent (g).

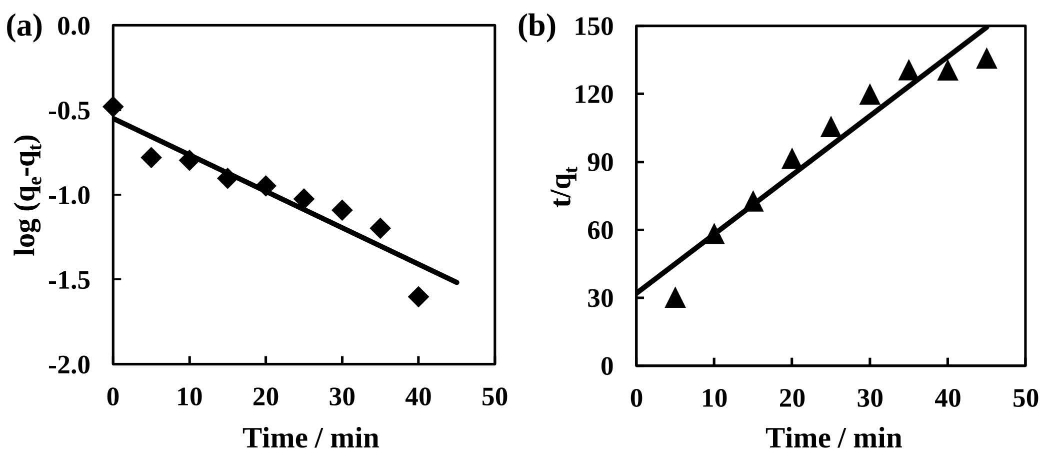

Fig. 5. (a) Pseudo-first order and (b) Pseudo-second order kinetic model for the adsorption of RB on sugarcane bagasse.

The values of kinetic parameters are obtained from the plot of log (q_e-q_t) vs log q_e and t/q_t vs t [Fig. 5]. All the determined values including correlation coefficient (R^2) are listed in table 1. The value of R^2 suggests that the adsorption process is followed by pseudo-second-order kinetics.

Table 1. Kinetic parameters for the pseudo-first and pseudo-second order models.

q_e (mg/g)	Pseudo-first order		Pseudo-second order	
	k_1	R^2	k_2	R^2
0.3313	0.021	0.890	0.285	0.935

The intra-particle diffusion (IPD) values can be obtained from the following equation,

$$q_t = k_p\, t^{1/2} \quad \text{.....................(5)}$$

Where, k_p is acronym for the intra-particle rate constant (mg g^{-1} min $^{-1/2}$).

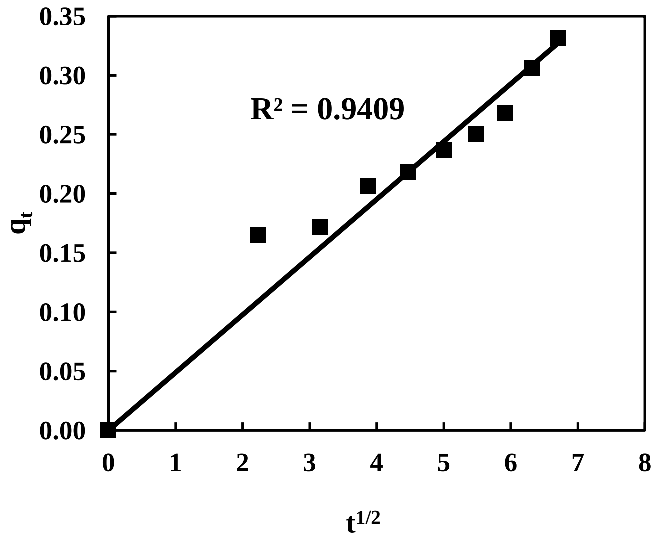

Fig. 6. A plot of IPD model for the adsorption of RB on sugarcane bagasse.

A plot of q_t vs $t^{1/2}$ is not a perfectly straight line which is an indication of occurring various steps such as transportation of RB molecules from bulk solution to the surface of SB through boundary layer diffusion, diffusion of the RB molecules from the external surface to the pores of SB and adsorption of the RB molecules to the active sites of the internal surface of the pores. The value of correlation coefficient (R^2) for IPD is 0.940 whereas it is 0.935 for the pseudo-second order kinetics. This suggests that the adsorption is followed by pseudo-second order kinetics but the plot not passing through the origin is an observation of some degree of boundary layer diffusion.

Conclusion

The extensive capability and the ease with which waste sugarcane bagasse can be combined with smart physiochemical characteristics makes it a potential replacement for commercially used adsorbents. The feasibility of RB removal from aqueous solution with sugarcane bagasse as a sorbent has been confirmed. Results revealed that the maximum removal of RB achieved at a bio-sorbent dosage of 5.5 g/100 mL (88.66%) with initial concentration of RB at 1×10^{-4} M, at temperature 19°C and at 45 minutes of contact time. The adsorption process is accompanied through pseudo-second-order kinetics with some extent of boundary layer diffusion. All of the results are beneficial to the practical application of sugarcane bagasse for the treatment of dye. The sugarcane bagasse is an alternative substitute to activated carbon as bio-adsorbent, which is plentiful in the nature. Moreover, it has a high adsorption capacity for RB. Therefore, the use of sugarcane bagasse as an adsorbent for the removal of RB from aqueous dye solution is expected to be cost effective. Careless dumping of the above-mentioned adsorbents may cause serious environmental problems. Instead of careless dumping, their use as a bio-sorbent may save the environment from devastation.

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