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Equilibrium, thermodynamic and kinetics studies on adsorption of eosin Y and red X-GRL from aqueous solution by treated rice husk

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ABSTRACT

Present study explored the adsorptive characteristics of eosin Y and red X dyes from aqueous solution onto treated rice husk (TRH). Batch experiments were carried out to determine the influence of parameters likes initial pH, adsorbent dose, contact time and initial concentration on the removal of eosin Y and red X. The adsorption kinetics of the two dyes on to TRH was found to follow pseudo-second-order kinetic model. The equilibrium data is successfully fitted to the Freundlich and Langmuir adsorption isotherm for eosin Y and red X, respectively. The thermodynamic analysis indicated that the sorption process was endothermic for eosin Y and exothermic for red X and the negative value of change in Gibbs free energy indicated feasible and spontaneous adsorption for both of dyes. The removal percentage of dyes was about 90% ($q_e = 31.72 \text{ mgg}^{-1}$) for eosin Y and 93.44% for red X ($q_e = 32.44 \text{ mgg}^{-1}$). Overall, the present findings suggest that this environmentally friendly, efficient and low-cost adsorbent is useful for the removal of eosin Y and red X from aqueous solution.

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1. Introduction

Most of the synthetic dyes are extensively used in several fields such as in textile industries, leather tanning, paper production, food technology, agricultural research, light harvesting arrays, petrochemical cells and in hair colorings (Robinson et al. 2002). Synthetic dyes are usually released into the environment from such industrial effluents and the discharge of highly colored synthetic dye effluents can be very damaging to the receiving water bodies. Moreover, dyes used in the textile industry may be toxic to aquatic organisms and can be resistant to natural biological degradation. Hence, the removal of color synthetic organic dyestuff from waste effluents becomes environmentally important (Hameed 2009). Eosin Y, a coal tar-xanthene dye, was chosen as the model anionic dye to avoid environmental hazards during investigation (Chatterjee et al. 2005). Cationic Red X-GRL, an azo dye, was selected as the model pollutant for this study because it is not biodegradable by the conventional activated sludge process, and it is widely used in textile, color solvent, ink, paint, varnish, paper, and plastic industries (Zhou and He 2008). Different physico-chemical processes like electro-kinetic coagulation, ion-exchange, membrane filtration, electrochemical oxidation, and photo-catalytic degradation process have been used for the treatment of dye-containing effluents (Hachem et al. 2001; Gemeay et al. 2003; Aksu and Karabayir 2008; Riera-Torres and Gutiérrez 2010; Cisneros et al. 2002). However, there are certain short comings. Coagulation process produces large amount of has no loss of adsorbent on regeneration, however, it cannot accommodate wide range of dyes, and is expensive. Membrane separation process is also effective in removal of dyes, however, due to relatively high investment and membrane fouling problem, its application is restricted. Adsorption is a well-known equilibrium separation process and an effective method for water decontamination applications (Dabrowski 2001). The adsorption process provides an attractive alternative treatment, especially if the adsorbent is inexpensive and readily available. This process is becoming an attractive and promising technology because of its simplicity, ease of

operation and handling, sludge free operation, and regeneration capacity. Adsorption produces a high quality product, and is a process which is economically feasible (Gupta and Suhas 2009). Almost complete removal of impurities with negligible side effects explains its wide application for the treatment of dye bearing wastewaters. Activated carbon adsorption process for the removal of dyes is an accepted practice. However, AC is expensive and its regeneration and reuse make it more costly (Fan et al. 2010).

Consequently, many investigators have studied the feasibility of using low-cost substances for the removal of various dyes and pollutants from waste waters (Mane et al. 2007). Several recent publications utilized different inexpensive and locally abundantly available adsorbents like bagasse (Ahmedna et al. 2000; Valix et al. 2004; Conrad and Hansen 2007) coir (Namasivayam et al. 2001; Kadirvelu et al. 2003), banana pith (Banat et al. 2003), date pits (Kannan and Sundaram 2001), straw (Mohamed 2004) and rice husk (Kadirvelu et al. 2000; Feng et al. 2004; Chuah et al. 2005). Rice husk is an agricultural waste, accounting for about one-fifth of the annual gross rice production (545 million metric tons) of the world and chosen as an adsorbent in several water treatment processes (Purkait et al. 2005). In nature, rice husk is tough, insoluble in water, woody and characterized by its abrasive inherent resistance behavior and silica-cellulose structural arrangement (Daifullah et al. 2004). Its major organic components of cellulose, hemicellulose, lignin and inorganic components of rice husks are found to be SiO_2 , H_2O , Al_2O_3 , Fe_2O_3 , K_2O , Na_2O , CaO and MgO (Purkait et al. 2005; Chandrasekhar et al. 2005; Foo and Hameed 2009; Hameed 2009).

Rice husk has good adsorptive properties and has been used for the removal of various heavy metals (El-Shafey 2007; Naiya et al. 2009); dyes (Chakraborty et al. 2011; Malik et al. 2003; Mohamed 2004), etc.

The main objective of this work is to study the adsorption potential of low-cost bioadsorbent, treated rice husk for the removal of hazardous dyes eosin Y and red X from the aqueous solution. The effect of dye concentration, adsorbent dose, temperature, and pH of the medium, on

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the adsorption characteristic of pretreated TRH in order to make a comparison between them. Also the adsorption isotherm models and various thermodynamic parameters were studied.

2. Materials and methods

2.1. Treatment of the adsorbent

Natural rice husk was collected from local rice-mill of north, Iran. It was separately washed with distilled water to remove dust like impurities and was dried in hot air oven (D-783 Emmendiogon 14) at 80°C for overnight. Natural rice husk was refluxing with NaOH 8% (w/w) at weight ratio 1:6 and heated to boiling for 6h, the filtrate is washed twice with distilled water and 10% HCl was added to pH=7. Then sieved (Damavand, Test sieve LTD, ASTM: 11) with 100 mesh and was used

for the batch experiment. The formed precipitate of silica was washed, dried at 100°C and thus the silica extracted by alkaline treatment was used as a sorbent material in this work.

2.2. Adsorbate

The dyes used in the present work were eosin Y (Merck, 98.7%), which is anionic in nature and red X-GRL (5-[4-(benzyl-methylamino phenylazo)-1,4-dimethyl-4H-[1,2,4]triazol-1-ium chloride) (Merck, 99.5%) used in the present work was purified from industrial cationic red X-GRL. The structures of the dyes are shown in Fig.1. Synthetic stock dye solutions were prepared by dissolving 0.1g of dyes in 100mL of distilled water.

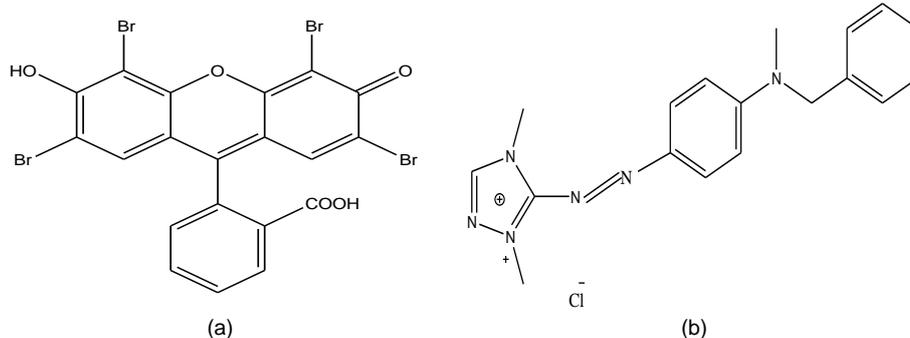


Fig.1. Structure of (a) eosin Y, (b) red X.

2.3. Batch adsorption experiments

The adsorption experiments were carried out in a batch process. Various parameters such as, initial dye concentration, adsorbent amount, temperature and pH of the medium were studied. For each experimental run, 150 ml of dyes solution of known concentration, pH₀ and a known adsorbent dose were taken in a 250 ml Erlenmeyer's flask. The initial pH adjustments were carried out either by hydrochloric acid or sodium hydroxide solutions before adding the TRH. The effects of temperature on the adsorption data were carried out by performing the adsorption experiments at various temperatures (15, 25, 35 and 45 °C) and the kinetics and isotherms for the adsorption data were studied under optimized condition of pH. The flasks were agitated at a constant speed of 170 rpm for 3 h in an incubator shaker (Model Jal tajhiz, TSL20) at 30°C. Definite volumes of 5ml of samples were at time intervals of 5, 15, 25, 35, 60, 90, 120, 150 and 180 min (Hameed 2009). The collected samples were then centrifuged and the concentrations in the supernatant solution were determined using UV-vis spectro photometer (cintra, GBC) at an absorbance wavelength of 510 and 520 nm for eosin Y and red X, respectively. The amount of adsorption at equilibrium, q_e (mgg⁻¹), was calculated by:

$$q_e = (C_0 - C_e) V / W \quad (1)$$

where C_0 and C_e (mgL⁻¹) are the liquid-phase concentrations of dye a t initial and equilibrium, respectively. V (L) is the volume of the solution and W (g) is the mass of dry sorbent used. The dye removal percentage can be calculated as follows:

$$R_e \% = [(C_0 - C_e) / C_0] \times 100 \quad (2)$$

3. Results and discussion

3.1. Characterization of TRH

A Fourier transformation infrared (FTIR) spectrum of TRH was obtained using KBr pellets in conjunction with Shimadzu FTIR 8400S spectrometer. The pellet for infrared studies was prepared by mixing a given sample with KBr crystals and pressed into a pellet. A spectrum was recorded in the mid- IR range from 4000 to 400 cm⁻¹ with a resolution of 1 cm⁻¹. The results of FTIR of the outer surfaces of NaOH treated rice husks are shown in Fig. 2. FTIR spectra showed that treated rice husk contained functional groups of the standard polymers α -cellulose, and coir pith lignin. This figure shows a broadband between 2900 and 3750 cm⁻¹ with little about 3400 cm⁻¹ which indicate the presence of both free and hydrogen bonded OH groups and Si-OH groups on the adsorbent surface. This stretching is due to both the

silanol groups (Si-OH) and adsorbed water (about at 3400 cm⁻¹) on the surface (Abou-Mesalam et al. 2003). The FTIR spectrum of TRH shows peaks in the region of 1650 and 1512 cm⁻¹. The broad peak in the region of 1650 cm⁻¹ indicates the presence of CO group stretching from aldehydes and ketones. The band at 1650 cm⁻¹ may also be due to conjugated hydrocarbon bonded carbonyl groups. The sharp peak at 1512 cm⁻¹ indicates the presence of primary amides and signifies C-N stretching and N-H in-plane bending. The peak at 1512 cm⁻¹ may also be due to the -NO₂ group symmetric stretching. The band around 1512 cm⁻¹ in TRH may also be attributed to the carboxyl carbonate structures (Ricordel et al. 2001). The peaks at about 1033 cm⁻¹ indicate the presence of Si-O-Si (Sharma et al. 2010).

3.2. Effect of pH

The pH value of the solution is an important factor that must be considered during adsorption studies. In the present adsorption system, the effect of pH was investigated for values between 1 - 9 and the result were presented for the both dyes in Fig. 3. As shown, for eosin Y at pH=2, the most percentage of dye removal was about 90% for an initial dye concentration of 100 mgL⁻¹ ($q_e=31.72$) and it decreased up to pH=4, then remained nearly constant (70.35mgg⁻¹) over the initial pH ranges of 4-9. TRH contains different nucleophilic functional groups such as carboxyl and hydroxyl. It was suggested that the adsorption of eosin Y onto TRH may be due to electrostatic attraction between anionic dye molecules and positive charged functional groups present on the surface of the adsorbents. This is due to the fact that the dye molecules become nucleophilic at higher pH (basic pH) which results in less adsorption on the nucleophilic sites of the TRH (Lakshmi et al. 2009). However, it has been found that dye's adsorption increases with increase in pH for red X, and maximum adsorption is found around a pH value of 8 ($q_e=32.44$ mgg⁻¹, $R_e=93.44\%$). This may be due to the fact that at higher pH values, the surface of adsorbent becomes negative which enhances the adsorption of positively charged red X cationic dye through electrostatic force of attraction.

3.3. Effect of initial dye concentration (C₀) and contact time

The effect of initial dye concentration on the percentage adsorption of eosin Y and red X dyes by TRH are shown in Fig. 4. It has been found that with the increase in concentration of the adsorbate, the adsorption percentage decreases, while the amount of dye removed at equilibrium increased with the increase in dye concentration in both the cases. The amount of eosin Y adsorbed at equilibrium (q_e) increased from 11.23 to 59.42 mgg⁻¹ as the initial concentration was increased from 50 to 250 mgL⁻¹, whereas the percentage removal decreased from 89.23 to

78.27% with increase in C_0 . The same results were obtained for red X, q_e increased from 17.71 to 49.75 mgg^{-1} , while the percentage removal decreased from 96.61 to 60.27% with increase in C_0 . This is so because the initial dye concentration provides the driving force to overcome the resistance to the mass transfer of dye between the aqueous and solid phase. The increase in initial concentration also enhances the interaction between adsorbent and dye. Therefore, an increase in initial concentration of dye solution enhances the adsorption uptake of dye (Sharma et al. 2010). Adsorbate and adsorbent contact time is great importance in adsorption process, because it depends on the nature of the system used. The effects of equilibration time on adsorption of eosin Y and red X dyes onto TRH are presented in Fig. 4. The obtained results show that as the contact time increases, the rate of adsorption increases first and then remains almost constant. Fig. 4 illustrated that the rate of adsorption of dyes were very fast during the initial stage of the adsorption processes. After fast initial rate of adsorption, uptake capacity for both the dyes increased with the time, and reached equilibrium value at about 25 min, since maximum adsorption is attained during this period. The concentration gradient will be responsible for these changes in the rate of adsorption. In the beginning, because of high concentration gradient, the driving force helped in this rapid adsorption. This rapid initial uptake of dyes may be an important parameter for a practical application of adsorption in industrial wastewater.

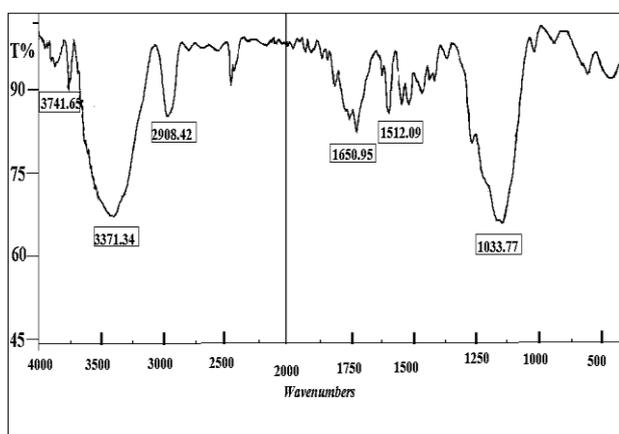


Fig. 2. IR spectra of TRH.

3.4. Effect of adsorbent dosage

The effect of adsorbent dosage on dye adsorption were conducted at initial dye concentration of 100 mgL^{-1} . Fig. 5 shows the effect of adsorbent dosage on the removal of eosin Y and red X. The dye uptake decreased from 38.28 mgg^{-1} to 17.18 mgg^{-1} for an increase in adsorbent dosage from 1 gL^{-1} to 5 g^{-1} for eosin Y. Whereas the percentage removal increases from 37.86 to 83.26%. For red X, q_e decreased from 87.119 to 42.43 mgg^{-1} but the removal increases from 18.45 to 44.3 % with increasing adsorbent dosage. For both dyes, it was observed that the amount of q_e was found to decrease with increasing adsorbent dosage. This effect can be explained on the basis of solute distribution between the adsorbent and bulk dye solution. According to figure, the removal increases with the increase adsorbent dosage. This indicates that with an increase of sorbent mass, more surface area is made available, and so is availability of more adsorption sites. But adsorption capacity decreased with increase in adsorbent dosage (Ho and McKay 1998).

3.5. Effect of temperature and thermodynamic analysis

The effect of temperature on the adsorption of eosin Y and red X by TRH was shown in Fig. 6. For eosin Y as you can see, equilibrium adsorption capacity increases from 38.62 to 42.34 mgg^{-1} , whereas for red X, q_e decreased from 31.62 to 23.34 mgg^{-1} , when the temperature is raised from 15 to 45 °C.

Better adsorption at higher temperature for eosin Y may be either due to acceleration of some originally slow sorption steps or due to creation of new active sites on the sorbent surface. Thus an increase in temperature will reduce the electrostatic repulsion between the surface and the adsorbing species, allowing adsorption to occur more readily. This could also be due to enhanced mobility of dye molecules from solution to the adsorbent surface (Sharma et al. 2010). Thermodynamic

parameters such as change in free energy (ΔG°), enthalpy (ΔH°), and entropy (ΔS°) were determined using the following equation:

$$\Delta G^\circ = \Delta H^\circ - \Delta S^\circ \quad (3)$$

$$\log\left(\frac{q_e}{C_e}\right) = \frac{\Delta S^\circ}{2.303R} + \frac{-\Delta H^\circ}{2.303RT} \quad (4)$$

where q_e is the maximum amount of dye (mg) adsorbed per unit mass of the TRH (mgg^{-1}), C_e is the equilibrium concentration (mgL^{-1}) of the dye in the solution, T is the solution temperature (inK), and R is the universal gas constant. ΔH° and ΔS° were calculated from the slope and intercept of van't Hoff plots of $\log(q_e/C_e)$ versus T^{-1} (Purkait et al. 2005). Using Eq. (4), standard enthalpy and the entropy changes of sorption process were determined from the $\log(q_e/C_e)$ versus T^{-1} plots (Fig. 7), and are also represented in Table 1. For eosin Y; the ΔG values indicate that the adsorption process is spontaneous in nature. The positive value of ΔH° suggests that the adsorption process is endothermic and favorable at higher temperature. While, for red X, the negative values of ΔG° and ΔH° indicate that the adsorption process is spontaneous and exothermic in nature.

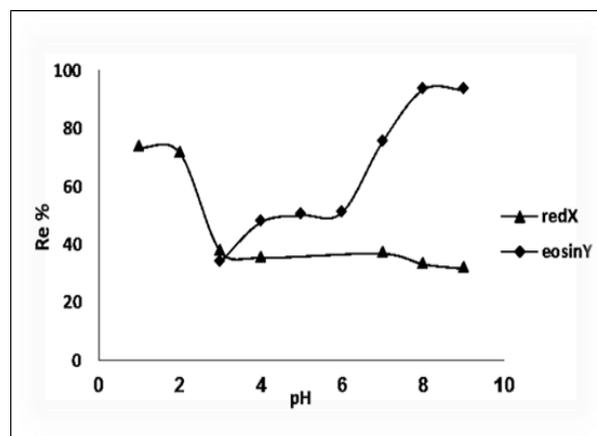


Fig. 3. Effect of pH on the percentage of removal dyes of eosin Y and red X onto TRH (Dye concentration = 100 mgL^{-1} , temperature = 30 °C).

3.6. Isotherm analysis

In order to optimize the design of adsorption system to remove dyes from aqueous solutions, it is important to establish the most appropriate correlation for the equilibrium curves. The equilibrium isotherms in this study were analyzed using the Langmuir, Freundlich and Temkin isotherms (Fig. 8). The Freundlich isotherm is derived by assuming a heterogeneous surface with a non-uniform distribution of heat of adsorption over the surface. Whereas, in the Langmuir theory, the basic assumption is that the sorption takes place at specific homogeneous sites within the adsorbent. The Langmuir isotherm is represented by the following linear equation:

$$\frac{C_e}{q_e} = \frac{1}{q_m b} + \frac{C_e}{q_m} \quad (5)$$

where C_e (mgL^{-1}) is the equilibrium concentration, q_e (mgg^{-1}) the amount of adsorbate adsorbed per unit mass of adsorbate, and q_m and b are Langmuir constants related to adsorption capacity and rate of adsorption, respectively (Langmuir 1918). The Langmuir constants b and q_m were calculated from this isotherm and their values are listed in Table 2. The essential features of the Langmuir isotherm can be expressed in terms of the dimensionless equilibrium parameter R_L , which is defined as $R_L = 1/(1+bC_0)$, where b (Lmg^{-1}) is the Langmuir constant as described above, and C_0 is the initial dye concentration. R_L values within the range $0 < R_L < 1$ indicate favorable adsorption.

The Freundlich isotherm is an empirical relationship showing the interaction between adsorbate molecules and heterogeneous surfaces. The linear equation is expressed as follows:

$$\ln(q_e) = \ln(K_F) + (1/n)\ln(C_e) \tag{6}$$

where K_F is the Freundlich constant ($\text{mgg}^{-1}(\text{mgL}^{-1})^{-n}$) and $1/n$ is the heterogeneity factor. The value of n indicates whether the adsorption process is favorable or not. The slope $1/n$ ranging between 0 and 1 is a measure of adsorption intensity or surface heterogeneity, becoming more heterogeneous as its value gets closer to zero (Freundlich 1907).

The Temkin isotherm equation assumes that the heat of adsorption of all the molecules in the layer decreases linearly with coverage due to adsorbent-adsorbate interactions that the adsorption is characterized by a uniform distribution of the binding energies, up to some maximum binding energy. The linear form of Temkin isotherm can be written as:

$$q_e = B\ln(A) + B\ln(C_e) \tag{7}$$

where $B=RT/b$, T is the absolute temperature in Kelvin and R is the universal gas constant ($8.314 \text{ J mol}^{-1}\text{K}^{-1}$). A is the equilibrium binding constant and B is corresponding to the heat of sorption (Temkin 1941). The adsorption data were analyzed according to E_q . (7). The correlation coefficients for both dyes were low and it can be said that the experimental data was not fitted better to the Temkin isotherm model. The results indicated that the surface of rice husk is heterogeneous in nature and did not possess equal distribution of binding energies on the available binding sites.

The values of the parameters are given in Table 2. From Table, the Freundlich and Langmuir isotherm models yielded the best fit with the highest R^2 value (0.906, 0.999) for eosin Y and red X, respectively.

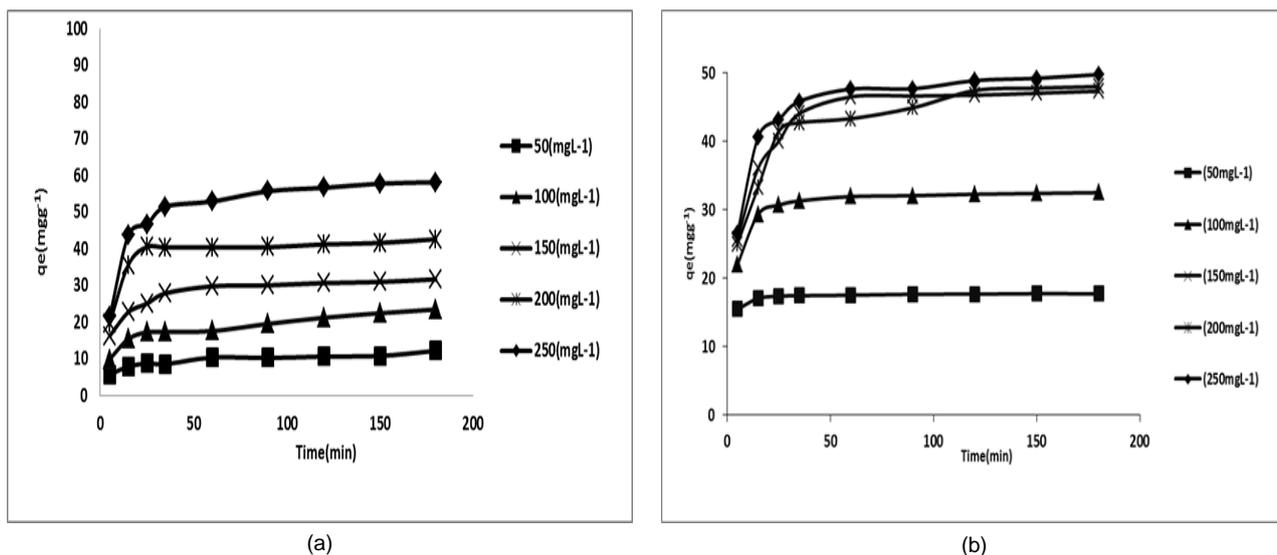


Fig. 4. Effect of initial concentration on the adsorption of (a) eosin Y ($\text{pH}=2, W= 3\text{gL}^{-1}$), (b) red X ($\text{pH}=8, W= 4\text{gL}^{-1}$) on TRH.

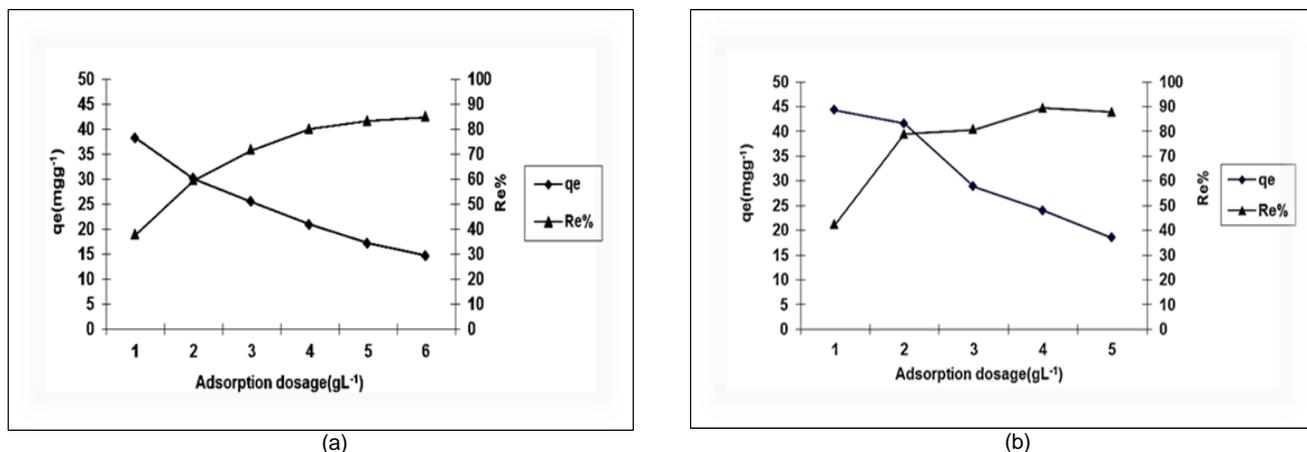


Fig.5. Effect of adsorbent dosage on the adsorption of (a) eosin Y onto TRH ($\text{pH}=2, c_0=100\text{mgL}^{-1}$, contact time= 180 min), (b) red X ($\text{pH}=8, c_0=100 \text{mgL}^{-1}$, contact time= 180 min).

3.6. Adsorption kinetics

Various kinetic models, namely pseudo-first-order, pseudo-second-order and intraparticle diffusion models have been used for their validity with the experimental adsorption data for dyes onto TRH. The study of adsorption kinetics describes the solute uptake rate, and evidently these rates control the residence time of adsorbate uptake at the solid-solution interface, including the diffusion process. The mechanism of adsorption depends on the physical and chemical characteristics of the adsorbent as well as on the mass transfer process (Abou-Mesalam 2003). The pseudo-first-order kinetic model has been widely used to predict dye adsorption kinetics. A linear form of pseudo-first order model was described by Lagergren (1898):

$$\log(q_e - q_t) = \log(q_e) - (K/2.303)t \tag{8}$$

where q_e and q_t are the adsorption capacities (mgg^{-1}) at equilibrium and at time t , respectively; K_1 is the rate constant of pseudo-first order adsorption (L min^{-1}). The plot of $\log(q_e - q_t)$ versus t , gives a straight line for the first-order adsorption kinetics as shown in Fig. 9a. The value of the first-order rate constant k_1 is obtained from the slope of the straight line. The obtained curves by plotting $\log(q_e - q_t)$ versus t , did not show a straight-line during the whole adsorption process, indicating that pseudo-first order kinetics could not be used to describe the adsorption behavior of anionic dyes onto TRH. The values of the parameters are given in Table 3.

The pseudo-second-order rate equation of McKay and Ho can be represented in the following form (Ho and McKay 1998):

$$t/q_t = 1/K_2 q_e^2 + t/q_e \tag{9}$$

where the equilibrium adsorption capacity q_e , and the pseudo-second-order constants K_2 ($\text{gmg}^{-1}.\text{min}^{-1}$) can be determined experimentally from the slope, and intercept of plot t/q_t versus t , Fig.9b. The correlation coefficients for the second-order kinetic model were close to nearly 1.0 for the both cases, and the theoretical values of q_{eq} also agreed well

with the experimental data. On the other hand, the correlation coefficients for the pseudo first-order kinetics were lower than those of pseudo second-order one. In addition, the theoretical q_e values calculated from the first-order kinetic model did not give reasonable values with obvious deviation from the experimental ones.

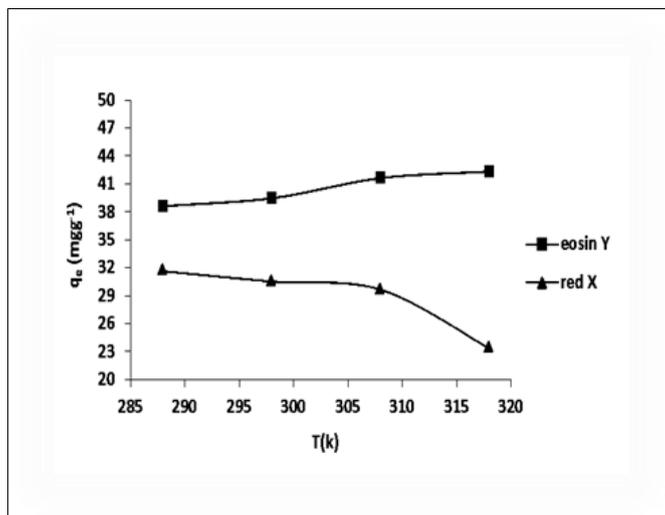


Fig. 6. Effect of temperature on the adsorption capacity of eosin Y and red X on TRH.

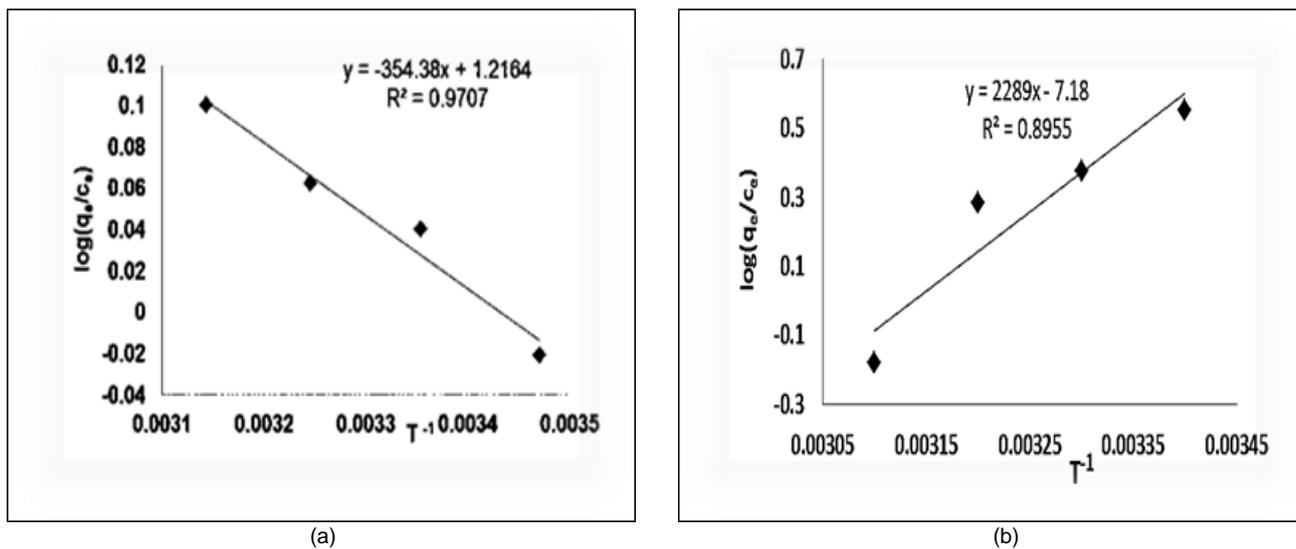


Fig. 7. Van't Hoff plot for the adsorption of (a) eosin Y (b) red-X on TRH.

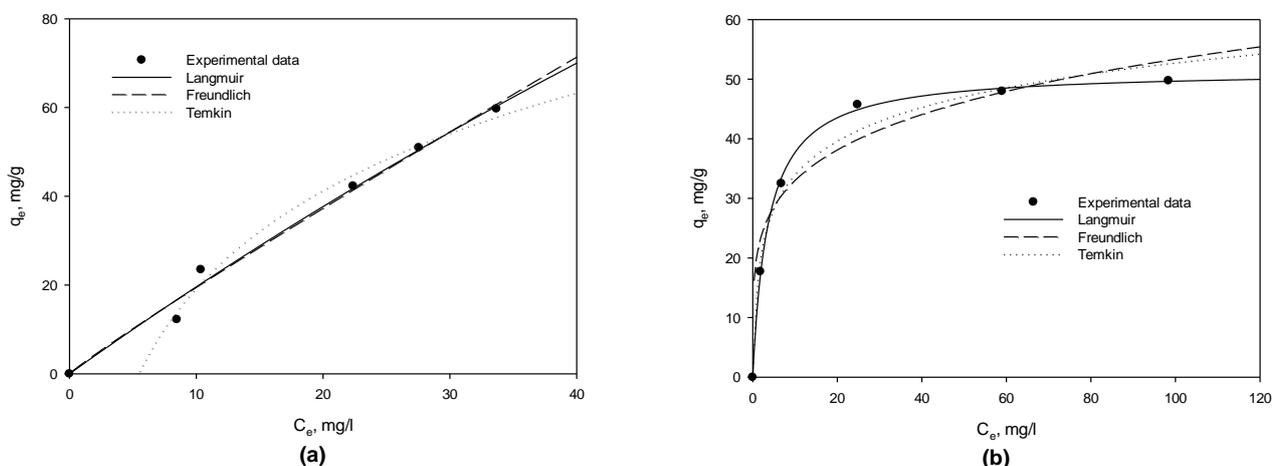


Fig. 8. Comparison of various isotherm equations for the adsorption of (a) Eosin Y and (b) Red X at Constant temperatures by TRH ($t = 3$ h, $C_0=50-250$ mgL^{-1}).

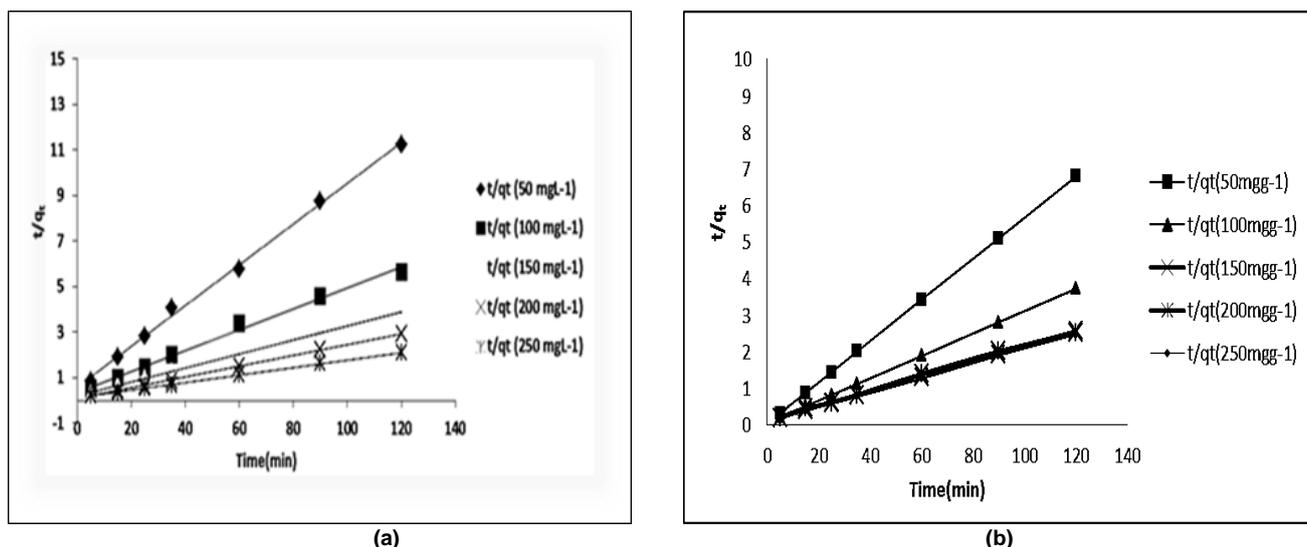


Fig.9. Pseudo-second-order kinetics for the adsorption of (a) eosin Y, (b) red X onto TRH.

Table 1. Thermodynamic parameters for the adsorption of (a) eosin Y and (b) red X on TRH.

Dye Concentration (mgL ⁻¹)	Type of dye	ΔH° (kJ mol ⁻¹)	ΔS° (J mol ⁻¹ K ⁻¹)	ΔG° (J mol ⁻¹), At different temperature			
				288	298	308	318
200	Eosin Y	6.78	23.28	288	298	308	318
				79.2	- 153.6	- 386.4	- 619.2
100	Red X	- 43.83	- 137.48	288	298	308	318
				- 4234.7	- 2859.9	- 1485.2	- 110.4

Table 2. Isotherm parameters for removal of dyes by TRH.

Type dye	Langmuir isotherm				Freundlich isotherm			Temkin isotherm		
	Q_{max} (mgg ⁻¹)	b (Lmg ⁻¹)	R_L	R^2	K_F [(mg ⁻¹ g)(mgL ⁻¹) ⁿ]	N	R^2	B	A	R^2
Eosin Y	58.82	0.025	0.17	0.747	2.11	1.01	0.906	27.35	5.206	0.877
Red X	52.63	0.270	0.36	0.999	17.45	3.95	0.902	8.126	6.612	0.951

Table 3. Kinetic parameters for the removal of dyes by TRH.

Dye	pseudo-first order kinetic model			q_e experimental (mgg ⁻¹)	Pseudo-second order kinetic model		
	K_1 (min ⁻¹)	q_e (mgg ⁻¹)	R^2		K_2 (gmg ⁻¹ min ⁻¹)	q_e (mgg ⁻¹)	R^2
Eosin Y	0.034	14.06	0.921	23.48	0.00537	32.25	0.999
Red X	0.027	5.128	0.863	32.48	0.0155	33.33	0.999

4. Conclusions

The present study shows that TRH is an effective adsorbent for the removal of both cation (eosin Y) and anion (red X) dyes from aqueous solution. Moreover, it was shown that TRH had a much higher equilibrium adsorption capacity on red X than on eosin Y. The adsorption capacity of dye was slightly changed by pH. The amount of dyes uptake was found to increase with the increase of initial concentration and adsorbent dose. The adsorption kinetic studies showed that the adsorption process followed pseudo-second-order

kinetic model. The Langmuir, Freundlich and Temkin adsorption isotherm models were applied to the adsorption data of dyes onto TRH. The Freundlich and Langmuir isotherm best fitted the adsorption equilibrium data for eosin Y and red X dyes, were studied respectively. The process is endothermic for eosin Y, while for red X dye is exothermic. The negative value of ΔG° indicated spontaneous adsorption for both of dyes on TRH. The interaction processes were accompanied by an increase of entropy value. This study concludes that the TRH could be employed as low-cost adsorbent for the removal of eosin Y and red X dyes from aqueous solution.

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